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Optical Pulsars and Black Arrows:

Discoveries as Occasioned Productions

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ABSTRACT

The current paper represents a methodological proposal. It seeks to address the question of how one might recognize a discovery as a discovery without knowing in advance what is available to be discovered. We propose a solution and demonstrate it using data from a study previously reported by Roschelle (1992). Roschelle investigated two students' discovery of certain abstract features of Newtonian mechanics while working within a computer-based microworld, the Envisioning Machine. We employ an approach we term *discovery-as-occasioned-production* to re-examine his data. Such an approach proceeds stepwise from the identification of some matter discovered, working backwards to see just where that matter entered the conversation and, then, finally, tracing from that point forward to illuminate how the proposal for a possible discovery was ultimately transformed into a discovery achieved. The notion of "evident vagueness," borrowed from Garfinkel, Lynch, and Livingston's (1981) account of the discovery of an optical pulsar, emerges as an important feature of our analysis. Following Garfinkel (2002), we present our findings as a "tutorial problem" and offer a suggestion for how a program of practice studies in the learning sciences might be pursued.

Keywords: scientific discovery, ethnomethodology, Conversation Analysis

In a now classic article, Roschelle (1992) provided a detailed analysis of the interaction of two high school students, 'Dana' and 'Carol,' as they worked together at a computer. The students were working with a computer-based, simulation environment known as the Envisioning Machine which Roschelle developed. As he (1991) described it, "The Envisioning Machine (EM) is a direct-manipulation simulation of the concepts of velocity and acceleration" (p. 25). To help users of the program develop an appreciation of these concepts, he also developed a set of problems, termed "EM Challenges." Solving the challenges in each case involved conducting experiments within the simulation environment. The activity incorporated the pedagogical strategy of discovery learning. Roschelle (1991) argued, "[I]n a discovery learning situation, students take control of most decisions regarding how and what to learn." For that reason, it "yields the most data about the impasses students face in learning scientific concepts, and the resources they have available for overcoming them" (p. 29).

Roschelle videotaped the students as they performed their experiments and solved the posed challenges. His report was based on a close analysis of these recordings. He (1992) described how they were able to "construct increasingly sophisticated approximations to scientific concepts collaboratively, through gradual refinement of ambiguous, figurative, partial meanings" (p. 237). This was accomplished, he observed, "through cycles of displaying, confirming, and repairing shared meanings" (p. 237) leading eventually to "convergent conceptual change." This entailed three elements: "(a) a large conceptual change from their previous concept, (b) a qualitative approximation to the scientific meaning of acceleration, and (c) a closely shared meaning between one another" (p. 238). His analysis, therefore, focused on two forms of convergence—the degree to which Dana and Carol's "shared meanings for conversations, concepts, and experiences" (p. 236) came together and the degree to which these mutual understandings came to align with a physicist's notion of acceleration. In sum, the EM activity was designed and resourced to produce a certain discovery and Roschelle's analysis focused on exploring just how that discovery was achieved in the case of Dana and Carol's work together at the computer.[i] The current paper re-examines Roschelle's data using a different analytic framing. Our purpose is not to challenge Roschelle's findings, but rather to explore our repertoire of methods for studying the processes of discovery and seek to expand it.

The work to be presented here lies at the confluence of several literatures. The first, known as "laboratory studies" is comprised of ethnographic accounts of what Star (1985) described as the "homely exigencies of daily scientific work" (p. 391). This research literature, which has its roots in anthropology and sociology, seeks to document how scientific inquiry gets done (see, for example, Knorr-Cetna, 1981; Latour & Woolgar, 1979; Lynch, 1985; Traweek, 1988). These studies have "attempted to suspend a priori understandings of what science is while examining particular cases of observation, experiment, and theoretical controversy" (Lynch, 1993, p. 113). A persistent finding is that there are "many levels of interpretive, interactive, and instrumental mediation between scientists' accounts and the 'natural' objects and facts described in those accounts" (ibid, p. 92).

A second literature with high relevance to our current investigation arose from Garfinkel's (1986) call for a program of descriptive research focusing on occupations and professions. Garfinkel is the founder of a school within contemporary sociology known as Ethnomethodology, a movement that takes as its foundational topic the vernacular methods by which members of society produce their world as understood (Garfinkel, 1967). Garfinkel's interest was in what he termed the "quiddity" or "just whatness" of work as it is performed. This eventually led to a series of ethnomethodologically-informed studies examining different forms of work including: mathematical proof (Livingston, 1986), jazz improvisation (Sudnow, 2001), policing (Bittner, 1967), and doing the "convict code" (Wieder, 1974). Garfinkel's interest in the workplace and the literature of laboratory studies intersect in what have been termed "ethnomethodological studies of scientific work" (Lynch, 1993, p. 113). A particularly well-known example is Garfinkel, Lynch and Livingston's (1981) report focusing on the practitioners' discourse leading up to a scientific discovery.

The current paper is centrally concerned with the processes whereby some matter previously unknown becomes, through the practical and embodied actions of local participants transformed into some *thing* there for the knowing. But herein lies a puzzle—how is it that we are able to talk about some matter being discovered while still engaged in the work of discovering it? The approach taken in our re-analysis of Roschelle's data is *practice-based*, which is to say that it is oriented toward offering a descriptive account of just how a discovery was actually done. But this, in itself, does not distinguish it from Roschelle's approach, which was exemplary in its orientation to users' practices. Second, our approach is *microanalytic*. It focuses upon the details of talk-in-interaction (Sacks, 1992; Levinson, 1983) as well as other embodied aspects of communication (see, for example, Jordan & Henderson, 1995; McDermott, 1976; Goodwin, 2003; Erickson, 2004) drawing, in particular, on prior findings in Conversation Analysis (CA).[ii] It might be thought of metaphorically as a magnifying glass for studying the details of discovery's work. Our vision is enhanced, not optically, but rather procedurally through fine-grained transcription and repeated viewings/hearings of produced recordings. Examining practice at a higher level of resolution permits an appreciation of subtle features that might be missed in simple field observation. This too, however, fails to distinguish our approach from that of Roschelle. In investigating the first form of convergent conceptual change described in his article, Roschelle attended closely to the methods by which Dana and Carol worked to coordinate their understandings.

Our concern, however, arises with regard to the second form of conceptual convergence he discussed. The EM was designed to teach the theory of mechanics. Roschelle's analysis focused, therefore, on whether or not the users of the environment developed conceptualizations of velocity and acceleration that matched those of properly-trained physicists. In re-analyzing Roschelle's data, we adopt a different framing. Rather than starting with an expectation of what *should* be discovered, we treat the object of discovery as something that needs itself to be dis-covered within the participants' unfolding interaction. We treat the matter discovered, therefore, not as a thing given or preordained, but rather as an *occasioned production*.[iii]

As analysts, we arrive on the scene with many things taken as understood (e.g., that the participants are students, that they are doing a lesson, that the purpose of the lesson is to teach Newtonian mechanics, etc.). Rather than use these understandings as a *resource* for explaining the participants' behavior, however, we make the ways in which these things are made understood the *topic* of our inquiry. Our task then becomes one of working out *in detail* how these understandings relate to observed practice. Sacks (1963) established the ground rules for this kind of investigation with the admonition, "whatever we take as subject must be described; nothing we take as subject can appear as part of our descriptive apparatus" (p. 2).

When studying a discovery as an occasioned production, the frame of analysis is developed within the analysis itself. We begin by locating something that is demonstrably treated by participants as a new understanding. This event marks the close of our analytic episode, but we still need to determine where it opens. To do so, we must trace backwards to see where the matter so treated first arose within the participants' developing talk-in-interaction. We refer to this first appearance as a *proposal-for-a-possible-discovery* to highlight its initially tenuous status. Such proposals are often only recognizable in retrospect. Having established the scope of the episode, the deliberate work of systematically tracing the transformation from a produced proposal to an achieved discovery begins.

Before turning to Dana and Carol's discovery, we will first look at another discovery, the discovery of an optical pulsar by two astrophysicists. This discovery had been described in the report mentioned earlier by Garfinkel et al. (1981). Their account had an unusual structure, however. The body of their report laid out certain key notions by which an analysis of the discovery might be undertaken, but the analysis itself was left, by and large, as an exercise for the reader. The necessary resources for carrying out it were provided in the form of various exhibits and transcripts attached as appendices. We take up this exercise in the section that follows. Following that, we will then examine the materials from Roschelle's study using the approach used to analyze the optical pulsar discovery and drawing on key notions taken from the Garfinkel et al. report. Garfinkel (2002) referred to instructive exercises of the type that we are dealing with here as "tutorial problems" (p. 145). We will return to the topic of tutorial problems later.

DISCOVERING AN OPTICAL PULSAR

To study how a discovery gets done, one must first determine exactly *what* was discovered. With reference to the discovery described by Garfinkel et al., however, this is easily done. In 1969, a report with the following title was published in *Nature*: "Discovery of Optical Signals from Pulsar NP 0532" (Cocke, Disney, Taylor, 1969). It proclaims a discovery-achieved and plainly summarizes just what that discovery might have been. The report was published on Feb. 8, the manuscript received on Jan. 28. It was a public announcement that something had happened. But when and where?

Accounts of discoveries are usually based on participants' recollections (Woolgar, 1976). In the case of the discovery of an optical pulsar on the night of January 16, however, there happened to be an audio recording of the actual event. Captured on it were the voices of three participants: John Cocke and Michael Disney, astrophysicists, and Robert McCallester, the "night assistant" at the Steward Observatory (Center for the History of Physics, 2003). If one were to ask, what were they doing on that particular night in on the mountain in the Arizona desert, the answer would not be 'making a discovery.' Though something was indeed discovered, their orientation to their actions as a discovery only emerged later. We might say instead that they were 'being astronomers' or that they were 'doing the work of professional astronomy.' This would certainly be a fair description. Both Cocke and Disney held doctorates in astrophysics and McCallester was a knowledgeable technician. They were, in short, each and all properly credentialed to carry out the work at hand.

An alternative treatment of their activity might highlight its tool-mediated aspects. We might, for example, employ 'operating a telescope' as a useful gloss for what they were doing together. 'Optical pulsar' is a name for something that emits pulses of light. A lighthouse, seen from afar, is an everyday example. Strobes and fluorescent lighting are also optical pulsars, though in the latter case you cannot visually detect the pulsations. At the time that the Cocke et al. report was issued, other astronomers had already discovered that certain objects in space operated as pulsars. This activity had only been detected in the radio range, however (Woolgar, 1976). The research carried out by Cocke and his colleagues represented a shift in instrumentation from the use of large and relatively imprecise *radio* telescopes to the use of an *optical* telescope. Optical telescopes suitable for professional astronomy are usually situated in remote places where the nights are clear and there is little locally-produced light to interfere with observations. It was the reflector telescope at Kitt Peak, therefore, that brought them to that particular desert mountaintop on the night in question.

To detect pulsations in the optical range, however, required more than just a telescope. Unless pulsing very slowly, optical pulsations are not visible to the human eye. Cocke and Disney needed some means of repeatedly folding time back onto itself in order to make the pulsing observable. They met this requirement using a piece of equipment, the "computer of average transients" (CAT), designed by Donald Taylor.[iv] It displayed on an oscilloscope screen "cycles of the pulsation waveform in phase" (Cocke et al., 1969, p. 525, see Fig. 1). The team was not just operating a telescope, therefore, but an elaborate instrumental assembly designed with a particular question in mind.[v]

There is contention for observation time on a professional telescope and researchers must justify their requests on the basis of what might be learned. To get time on the telescope at Steward Observatory, Disney and Cocke had had to submit a research proposal. In it they had described a plan to “search known white dwarfs for optical pulsations” (Center for History of Physics, 2003). The submitted proposal, therefore, tied their practical activities to an ongoing conversation within the disciplinary community. This also offers the basis for a new and more concise characterization of their activity, that of searching for an optical pulsar.

<<Insert Figure 1 about here>>

Though they were engaged in a search using the approved tools and methods of their profession, no one, including Cocke and Disney, really expected them to find anything. Their contemporaries entertained serious doubts that there were any optical pulsars out there to be found (Center for the History of Physics, 2003). And even if they did exist, Cocke and Disney were not well-positioned to be their discoverers. Both were theoretical physicists with little practical experience in the observatory (Center for History of Physics, 2003). They were also not optimally equipped. The 0.9-meter reflector telescope at Steward Observatory upon which they were to conduct their studies was both old and, by contemporary standards, disappointingly small. State-of-the-art astronomy had moved up to larger and more sophisticated devices. Given their junior status, however, and their general lack of experience, they had decided against applying for time on a more powerful instrument. By the night of January 16, Disney and Cocke had already spent five nights on Kitt Peak and had found nothing.

EVIDENCE OF A DISCOVERY-ACHIEVED

Their night’s work on January 16 was segmented into a series of *runs*. Each run addressed the question of whether or not optical pulsars exist in a very constrained way. It represented an observation at a particular location in space at a particular frequency range at a particular level of gain, etc. They began their evening’s work with Run #17 and ended with Run #33. Partial transcripts for Runs #18 and #22 can be found in Appendix B.[vi] Transcripts of additional runs can be found in Garfinkel et al. (1981).

By Run #22 something had occurred. Something had been noticed in Run #18 and it was detected again in Runs #19 and #20. It was not until Run #22, however, that it was fully established as a discovered thing. By Run #22, the optical pulsar had shifted from something being sought to “something in-hand, available for further elaboration and analysis, and essentially finished" (Garfinkel et al., 1981, p. 156). We encounter the following exchange midway through this run:

Excerpt 1

23 Disney: We'll have to figure out what the hell this
24 means now.
25 (1.0)
26 Cocke: Ya::h. (0.5) HUH huh. (0.3) Theoretically?
27 (0.5)
28 Disney: Well- we- well- wa- we should be able to work
29 ou:t ⌈(.) how many photons are coming in per
30 second: to this pulse. (Correct)?
31 Cocke: ⌊(Yup.)
32 Cocke: Uh ⌈huh
33 Disney: ⌊The bloody size of the pulse.
34 Cocke: Well, we should be uh huh. =
35 Disney: = Uh:::: and that will should be and that will
36 give us some idear of the luminos:ity of this
37 object.
38 Cocke: Uh huh.

An explicit connection is made here between "this object" (line 37), the discovered pulsar, and its local manifestation, the data plot visible on the CRT display before them. "This object", of course, refers to the "independent Galilean pulsar" (Garfinkel et al., 1981, p. 138), the thing for which they have been searching. Disney asserts that a property of the pulsar (i.e., luminosity) can be estimated from the size of the visible curve. His assertion treats the pulsar, therefore, as an accomplished fact. A feature previously detected on the display is now understood in a new way; the optical pulsar has been "thingified" (Rawls, 2008, p. 4).

Shortly after this exchange Disney and Cocke notified their collaborator, Taylor. They repeated the observations together on the following night. The day following that, a telegram was sent to the International Astronomical Union requesting confirmation of their finding by other astronomers.[vii] Their object of discussion, therefore, had been transformed from a possibility to a confirmable and then confirmed reality. But how was this transformation actually realized?

Locating a Proposal-for-a-Possible-Discovery

To locate where the possibility of the 'independent Galilean pulsar' enters the conversation, we must trace back to Run #18. Figure 1 provides a reproduction of the CRT display of Taylor's CAT device approximately midway into this run. The following exchange is heard:

Excerpt 2

```
13  Disney: We've got a bleeding ↑pulse here.
14          (2.0)
15  Cocke:  ↑He::y.
16          (4.5)
17  Cocke:  Wo::w!
18          (1.2)
19  Cocke:→ You don't suppose that's really it do you?
20          (1.8)
21  Cocke:  It ca:n't be.
22  Disney: (Sure) it's right bang in the middle of the
23          period. (Look), I mean right bang in the middle
24          of the sca::le. It really looks something to me
25          at the moment.
26          (0.8)
27  Cocke:  Hmmm.
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Drew (1984) discussed what he termed "speaker reportings" in the context of invitation responses. He noted that, "the speaker is officially responsible only for the reporting, and not for what is made from (detected in) that" (p. 137). As he elaborated, "By just detailing some activities or planned activities (or other circumstances), speakers withhold officially taking positions about the possible implications of their reportings" (p. 137). Though Disney's turn in line 13 draws attention to something ("a bleeding pulse") available on the CAT screen to both Disney and Cocke,[viii] he stops short of specifying the possible upshot of his noticing. It does set the stage, however, for what is to follow.

An emergent pattern on the screen has now been given a name and has been made available as a discussable. A pulse is not a pulsar, however, and Disney's announcement is not quite a proposal-for a possible-discovery. A pulse signifies an emerging pattern that could be evidence of the thing sought, but could also be artifact. Cocke's response (line 15) delivered after a pause is non-committal. It acknowledges Disney's report and registers surprise. After a longer pause Cocke upgrades his appraisal. It is not until line 19, however, that the possibility is raised that what they are looking at might represent evidence of an optical pulsar. Cocke's utterance marks a transition point in their activity, therefore. Through it, the work of the night shifts from a search for an unknown to that of potentially confirming something found. It heralds a discovery possibly to come, but without actually declaring one. It is only made recognizeable as a discovery-relevant noticing in retrospect after we find sometime later that they have come to an agreement that what they were seeing in this moment was something new.

His utterance is constructed as an inquiry and would appear ("you don't suppose") to address the listener's state of belief. It can be seen to be doing more than simply seeking information, however. Koshik (2002) has written about yes/no questions like these. She has suggested that such questions may be "designed, in the first instance, not to display an expectation for a certain answer, but to display the epistemic stance of the speaker, sometimes acting more like assertions than questions" (p. 1855). That is, though the construction of a "you don't suppose" query might seem to display a preference for a negative response, the query can in some circumstances actually work as an affirming statement. Koshik (2005) refers to these "grammatically negative questions" (p. 12) that function as assertions as "reversed polarity questions (RPQs)" (p. 13). She also notes that the intensifier *really* plays a role in reversing the polarity of a statement. The absence of a response in line 20 might be construed as evidence that Cocke's utterance was heard in just this way as an assertion, not a question.

But if Cocke's utterance states a claim, what sort of a claim does it make? The assertion embedded in Cocke's utterance is that "that's really it." But how are we to make sense of such a double pronominal construction? Pronouns are not just a shorthand method of reference. In his lectures on "tying rules", Sacks (1992) explored the function of pronominals. If Speaker A names some matter using a noun phrase and Speaker B replies, but refers to the matter using a pronoun such as *it* or *that*, Sacks argued the second utterance was "tied," through this usage, to the first. He proposed, therefore, that pronoun usage is first and foremost a mechanism for doing understanding. He wrote,

> Tying an utterance to an utterance is the basic means of showing that you understood that utterance. The elaboration of tying means that one can, in due course, have a way of showing that you understood any given utterance that went before. But it's showing that in a very special and interesting way. Indeed the only workable way. (Vol. 1, p. 718)

Can we analyze Cocke's "that's really it" in terms of what it treats as understood?

The word *that* can be used to serve a variety of grammatical functions in English. Here it serves as the subject of the Cocke claim, but in such a slot it could be used at least two different ways. Used demonstratively, the pronoun would be accompanied by some sort of embodied gesture, a point or a nod or a directed gaze. If such a gesture was produced here, however, we would have no way of knowing it, since we have only an audio recording upon which to construct our analysis. Alternatively, it could be used anaphorically. Used in this way, the recipient would have to locate a grounding expression in the local (usually prior) text. There is no such expression, however, within the speaker's current turn at talk nor in his two prior turns (lines 15 and 17). We do have a candidate in Disney's prior turn, however, and it is the noun phrase "a bleeding pulse." Whether it is used demonstratively or anaphorically, we hear *that* as tying Cocke's utterance to Disney's prior noticing and acknowledging the feature of the display that Disney has made relevant. His "a bleeding pulse" and Cocke's *that* are heard as co-referencing a feature of the display. Cocke's proposal is assembled, therefore, using components of Disney's reporting. But what then does *it* reference and what are the implications of its use here?

In English, *is* is a coupling verb.[ix] It may be used for a variety of purposes, e.g., asserting the subject and object to be identical, declaring the subject to be an instance or subset of the object, assigning a property to the subject, etc. To be felicitous, however, the joining must convey some news—the coupling verb must bring together two things that were formerly seen as distinct in order for the conversation to progress. That would suggest in this case that whatever was referred to by *it* must in some way be different from whatever was referenced by *that*. If *that* referenced something available on the CAT screen, however, what is to serve as the antecedent for *it*? There are no likely candidates in evidence. So the pronominal reference might have the appearance of being defective.

We should begin by noting, however, that, though *it* is used without apparent antecedent, it does not appear to pose a problem of understanding for the participants. This kind of pronoun usage has been described previously. Two treatments are particularly helpful to understanding the case at hand. The first is Goodwin's (1996) notion of a "prospective indexical."[x] An indexical is a term whose sense is derived through reference to its environment of use. Pro-terms like *he*, *she*, *we* and *it* are indexicals that conventionally reference something previously described. Prospective indexicals are indexicals that instead of referencing back, refer forward. Goodwin (1996) wrote:

> Hearers must engage in an active, somewhat problematic process of interpretation in order to uncover the specification of the indexical that will enable them to build appropriate subsequent action at a particular place. Moreover this analysis is not static, complete as soon as the prospective indexical is heard, but is instead a dynamic process that extends through time as subsequent talk and the interpretive framework provided by the prospective indexical mutually elaborate each other. (p. 384-385)

A related treatment is attributed to Harvey Sacks. Sacks (1978), in his analysis of the telling of a dirty joke, discussed "a something-or-other 'it' which has no prior-named referent" (p. 256).[xi] The Sacksian IT, like a prospective indexical, projects a future resolution. Garfinkel et al. wrote:

> [I]t is produced, recognized, and understood before it has a definiteness of sense or reference. 'IT' is used and oriented in that and in the way that it has no sense or reference, and thus as a way a sense and reference is achieved for 'IT', and as a condition under which a sense, definitely, clearly, after all, etc., is achieved. (p. 157)

The thing that was to eventually become the "independent Galilean pulsar," was at the time of Cocke's discovery proposal something else, something "evidently vague" (p. 135). It was a thing still unformed and untested, a thing that "could go away and be gone forever" (p. 138). Garfinkel et al. refer to this still unformed thing as the "evidently vague IT." Whereas the Sacksian IT refers to a feature of language-in-use, Garfinkel et al. use the "evidently-vague IT" to refer to the actual thing in the process of being discovered, the thing that will eventually evolve from "an object-of-sorts with neither demonstrable sense nor reference" (p. 135) in Run #18 to being, in Run #22, "a perspectival object with yet to be 'found' and measured properties of luminosity, pulse amplitude, exact frequency, and exact location" (p. 156). They place scare quotes around 'found' here because the "evidently vague IT" designates the thing being sought before the astrophysicists have fully convinced themselves that anything has been found or, indeed, that there *is* anything to find. It is, in their words, an "object-not-yet" (p. 135), something brought into being through their membered practices of inquiry. They continued:

> By the end of the night's work [the optically discovered pulsar] is a 'relatively finished object.' But early in the evening [it] is not only *not* finished; it is witnessably vague. It has the properties of a Sacksian 'IT. ' (p. 157)

A transcript of the early part of Run #18 was presented in Appendix 3 ("First Noticings") of the Garfinkel et al. report. They note:

> After Disney's announcement of the 'pulse', he and Cocke mention developingly-observed 'properties', such as 'it's right bang in the middle of the period'; 'it really looks like something (from here) at the moment'; 'it's growing too'; and 'it's growing up the side a bit too'. The optically-discovered pulsar is referenced as a locally embedded phenomenon whose 'properties' are come upon in a developing sequence of locally pointed noticings. (p. 149)

No special attention seemed to be paid to Cocke's, "You don't suppose that's really it, do you?" (line 19) here. But not only did the witnessably vague object of their inquiries exhibit the properties of a Sacksian IT, Cocke actually *employed* this very structure to describe that object. This is an example of a place where Garfinkel, Lynch and Livingston provided the conceptual framing for the analysis, but left it as an exercise to the reader to apply the analytic terms to the data.

Though the referent of *it* in line 19 may only be specified vaguely, that does not mean that it could be anything at all. When Cocke asks, "You don't suppose that's really it, do you?" the possibilities for what he might be talking about are still pretty limited. Garfinkel et al. wrote, "It is astonishingly clear in the tape that the possibility of their discovery and achievement inhabits their work from its outset" (p. 140). If what Cocke and his colleagues were doing that night was in fact engaging in a search as we argued earlier, then the object of their search, an optical pulsar, is central to the activity in which they are jointly involved. Indeed, the activity and the possibility of the object are co-constitutive. The relevance of the optical pulsar was built, therefore, into the very activity that they were performing together. One might even say that it was omni-relevant within that activity. By referencing the object of their search in his query, Cocke linked their actions to the wider concerns of the research community of which Cocke and Disney were members.

It, therefore, not only tied forward to the object to be discovered, but also back to the scientific goals that motivated the search and that brought them together in the desert on that particular night. It had both a prospective and retrospective orientation. *It* functions here as a double entendre of sorts, not in the usual sense of simultaneously indexing multiple referents, but rather co-referencing a common object, but doing so via different paths. In this way, it is suspended in a referential web that simultaneously projects and recalls the object of interest. It is an indefinite pronoun that provides its own "interpretive framework" (Goodwin, 1996).

In its construction Cocke's noticing gives subtle treatment to what is known and what is yet to be understood. The question remains, however, why formulate the matter quite this way? Wouldn't it be easier to simply say, "That might be an optical pulsar" or even "Look an optical pulsar"? By formulating the possible discovery as a RPQ, by employing an evidently-vague pronoun reference, Cocke displays an orientation to proper scientific skepticism. For their observation to represent a credible scientific discovery, it must be demonstrated to be a real finding and not an artifact. Claiming something to be a discovery before ruling out other explanations would be inconsistent with the behavior of a competent scientist. Cocke, therefore, is demonstrating his alignment with and adherence to, the known procedures by which the referential work of scientific discovery is done. In other words, by stating the claim as a question and then offering his own response ("Can't be."), he is displaying an orientation to proper disciplinary skepticism. His formulation can be seen, therefore, as an elegant solution to an interactional dilemma—how does one raise the possibility of a claim without actually making one? We see in it the everyday work of accountably producing science.

Transforming the Proposal to a Discovery-Achieved

We also see revealed the sequential organization of a discovery-in-progress. It begins with a noticing or reporting, one that orients attention to some feature of the environment, but without claiming a discovery. The discovery proposal, which follows and with which we have concerned ourselves centrally here, raises the possibility of a discovery, but again without specifying exactly what the discovery might be. It projects a discovery to be, but it's status as a proposal-for-a-possible-discovery is only made evident in retrospect. Garfinkel et al. wrote, "the optically discovered pulsar is accountably contingent upon further activities which are projected in an interactionally occasioned manner" (p. 154). When Disney proposes, "We'll have to figure out what the hell this means now" (line 23), he anaphorically references the possible discovery proposed by Cocke. How the proposal-for-a-possible-discovery was transformed to a discovery-realized was the central focus of the Garfinkel et al. study. Referring to the researchers' night's work, they wrote, "their unavoidably 'situated' practices become progressively witnessable-and-discourse-able as 'the-exhibitable-astronomical-analyzablity-of-the-pulsar-again'" (p. 134).

The phenomena described here (Sacksian ITs, prospective indexicals, RPQs) are not the special province of astrophysicists and scientists. They arise routinely and ubiquitously in everyday interaction. They are matters that hide in plain sight. When pointed out, however, they are easily recognized by all. Here we examine precisely how they were placed into service in the work of carrying out a discovery. Such methods are remarkably well suited to the practicalities of discussing things in the process of being discovered. We see how their use is ably fitted to the task of displaying understandings of just what it is being done in the moment. We find in them not only new insights into the practicalities of discovery work, but also a window onto the basic processes through which understanding itself is produced.

DISCOVERING THE PHYSICS OF MOTION

Using terms and concepts developed by Garfinkel et al. in their description of the discovery of the optical pulsar, we will now return to our principal project, that of re-examining the Roschelle data using a different analytic framing. Dana and Carol were volunteers in a study in which subjects worked in pairs to complete a series of 17 problems (the "EM Challenges") by conducting experiments in the simulation environment. These experiments were 'mock-ups' in a double sense—not only were the students called upon to re-discover well-established scientific facts, but they were also doing so in a simplified and idealized 'microworld.'[xii] Each experiment took the form of a simulation run and the students might conduct multiple runs in the course of solving any particular challenge. The problems were done over two work periods scheduled on two consecutive days as an after-school activity. The materials that formed the basis for the current analysis consisted of the description of the research protocol in Roschelle's (1991) dissertation, the transcripts of the five "Episodes" in Roschelle's (1992) published analysis, and 9 video clips provided to us by Roschelle. Roschelle's analysis focused on approximately 3 min. of interaction that occurred while the students solved two particular EM problems. They encountered these two challenges about 15 min. into their second day of participation in the study. The first three video clips captured the students' work on the first of these challenges up to and including its solution. The camera was position behind the students shooting toward the computer screen. It caught the action on the screen as well as the students' points and gestures in front of the computer. Clips #4 and #5 represented their post-solution reflection. The students moved on to the second challenge in Clip #6 and continued to work on it through Clips #7 and #8. We never actually see the final simulation run for the second challenge. Clip #9 represented an interview conducted shortly after they produced a solution to the second problem. Transcripts for the nine clips can be found in Appendix C.

Evidence of a Discovery-Achieved

Like the astrophysicists described by Garfinkel et al., Dana and Carol advanced through a "developing sequence of locally pointed noticings" (p. 149). Though they did not publish a report in *Nature*, at the conclusion of the second analyzed problem Dana did exclaim "Oh my god! It's all so much clearer now!" (Clip #7, 3:32:26). This would seem to suggest that something had happened; that somehow a new understanding had been developed. But, what was the referent of *it* and how did it become clarified? Using the same analytic approach employed in the optical pulsar example, we seek evidence of a discovery achieved and then, using this formulation as a guide, trace back through the participants' talk to locate where the matter discovered initially entered the conversation. Our attention is again directed to the discovery proposal as a focal point for our analysis. Oddly, while the analysis of the discovery of optical pulsar was relatively straightforward, we find that Dana and Carol's discoveries in the highly simplified world of the Envisioning Machine to be considerably more complex.

The procedure in Roschelle's study called for the student pairs to be interviewed every time they completed a few challenges (Roschelle, 1991). The interviews were free-form and the students were required to explain how their solutions worked. Shortly after completing the two challenges analyzed in the article, Roschelle approached the pair and asked, "So, could you explain to me how it works?" (See Clip #9 in Appendix C). His question presupposed several things. First, that the simulation runs operated in an orderly and accountable fashion, that is that the simulations behaved according to some underlying explanatory principle. Second, that the principle operated in essentially the same way across the problems. Third, that the principle, whatever it might be, could be articulated in mutually intelligible ways. And finally, the question presupposed that they, the students, had both the capacity and obligation to produce this articulation.

Producing an explanation, therefore, was an important and understood aspect of their participation. To do it, Dana and Carol needed to determine which features within the dynamically unfolding scene before them to which they needed to attend (and those that they needed to disregard). Their task, in short, was one of rendering the EM display as legible.

Several observations might be made with regard to the design of Roschelle's query. It begins with the particle *so*. Raymond (2004) has described how, when used to initiate a turn at talk, *so* "does not itself begin an action so much as invoke the continuing relevance of one" (p. 210). Coming at the conclusion of the pair's most recent problem solving session, Roschelle's opening both references that activity and makes it relevant as a topic. It is structured as a simple yes-no question. Much has been written about how such queries can be employed in pedagogical settings (Koshik, 2005; Hutchby, 2005), settings in which questions are asked for which the answers are often known (Mehan, 1979). Roschelle's question, though having the form of a simple yes-no question, was neither simple nor do we have any reason to believe that the answer was known. His query was open-ended and provided great latitude with respect to how one might go about answering it. Note its similarity to "Rose's gloss" (Garfinkel & Sacks, 1970). By leaving the reference of *it* deliberately vague he leaves it as a task for the students to work out just what it might mean. But by this arrangement, he too is obliged to seek the identity of the evidently-vague IT in the students' response.

Cocke and Disney's discovery came at the conclusion of months of careful preparation. Though the discovery required special instrumentation, a firm grasp of prior research and complex calculations, their ultimate finding proved to be a simple one—optical pulsars exist. Carol and Dana, on the other hand, came to the problem with considerably less preparation and advanced expectations. Lacking a background in calculus and physics, they also lacked a specialized vocabulary for discussing what they had found. Their account of their discovery was complex, verbose, confusing, and remarkably creative. They used their bodies to help reproduce what they had seen and discovered. Carol self-selected to begin and offered the following response:

Excerpt 3 (Clip #9: 3:55:34–3:55:58)

```
132 Carol:        Yeah, I could show if: (1.2) you have the (0.3)
133               light arrow and the black arrow? (1.6) ahm:
134               (0.7) The light arrow's tip moves along the
135               line of the black arrow and stops (0.3) at the
136               end of the black arrow like
137 Dana:         ⌈And then
137 Carol:        ⌊(It hinges/like) it moves (0.7) like from the
138               ball like that if that was like an axes if that
139               was like (.) a hinge or something? And it moves
140               along the line of the black arrow and stops
141               (0.7)
142 Dana:         ⌈And then like continues (0.6) as the path:
143 Carol:        ⌊at the tip and then it goes that way (.) as
144               the (path/thin) arrow
```

In an EM simulation run, two objects, a black and white ball, travel across the screen each leaving a trail of dots (see Fig. 2). For each ball, the dot trail revealed not only the path taken, but also, in the spacing of the dots, the speed with which it traveled. The nature of each EM challenge was to make the trail produced by the white ball match that of the black. The white ball was drawn with a thin arrow ("light arrow") indicating its instantaneous speed and direction. The initial position, speed, and direction of the white ball could be set by moving the ball itself and/or manipulating this arrow. Those familiar with calculus will recognize the arrow as representing a velocity (vel) vector. A second vector, drawn with a darker line ("black arrow") represented acceleration (acc).[xiii] Unlike velocity, which could only be set at the beginning of the simulation run, acceleration could be applied in 1 sec. pulses at pre-specified points within the simulation. The acc vector was drawn with its tail positioned at the tip of the vel vector.

<<Insert Figure 2 about here>>

The simulation screen, in its design, offered a dynamic representation of a number of abstract principles of Newtonian mechanics. It instructed a certain way of thinking about motion that was made concrete in the dot trails, the vectors, the VSD animation, etc. The design of the activity and the individual challenges also directed the students' attention to what parts of the environment stood in need of explanation. In the two challenges analyzed here, for example, only the acc vector needed to be manipulated to produce a solution. This also implied, however, that the acc vector played some sort of role in what we have been referring to as the underlying explanatory principle.

By way of a response to Roschelle's query, Carol produced a gestural animation of the behavior of the vel and acc vectors during a simulation run (see Roschelle's [1992] description, pp. 259-262). It was not the behavior of the vel and acc vectors attached to the white ball that she depicted, however, but rather the behavior of the vectors as reproduced in the lower, left-hand corner of the screen. To help students better visualize what was happening in the simulation, a special graphic, known as the Velocity Space Display (VSD), was provided there. It was an animation of the "vector addition triangle" (Roschelle, 1992, p. 261) familiar to all students of calculus-based physics. The vel vector in the VSD had the same length and direction as the vel vector attached to the white ball, but its point of origin was fixed. During an impulse period (Fig. 3c), the tip of the vel vector in the VSD traveled along the length of the stationary acc vector. When the period ended, the acc vector disappeared, but a dot trail remained in the VSD revealing the path of the tip of the vel vector (Fig. 3d). This differed from the behavior of the two arrows that traveled with the white ball in the simulation (Roschelle, personal communication). The tip of this vel vector remained fixed to the tail of the acc vector (see Fig. 3b) which was mobile during the impulse period (see Fig. 3c). At the completion of the impulse, the acc vector, like the acc vector in the VSD, disappeared, but, in this case, left no trail of dots (see Fig. 3d).

<<Insert Figure 3 about here>>

The analysis at this point becomes more complex. Whereas in the discovery of the optical pulsar, we had only an audio record to study, here we have video recordings. Carol and Dana produce their understandings as embodied matters making it necessary to describe not only their vocal interaction, but also their gestures, gaze and interaction with the computer.

Carol reenacted the actions of the vel and acc vectors in the VSD using the index fingers of her right and left hand, respectively (see Fig. 4). She performed this demonstration with her back turned toward her audience, so that her perspective (and that of her audience) was the same as if all three were viewing it on the computer screen. As she performed this reenactment, she provided a running narrative account ("the light arrow's tip moves along the line of the black arrow"). Carol employed the simile of a hinge ("like a hinge or something"). Her elaboration "like from the ball" is interesting. Her gestural animation of the behavior of the vectors corresponded to the behavior of the vectors in the VSD, but her phrasing located the pivot point around which the vel vector rotated at the ball. Her formulation, therefore, implicitly treated the two sets of vectors, the vectors of the VSD and the vectors that travel with the white ball, as equivalent with respect to this pivoting action. She completed her formulation with a statement that is difficult to catch. Roschelle transcribed it as "it goes that way as the thin arrow." This makes sense in terms of the description she had been constructing, but we have trouble hearing the modifier as "thin."

<<Insert Figure 4 about here>>

Dana had attempted to build onto Carol's formulation at lines 137 and 143, but was cut off both times. She began again as follows:

Excerpt 4 (Clip #9: 3:55:54–3:56:14)

```
143 Dana:   ⌈And then like continues (0.6) as the path:
144 Carol:  ⌊at the tip and then it goes that way (.) as
145         the (thick) arrow
146         (0.7)
147 Dana:   It like changes the path: >like if< (0.4) this
148         is the black arrow and this is the light one
149         (0.4) it like goes up (0.6) and then when you
150         change it (0.4) when you put the arrow down it
151         like goes along ⌈that   and it gets here =
152 Carol:                  ⌊yeah
153 Carol:  = Yeah. It stays hinged to the ball ⌈>where
154         ever the ball is<
155 Dana:                                       ⌊Yeah.  It
156         stays hinged and then it starts going like
157         that.
```

Dana constructed a reenactment of her own, setting up her right hand to serve as a vertically-positioned acc vector and her left as a horizontally-positioned vel vector (see Fig. 5). Her gestures were performed in front of her face as she turned toward her audience. While Carol's formulation of "how *it* works" focused on the change in orientation ("it hinges") of the vel vector, Dana's reenactment directs attention to the altered path of the ball. She demonstrated in this way how the manipulation of the acc vector resulted in a particular trajectory of the ball.

<<Insert Figure 5 about here>>

Dana and Carol's accounts are clearly related, but they are not necessarily the same. By offering a second account Dana simultaneously presents her formulation as distinct and marks her interlocutor's as incomplete. Carol contested this by intervening in Dana's ongoing gestural reenactment. She placed her hand on Dana's right wrist (see Fig. 6), demonstrating just where the hinging occurred, and recapitulated her account (lines 153-154). Dana, taking the final word, conceded the validity of Carol's treatment ("yeah it stays hinged") but then re-asserted her own.

<<Insert Figure 6 about here>>

Unlike the optical pulsar example where a simple proposal ("You don't suppose that's really it, do you?") was developed and elaborated over multiple observations, we find here a plurality of noticings that have not yet been fully integrated. Carol and Dana have each described certain regularities in the behavior of the simulation, but they may not be the same. Taking their response to Roschelle's query as the close of our analytic episode, we have yet to establish where it begins. Our task, therefore, is to locate where these noticings first emerged in the conversation. Before reading our analysis, however, we suggest that you might first want turn to Appendix C and develop your own theory about where Carol and Dana produced a proposal (or proposals) for a possible discovery. Doing so will help familiarize you with the data and put you in a better position to evaluate the claims of the sections that follow (cf., McDermott, Gospodinoff, & Aron, 1978).

Locating a Proposal-for-a-Possible-Discovery, Part 1

In the recordings provided to us, the hinge-action metaphor ("on its hinge") first appears in Clip #4 and its production is a bit of a mystery. Carol sat to the left (looking toward the screen) and Dana to the right. Dana was in control of the mouse. The keyboard was pushed to the side out of reach. They were in the midst of working on the first of the two EM challenges analyzed by Roschelle (1992). In this problem, the dark ball initially had a horizontal trajectory and then veered 45° off its prior course toward the bottom of the screen (see Fig. 3d). We find the following exchange:

<u>Excerpt 5 (Clip #5: 3:30:32–3:30:57)</u>

```
39  Dana:   Now you're saying this is the black arrow?
40  Carol:  Yeah.
41  Dana:   And it pulls it the other arrow ⌈on its
42          hinge.
43  Carol:                                 ⌊On its
44          hinge. It pulls the other arrow on the hinge
45          down to the tip of the black arrow.
46          (1.3)
47  Dana:   Making the line that you see here?
48  Carol:  Right.
```

As we see, the hinge-pulling metaphor was produced in unison by Dana and Carol (lines 41-44). We can only speculate how both parties converged on the same formulation at precisely the same time. Given that the recording occurs on their second day working with the EM, maybe this was a metaphor that one of them had introduced earlier and was now a local convention for discussing this action of the arrow. Alternatively, maybe this concordance merely reflected the fact that this was just the most obvious and natural way for them to describe the phenomenon as they understood it. We don't know.

A more critical question to the current analysis pertains to Dana's "and it pulls it" (line 41). What sense can we make of this construction? Her extended turn was presented as a check on a proposal offered by Carol (lines 34-38) in a previous exchange provided below:

Excerpt 6 (Clip #4: 3:30:17–3:30:34)

30 Dana: What I don't understand is ho::w (0.2) the

31 length thing (0.3) the (0.2) positioning of

32 that arro::w

33 (1.5)

34 Carol:→(.hh)OU:H, you know what I think it is? It's

35 like the li::ne, (0.3) that arrow it's the

36 li::↑ne of where it pu:lls that down >like

37 see< how that makes this dotted line↑ .hhh

38 that was the black arrow (.) it pu::lls it.

The subject of Dana's utterance (lines 30-32) in the beginning of this exchange is only made clear by her gesture with the cursor performed after the utterance's completion. Though not grammatically constructed as a question, Dana's utterance is heard as a request for information.

Carol's response begins with the particle *oh*. Jefferson (1978) described how oh-prefacing can be used as a "disjunct marker" (p. 221), that is as an indication to the listener that the utterance to follow is not "topically coherent with prior talk" (p. 246). Without oh-prefacing, Carol's turn at line 34 would appear in a slot where a response to Dana's request for information might be relevant. Instead, her utterance is heard as triggered by something other than what came before; the oh-prefacing "injects an extraconversational contingency, adumbrated by the particle and subsequently [to be] elaborated upon, into the talk" (Heritage, 1984, p. 300). Further, oh-prefacing appears to do a very particular kind of work:

> Evidence from the placement of the particle in a range of conversational sequences shows that the particle is used to propose that its producer has undergone some kind of change in his or her locally current state of knowledge, information, orientation or awareness. (p. 299)

Heritage warns us, however, not to take the change-of-cognitive-state notion too literally:

> [T]he utterance of *oh* is a point event, whereas a change of cognitive state is likely a processual one that dawns, emerges and consolidates. Additionally, like 'ouch', *oh* can be withheld in the face of its corresponding cognitive event, or produced in the absence of such an event… (Heritage, 2005, p. 201)[xiv]

Though it cannot, therefore, be counted upon as a reliable index into what the participants are holding in their heads, oh-prefacing has consequences for the unfolding conversation. Heritage (1984) observed that its deployment is "informative for other participants and is implemented in, or accomplice to, the achievement of a variety of interactional tasks" (p. 299).

In this way, Carol's opening projects a report by the speaker of the speaker's understanding of some matter. Her proposal not only marks a shift in topic, but also marks that which is to come as a newly-developed understanding. Given that Carol's turn appears in a position in which a response to Dana's request for clarification might be relevant, one might naturally presume that *it* ties back to Dana's "length thing." What we find instead is our old friend the Sacksian IT. Rather than referencing a prior antecedent, it projects forward; it is a prospective indexical. We also see here the power of evident vagueness. The ambiguity of reference gives Carol considerable flexibility for how she might formulate her new understanding.

If her proposal does not tie back to Dana's concern, however, to what might it refer? Just prior to the exchange captured in Excerpt 6, Dana had conducted a run using a particular setting of the acc vector (see Clip #3 in Appendix C). This setting happened to work for the challenge that they were in the process of solving, but Dana expressed uncertainty about just *why* it worked. She observed, "But it doesn't go down at a ninety degree angle I don't understand" (lines 26-27). In this way, Dana had, prior to Excerpt 6, posed a puzzle with regard to the *direction* of the resultant vector. Though she subsequently raised an additional concern pertaining to the magnitude of this same vector ("what I don't understand is how the length thing …"), Carol's proposal appears to address the former issue. Dana's reporting, "it doesn't go down at a ninety degree angle," like Disney's "we've got a bleeding pulse here," provides the starting materials for the construction of a discovery proposal.

The presentation of Carol's proposal (lines 34-38) is complex. At its heart is a simple noticing that is repeated twice—"it pulls that down" (line 36) and, in more condensed form, "it pulls it" (line 38). The object of the pulling has already been described, though it is not specified until Excerpt 5. In this excerpt, which actually followed Excerpt 6, we find a third and expanded version of Carol's noticing, "it pulls *the other arrow* on its hinge down to the tip of the black arrow" (lines 44-45). The question remains, however, what is the agent of the pulling? That is, what is the referent of the initial *it* in both expressions?

In terms of positioning, the first noticing (lines 38-39) comes after the clause "that arrow it's the line of where [it pulls that down]." The reference to "that arrow" is accompanied by a point to the acc vector in the VSD. Similarly, the second formulation was prefaced by "that was the black arrow [it pulls it]." In both cases, therefore, the antecedent for the subject would seem to be the acc vector in the VSD, but this can't be right. This vector temporarily appeared in the VSD during the acceleration impulse, but subsequently was replaced by a dotted line. It was stationary while the vel vector was being re-oriented. Carol's formulations of the noticing are in each case accompanied by, what Roschelle terms, a "grasp-and-drag" gesture performed in front of the screen (see Roschelle [1992], pp. 243-245). Her gesture resembled the act of pinching a small object and then sliding it downward. Clearly this pulling action could not be done by "the black arrow," not the black arrow in the VSD at any rate.[xv] We have here, therefore, another evidently vague reference, one that leaves room for later elaboration and specification. The status of Carol's announcement as a proposal for a new understanding is secured only later when we (and they) eventually come to recognize what that understanding might be.

Earlier, we argued that Cocke's deployment of an evidently-vague pronoun reference displayed an orientation to canonical science, one that reflected proper disciplinary reserve. Are we to assume that Carol's usage here achieves the same purpose? Not likely. Evidently-vague reference is apparently a device that is used in many places to serve many different purposes. In the current context, it would appear to simply provide Carol with a means of referencing something that she has noticed, but for which she has not yet acquired a technical vocabulary with which to otherwise describe.

Dana's clarifying question (line 47, Excerpt 5) linked the hinge-pulling metaphor to the path of the white ball. What got misplaced in this exchange, however, was Dana's original concern with the "length thing." As we will see, this concern will lead to a new noticing and an additional discovery proposal, this time from Dana.

Locating a Proposal-for-a-Possible-Discovery, Part 2

Having successfully reproduced the behavior of the black ball in the first problem, the students moved on to the next EM challenge (see Clip #6 in Appendix C). As the run began, the white ball was positioned just below the black. The initial velocity was the same for both balls. Mid-run, the black ball began to execute a right-angle turn toward the bottom of the screen (see Fig. 7). A 1 s. acceleration vector was also applied to the white ball at this moment, but the acc vector had the same orientation as the initial vel vector, resulting in an increase in velocity along the ball's initial path ("It speeded up.

Did you see that?"). To satisfy the challenge, therefore, the students needed only to adjust the orientation for the acc vector. Most of the parameters were already in place.

<<Insert Figure 7 about here>>

For this challenge, Carol had taken a turn controlling the mouse. As she enunciated "Let's reset," she restarted the simulation from the beginning, but this time set to pause at the beginning of the impulse period. The following exchange occurred as they conducted their second simulation run:

<u>Excerpt 7 (Clip #6: 3:31:44–3:31:59)</u>

```
82  Dana:   Now watch the bottom arrow.  Look it, it gets
83          lengthened. (0.9) But how::,
84          (0.6)
85  Dana: →Look look ⌈it gets lengthened tah OH: ((slaps
86          table twice)) I got it!
87  Carol:           ⌊(It gets speeded up.)
88          (0.4)
89  Carol:  What?
90  Dana: →When you add on this arrow (.) it's the length
91          of the total (.) that it it assumes
```

Here we have a double reporting. Dana begins with a noticing, "Now watch the bottom arrow. Look it, it gets lengthened" (lines 82-83). Her "but how" (line 83) seems to represent a return to her previous request for clarification pertaining to the "length thing" (lines 30-32, Excerpt 6). She reiterated the noticing in line 85, this time with an accompanying gesture. As she enunciated "it gets lengthened," Dana performed a gesture with the index finger of her right hand drawing it from the tail of the vel vector in the VSD to the tip of the acc vector. Following Drew's (1984) account of speaker reportings, Dana reports something seen, but does not elaborate on what it might imply for their current understanding. The two noticings serve as prologue to her subsequent proposal.

We have already commented on the importance of oh-prefacing with regard to Carol's earlier discovery proposal (lines 37-41, Excerpt 6). Dana began line 85 as an animated demonstration, but then abruptly shifted into a different organization. Her utterance assumes the shape of what Terasaki (2004), in her description of news delivery sequences, referred to as a "Pre-Announcement First" (PAF). Like oh-prefacing, use of a pre-announcement structure provides an apparatus for managing participants' understandings. According to Terasaki, pre-announcements consist of a two-part pair. They have the following signature format:

Pre-Announcement First: "I got it!"
Solicit Turn: "What?"
Announcement: "When you add on …"

In the first part, the PAF, one party indicates that they have knowledge that is likely to come as news for the other. If the other party wishes to learn what the news might be, they request it in the second pair-part or Solicit Turn and the news gets delivered. The pre-announcement, therefore, serves to create a lexical environment whereby the announcement will be recognized as news. If this is true, however, how then is the PAF made recognizable as such? Terasaki argued that, "it is the presence of sequentially-implicative pro-forms and verbs which in part account for recipient's recognition of an item as a Pre-Announcement First" (p. 201). PAFs such as "You know what?" or "Guess what?" set up for the staged delivery of a piece of news by announcing its availability without revealing specifically what the news might be. They are, in short, designed to be evidently vague. Dana's Sacksian IT (line 86) accomplishes the same here and makes relevant a Solicit Turn from Carol (line 89). In this way, the pre-announcement structure provides a framework for the subsequent production of a discovery proposal.[xvi]

The initial clause of her announced proposal ("When you add on this arrow") was accompanied with a point to the acc vector in the VSD. Then as she enunciated "it's the length of the total," Dana repeated her gesture of line 85. She left ambiguous what the referent of *it* (the resultant vel vector attached to the ball, the vel vector in the VSD) in "that it it assumes" might be.

Dana, by offering a possible alternative treatment, presents her formulation as different from Carol's prior proposal and marks it as potentially incomplete. In the talk that followed, Carol contested these implications:

```
Excerpt 8 (Clip #6: 3:31:55–3:32:06)
90  Dana:   When you add on this arrow (.) it's the length
```

```
91          of the total (.) that it it ⌈assumes
92   Carol:                             ⌊That’s what I’m
93          saying (0.3) is that the black arrow pulls out
94          this arrow >that’s just what I was saying<
95          (0.3) to its ⌈tip
96   Dana:               ⌊Oh well I
97   Carol: But (0.2) you were doing it >saying it in a
98          different way.< (0.4) So
```

Carol here claimed ownership of Dana’s noticing (lines 92-95). She began by repeating her previous “it pulls it” observation (Excerpt 6), in a fully expanded form, “the black arrow pulls out this arrow.” As she spoke, she re-positioned the cursor over the top of the VSD. On “this arrow,” she drew the cursor through the tip of the vel vector; on “to its tip” she traced the length of the acc vector from its tail to its tip. This articulation of her theory about the action of the vectors, however, was prefaced by a challenge to Dana’s formulation. She asserted “that’s what I’m saying,” which she then repaired to “that’s just what I was saying.” Carol’s shift to the past tense creates a slight distance from her previously articulated theory. Placing her own formulation in the past also bestowed primacy upon it. She, therefore, sought to downgrade Dana’s contribution from an alternative proposal to a mere re-formulation (“you were … saying it in a different way”) of her own prior proposal.

On the surface, the two noticings do not appear to be equivalent at all. The VSD had not been a part of the screen when the students did their first day of problem solving using the EM.[xvii] Their respective proposals directed attention to different features of this display. For one thing, Dana’s formulation involves addition;[xviii] Carol’s “pulling.” Further, in elaborating on her proposal, Carol had directed attention, through the hinge-pulling metaphor, to the effect of the acc vector on the direction of the resultant velocity. The metaphor, in this way, stressed rotation around a fixed axis, not a change in magnitude. By producing them as equivalent, Carol enriched her own theory so that “pulling” now pertained, not only to a change in angle, but also change in length. At the same time, it integrated their individual contributions and resolved Dana’s open issue about the “length thing.” Note the pronoun usage in “saying it in a different way.” The evidently vague reference provides ample scope for accommodating the yet to be fully articulated explanatory principle.

Not only did their proposals stand in need of reconciliation, but their noticings with regard to the VSD also needed to be connected to or reconciled with the behavior of the white ball. Dana had made an effort in this direction in Excerpt 5 when she observed, “Making the line that you see here” (line 47). The enunciation of *here* in that excerpt was coordinated with a cursor point to the white ball’s dot trail. It leaves as an open question, however, we get from Dana’s “it pulls it” noticing and Carol’s “length thing” to Dana’s summation in Excerpt 4, “[i]t like changes the path” (line 147).

Transforming the Proposal(s) to a Discovery-Achieved

Following Excerpt 8, Carol and Dana continued to work toward finding a solution for the second problem. Their discussion was nicely summarized by Roschelle (1992, pp. 254-257). In the earlier excerpts, Carol and Dana constructed the “it pulls it” and the “length thing” formulations through a combination of talk and gesture. Their pointing was performed either with the cursor or directly using their hands. Here, however, Carol was performing instrumental actions—using the mouse to select and drag the tip of the acc vector—as she narrated her actions. In this way, she provisionally and publicly offered a solution to the second problem. At the same time, she produced a third formulation, one that integrated the action of the vectors with the motion of the ball. The exchange proceeded as follows:

<u>Excerpt 9 (Clip #8: 3:33:03–3:33:14)</u>

```
112 Carol:  Ri⌈ght it does.
113 Dana:     ⌊That’s per⌈fect!
114 Carol:               ⌊It travels right along that
115         edg:e.  (0.5) So we want it to travel along
116         that edg:e until (0.4) there. (0.6) Cuzz that
117         will make it come (.) down straight.  See it
118         will travel along that edge =
119 Dana:   = yeah =
120 Carol:  = Until it’s straight there =
```

Carol’s new formulation, which began as “it travels right along that edge” was repeated three times, each time as a demonstration. As she articulated, “It travels right along that edge” (lines 114-115), she traced with the mouse from the tail of the acc vector to its tip. The identity of the pronoun reference seems clear—we are talking about the tip of the vel vector as it was transformed during the impulse period. She reproduced with her gesture the action of VSD animation. When she repeated the formulation (lines 115-116), she depressed the mouse button, selecting the tip of the acc vector, while articulating *edge*, and released the button on *there*. The production of *there* was delayed until she had moved the tip to its new position. Having dragged and repositioned the tip of the acc vector, Carol then offered the following explanation, "cuzz that will make it come down straight" (lines 116-117). Curiously, her action with the cursor went *up* at this point, marking a line from the tip of the acc vector to the center of the white ball. This line represented the projected course of the ball (in reverse). Suggesting that the *it*, in "cuzz that will make it come down" might refer to the ball. She then returned to her formulation and repeated the gesture of tracing from the tail of the acc vector to its tip.

Over the course of Carol's long turn at talk (lines 117-118, 120), the referent of the indefinite pronoun is left evidently vague. Her talk and gestures leave it ambiguous whether she is talking about the tip of the vel vector, the dot trail of the white ball, or the ball itself. When she observes, however, "that will make it come down straight" (lines 116-117), she appears to be referring to the target behavior of the white ball. Though Carol's "See it will travel along that edge" offers a new way of viewing the screen, we do not treat it as another discovery proposal. It incrementally builds upon Carol's earlier proposal pertaining to the direction of the resultant (Excerpt 6, lines 34-38) and Dana's proposal concerning its magnitude (Excerpt 7, line 90-91), while helping to clarify their significance. At the same time it provides a bridge linking these proposals to the behavior of the white ball. It also provides a bridge connecting these proposals to Dana's subsequent description of their discovery ("It like changes the path, " "it like goes along that," Excerpt 4).[xix] In this way, the behavior of the vectors (both those attached to the white ball and those in the VSD) was tied to the modified path of the white ball. Bridges can be traversed in both directions, however, and we see here the prospective/retrospective character of a discovery-in-progress.

DISCOVERIES AS OCCASIONED PRODUCTIONS

We introduced here a way of analyzing the work of the discovery, an approach that treats a discovery as an occasioned production. It proceeds stepwise from the identification of some matter discovered, working backwards to see just where that matter entered the conversation and, finally, tracing the transformation from a proposal for a possible discovery to discovery achieved. This approach incorporated key ideas from the Garfinkel et al. report, but employed a somewhat different analytic framing. We applied this approach both to the audio recordings of the discovery of an optical pulsar and to Roschelle's EM data. But, what have we learned from this exercise?

We found first that the procedure for introducing a possible discovery is a negotiated and collaborative one. Proposals for a possible discovery, i.e. utterances within which the possibility of a discovery is initially raised, occur in environments in which mutual attention has been directed through a prior reporting. Such proposals do not, therefore, appear *deus ex machina*. In two of the three cases described here, the reporting and the proposal were produced by different speakers. In all cases, the proposal was constructed using discussables provided by the prior reporting. Though it seems logically possible that these two forms of communicative effort (attention orienting and possibility raising) could be combined in a single utterance, we saw no cases of that here and it would be interesting to seek out additional examples of discovery to see if that ever occurs. We also found that discovery proposals may, on different occasions, be packaged in quite different ways. In the case of the discovery of the optical pulsar, we find Cocke using a RPQ, while Dana and Carol both employed a news delivery sequence with an oh-prefaced pre-announcement for their respective proposals. Again, it would be interesting to examine additional discovery accounts to see if these structures are reproduced elsewhere and if (quite likely) there are yet other viable ways of organizing a discovery proposal.

More generally we found in the Roschelle data, just as Garfinkel et al. had described in the case of the discovery of the optical pulsar, that there is a real value to being "evidently vague." This is counterintuitive. Most theories of communication would hold that mutual understanding depends upon specificity of reference. Clark and Marshall's (1981) model of reference repair, for example, calls for supplying new or more specific information as a means of disambiguating unclear references. But in situations in which some matter previously unknown becomes, through the work of discovery, knowable, it is useful, possibly even essential, to be deliberately vague. In such situations, transitional means of reference are needed and the Sacksian IT and the other structures of evidently-vague reference described here can be used for that purpose. They provide a signifying mechanism that remains open through the process of discovery right up to the point at which it becomes ultimately realized.[xx]

The two papers revisited here, Garfinkel et al.'s account of the discovery of an optical pulsar and Roschelle's analysis of Carol and Dana's work with the Envisioning Machine, can be contrasted in terms of the nature of the discoveries achieved. Atkinson and Delamont (1977) argued that classroom science is structured to provide "concrete display[s] of the warranted production of factual science" (p. 100). They made a distinction between what they termed *hot* discovery, the outcome of situated inquiry into some question for which no answer is current available and *cold* discovery, exercises designed to reproduce previously settled inquiries. Cocke and Disney's collaboration at the Steward Observatory led to a hot discovery. The EM and its associated challenges were designed with the purpose of introducing learners to the established principles of Newtonian mechanics (Roschelle, 1991). Dana and Carol, therefore, were doing the work of cold discovery. The value of evident vagueness would seem to be the same regardless of whether we are talking about hot discovery or cold. This should come as no surprise since the pragmatic requirements for talking about a thing discovered are unchanged whether the discovery occurs under pedagogically-arranged circumstances or in a professional laboratory. This would seem to resonate with Lynch and Macbeth's (1998) proposal that all discoveries, whether hot or cold, consist in "different articulations of no less situated knowledges" (p. 294).

One thing that emerged when we positioned our description of the discovery of the optical pulsar alongside our re-analysis of Roschelle's data, however, was a surprise. We found that the structure of the analysis of Dana and Carol's discovery work was considerably more complex than the structure of the analysis of the discovery of the optical pulsar. This is counterintuitive given that the underlying math and science was clearly much simpler. This is not to say that their discovery was experienced or oriented to as more complex, but only that it presented itself for analysis as more complex. Though the discovery of the optical pulsar required advanced planning and careful calculations, the question to which Cocke and Disney addressed themselves was actually a very simple one—do we have evidence of a pulsar or not? For Carol and Dana, it was more difficult and the question that motivated their inquiry was a little more elusive. Furthermore, their task involved producing an explanation for which they had no ready vocabulary with which to articulate. To produce the thing as understood, they had to invent one ("pulling like a hinge," "the length thing"). Finally, they also had to find ways to reconcile potentially differing accounts. Arriving at an understanding, therefore, required more work interactionally because there was more work that needed to be done. We might say that part of professional science's prowess resides in its capacity to reduce complex inquiry to clear and simple questions. Lacking the tools to make the job simple, Carol and Dana were left to pursue a more complicated course to constructing their discovery. So, while we argued that Cocke and Disney used evident vagueness in ways that displayed an orientation to scientific rigor, Dana and Carol's use it in ways that served the opposite purpose—it displayed their status as non-scientists.

Having now employed our method to produce accounts of how two discoveries were occasioned, what is the reader to do with them? Of what value would our description of Dana and Carol's discovery be to a teacher or designer interested in implementing discovery learning methods in a classroom? It should first be conceded that microanalytic methods like the one demonstrated here do not lend themselves to use within the situation of study. It would clearly be very difficult, for example, for a teacher to analyze proposals-for-a-possible-discovery while simultaneously managing a busy classroom! The critical details of practice are best appreciated from the outside looking in, with repeated viewings and using carefully constructed transcripts. Though our method may not be useful *in* the classroom, we would argue that the findings produced using it might hold value for those interested in understanding instructional practices and improving them.

Roschelle's EM environment and its associated challenges stand as an example of an instructional innovation. Any such innovation requires that teachers and students produce the desired forms of practice that the innovation was designed to support. These practices are not *caused* by the innovation, but must be produced in use. They cannot be assumed, but must instead be studied as occasioned productions. The method introduced here as a means of investigating how discoveries are produced is one example of how the practices of producing an instructional innovation (here discovery learning) might be studied. This leaves unanswered, however, the question of how the praxeological accounts produced using such methods are to be read by teachers, researchers, and designers.

A praxeological account does not so much *capture* a practice as provide *instruction* in how it might be found. This is an important point. As a simple example, Livingston (1987, Chaps. 2 & 4) provided a description of a service line. This is a sociallyorganized affair with which we are all very familiar. We have all observed formatted queues, stood in lines ourselves, and know how to competently participate in their production. However, a queue is, to borrow an expression from Garfinkel and Livingston (2003), “a Thing-in-its-details” (p. 23). A description that fails to capture these details runs the risk of “losing the phenomenon” (Garfinkel, 2002, pp. 264-267; also pp. 162-166). Garfinkel refers to those features that make something recognizable as a service line as its “phenomenal field properties.” The goal of a praxeologic account is to make these essential details visible. But to know how to recognize service lines and to be able to reproduce them, one must do more than just read the descriptive account. Garfinkel (2002) instructs,

> Read these descriptions while watching a formatted queue. Do not read only this description. And do not read this description while watching only one formatted queue. When reading this description, tour several queues. Tour many queues. (p. 256)

The results of an ethnomethodologically-informed study, therefore, are not to be treated as specifications of practice, but rather as guides for locating the field properties that make the practices recognizable for what they are. They are, in short, tutorial problems.

Turning from queues to the work of doing discovery, we now see exactly why the Garfinkel et al. report was written in the way it was. It was written in a way that enabled us to discover for ourselves just how a discovery was produced. When Garfinkel described his exercises as tutorial problems he was not being pedantic. The crucial features that make a practice recognizable for what it is, elude simple specification. They can be discovered, however, by working through a properly designed problem. In this way, tutorial problems, “if done properly, reveal why they were done” (Rawls, 2002, p. 33).

We see in this how a program of practice studies in the learning sciences might proceed. The work of uncovering the field properties of the discovery at Kitt Peak Observatory (or Carol and Dana’s discovery in the EM environment) is similar to that of elucidating the critical details of instruction in settings of innovation. Our project, then, becomes one of producing praxeologic accounts of instructional practices, accounts that are written to be read as tutorial problems.

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Endnotes

[i] Roschelle described Dana and Carol's achievement in terms of conceptual convergence. Our unmarked shift from talking about conceptual change to talking about discovery is consistent with usage within the learning and cognitive science communities that seems to employ these terms interchangeably. Thagard (1992) and Dunbar (1994), for example, described scientific discovery in terms of conceptual change. In the same vein, Strike and Posner (1985) described all learning from a constructivist perspective as conceptual change.

[ii] The foundations of CA research were presented in the Sacks (1992) lectures. Consult ten Have (1999) or Schegloff (2006) for useful introductions to the methodology.

[iii] A broader question with high relevance to the learning sciences concerns how we might adapt our research practices to treat, not only discoveries in discovery learning, but all forms of instruction as 'occasioned productions'? We will return to this later.

[iv] Taylor's name was listed as the third author on the report announcing the discovery. In addition to designing the instrument that made the discovery possible, he had participated in the observations done on nights prior to the one on which the discovery was made and rejoined Cocke and Disney on the evening following the discovery.

[v] For additional discussion of the role of equipment in discovery practices see Latour & Woolgar, 1979; Lynch, 1985; Pickering, 1995; and Traweek, 1988.

[vi] The transcription conventions are summarized in Appendix A. If this notation is unfamiliar to you, you might find it helpful to read the transcripts aloud with a partner. Try to attend, as you do so, to all the marked features of timing and delivery.

It has been argued that transcripts are, in their design, theory-laden (Ochs, 1979). Transcriptions can be easily modified to conceal the identities of the subjects and readily lend themselves to presentation on a printed page. They have, as a result, historically been the stand-in of choice for vocal practice in the literature on language and social interaction. They work best when the analysis focuses chiefly on talk and less well when embodied aspects of interaction are considered. Nonetheless, they are an important tool for reconstructing an analyzed event and that is how they are used here.

[vii] Lynch (1993) reported a "brief telegram announced their findings simply by formulating the date and time, period of the pulse, celestial coordinates, and identity of the 'source' star in the Crab Nebula" (p. 213) was dispatched to other observatories around the world. Other astronomers were soon able to replicate Cocke and Disney's finding and locate additional examples of optical pulsars. Lynch found it remarkable that they were able to do so using such sparse instructions. We find it also interesting that the sighting of one optical pulsar made them suddenly visible to all.

[viii] Though he does not appear in either of the quoted excerpts, it should be remembered that the night assistant, Robert McCallester was also present on the telescope platform. While the dialog

would suggest that Cocke and Disney were both monitoring the CAT display, we do not know if it was also available to McCallester. There are many aspects of this activity that are unknown to us—How were the participants positioned with regard to each other? What displays and gauges were available to each? Were their hands free for pointing and gesture and were they used for such? Despite these large gaps in our record, however, it is still possible to make certain grounded claims regarding the organization of the discovery talk.

[ix] Linguists refer to such verbs as *copulas*.

[x] See Arminen (2008) for further development of this connection.

[xi] For a related notion see Garfinkel and Sacks' (1970) discussion of "Rose's gloss" (p. 366). While driving through a city that he was visiting, Rose looked out the window and said to his host, "It has certainly changed." By leaving *it* open in this way, Rose was able to work out just what he was in fact looking at (and thereby specifying) by locating it in his interlocutor's reply. As Garfinkel and Sacks argue, the "definiteness of circumstantial particulars *consists* of their consequences" (p. 366). The connection of "Rose's gloss" to the Sacksian IT was suggested by John Heritage.

[xii] The term is borrowed from Garfinkel and Sacks (1970) who specified that something is a *mock-up* precisely in the ways in which it serves to give "an account of an observable state of affairs" (p. 263). That is, it must both provide for "an accurate representation of *some* relationships and *some* features in the observable situation," but, at the same time, make "specifically and deliberately false provision of some of the *essential* features of the situation" (p. 263, authors' italics).

[xiii] We will refer to the light and dark arrows as the *vel* and *acc* vectors, respectively. We do as a notational convenience, but with a certain amount of trepidation. Such labels allow us as auditors to recover the sense of the display as an animated form of vector arithmetic. It is easy to be seduced, however, into presuming that the participants might have also understood these representations in this membered way. So beware.

[xiv] One might note the similarities between Heritage's description of changes in cognitive state as "processual" and "one that dawns, emerges, and consolidates" and our earlier discussion of discovery-in-progress.

[xv] As mentioned earlier, the behavior of the vectors attached to the white ball differed in subtle ways from the behavior of the corresponding vectors in the VSD. One could actually visualize the acc vector that traveled with the white ball as "pulling" the tip of the vel vector (see Fig. 3). Based on their affiliated gestures, however, Dana and Carol's talk appears to be oriented to the vectors in the VSD.

[xvi] The alert reader might have noticed that Carol's previously described proposal for a possible discovery (Excerpt 6) also employed a pre-announcement structure, one in which the Solicit Turn was pre-empted. Their proposals, therefore, had parallel organizations.

[xvii] See Dana's turn (lines 132-138) in Clip #9 in Appendix C.

[xviii] See Fig. 8 (p. 253) in Roschelle (1992).

[xix] It is interesting that it was Dana, not Carol, who articulated this understanding in the debriefing interview. This is possibly the strongest piece of evidence for the first form of convergence described by Roschelle (1992), that is convergence of their collective understanding of what they were doing together.

[xx] We thank one of the anonymous reviewers for suggesting this argument.

Figure captions

Figure 1. A re-creation of the first observed pulse from an optical pulsar as seen on Taylor's "Computer of Average Transients." (Reprinted by permission from Macmillan Publishers Ltd: *Nature, 221*, 525-527, copyright 1969).

Figure 2. The components of the Envisioning Machine (EM) screen.

Figure 3. A reconstruction of the Envisioning Machine display as Dana and Carol conducted an experimental run while solving the first challenge.

Figure 4. Carol's reenactment of the action of the Velocity Space Display (VSD) in Excerpt 3.

Figure 5. Dana's demonstration of the motion of the white ball in Excerpt 4.

Figure 6. Carol's intervention during Dana's demonstration (see Figure 5).

Figure 7. A reconstruction of the Envisioning Machine screen midway through Dana and Carol's initial run for the second challenge (beginning of Clip #6 in Appendix C).

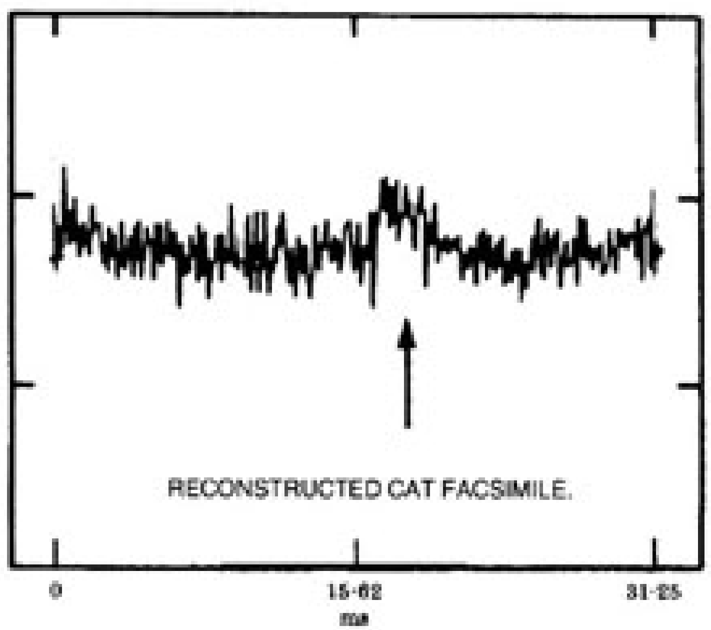


fig. 1

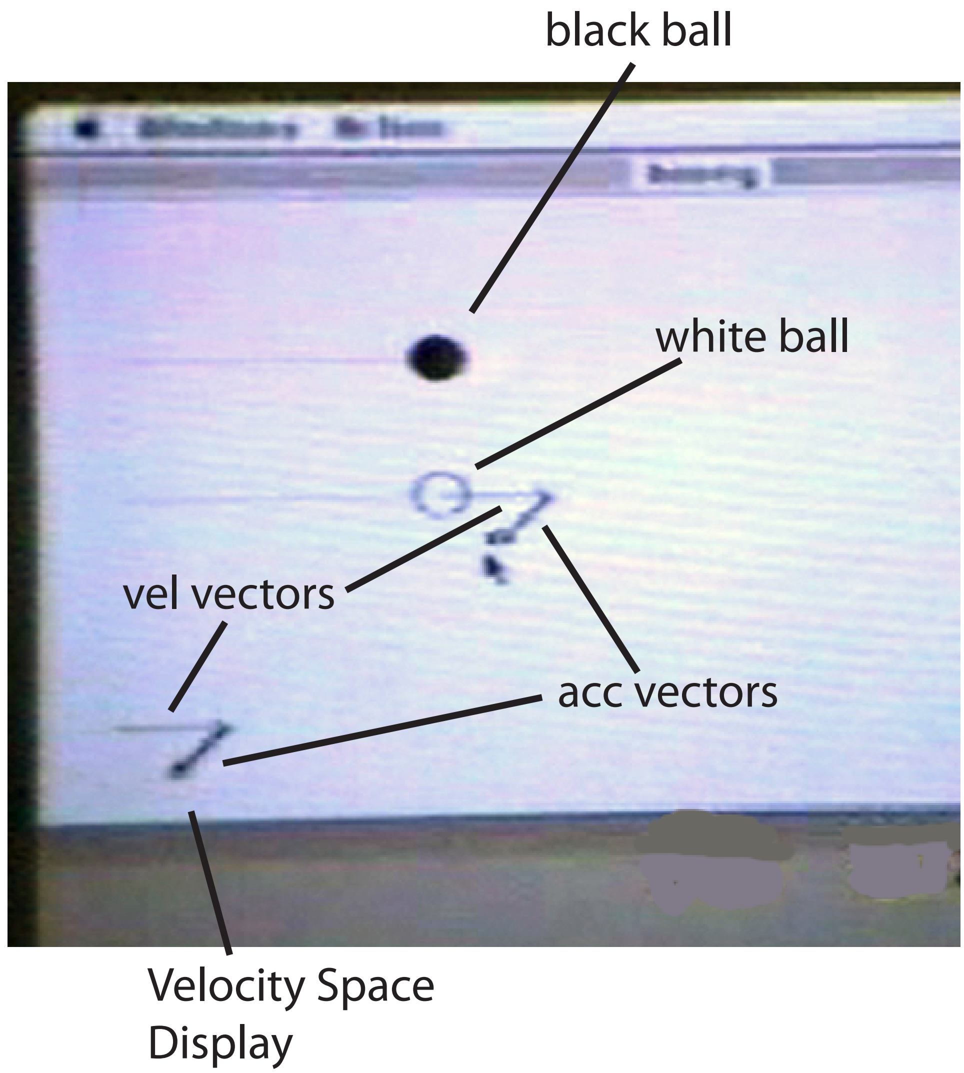

black ball
white ball
vel vectors
acc vectors
Velocity Space
Display

fig. 2

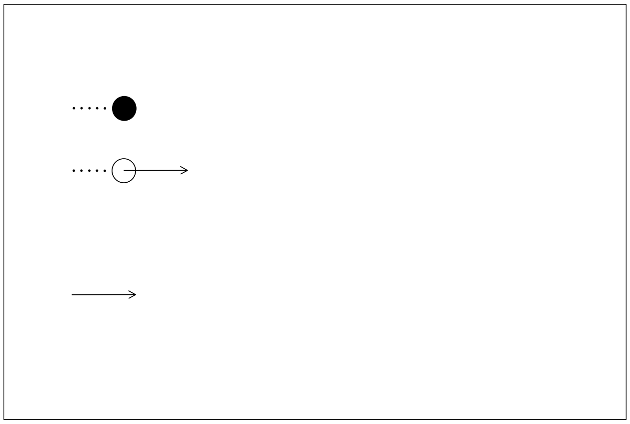


Fig. 3a

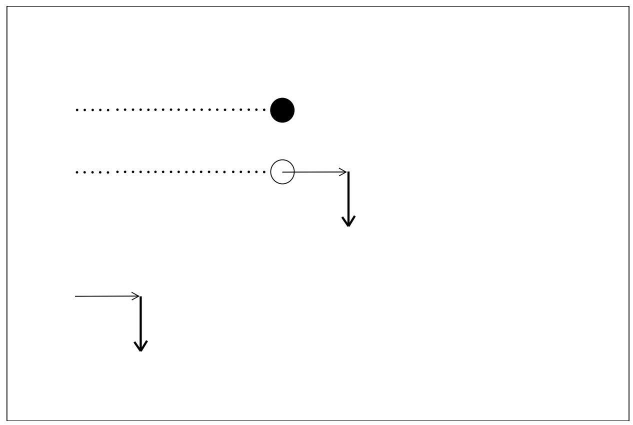


Fig. 3b

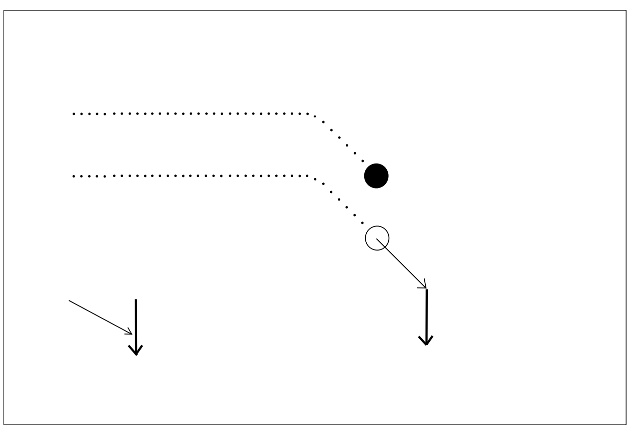


Fig. 3c

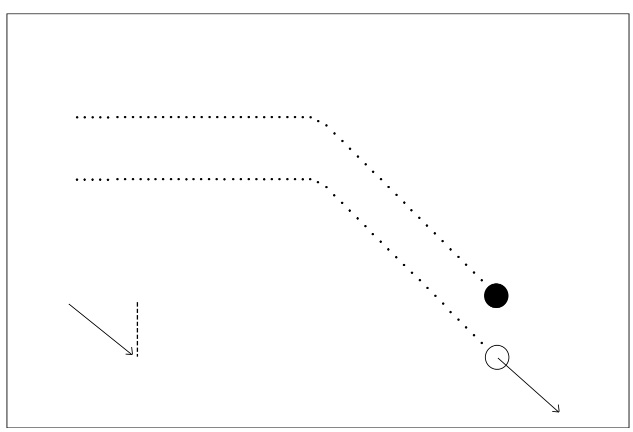
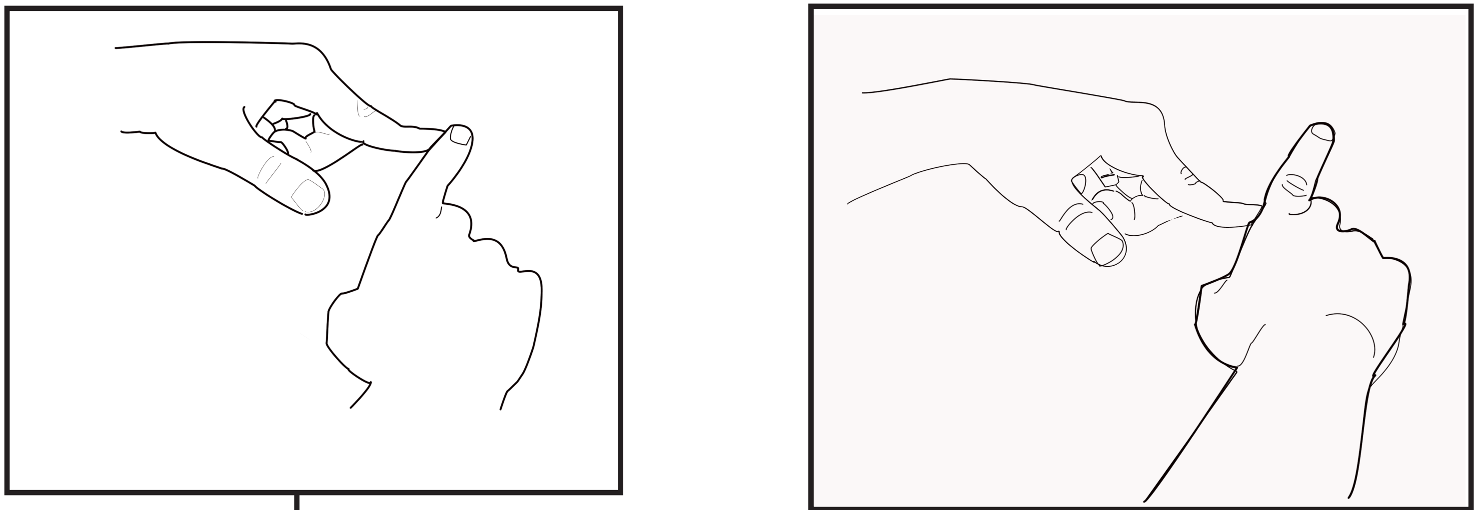


Fig. 3d

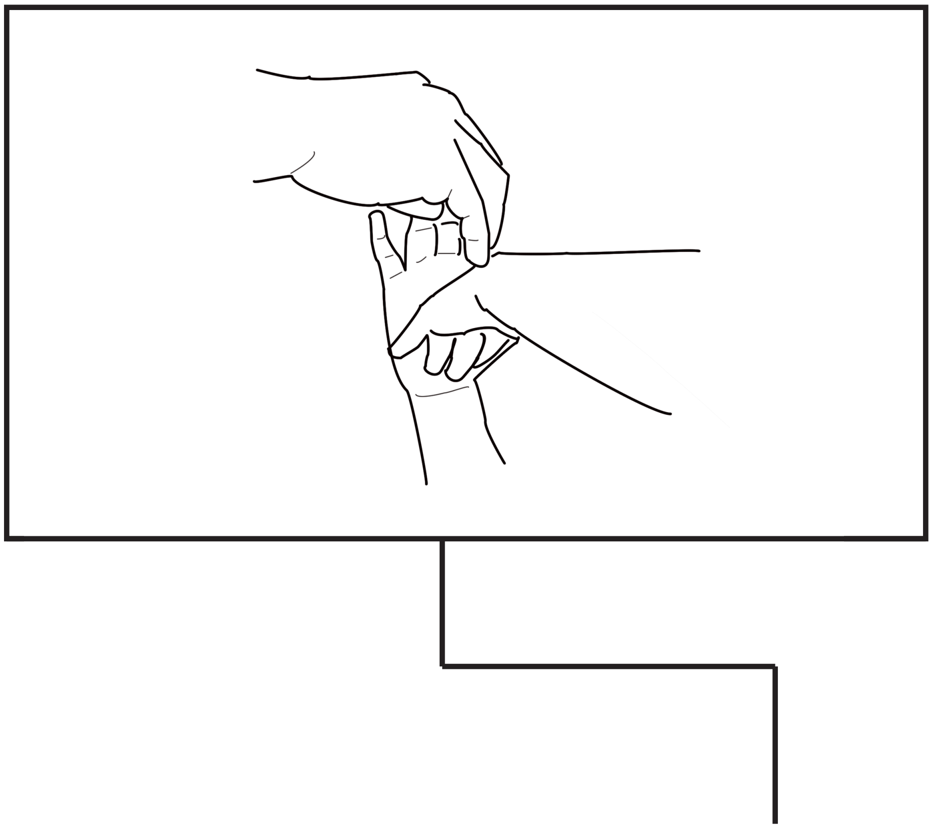


(0.7) The light arrow’s tip moves along the line of the black arrow and stops

fig.4

change it (0.4) when you put the arrow down it
like goes along [that and it gets here =

fig.5



153 Carol: =Yeah It stays hinged to the ball [>where
153 ever the ball is<
155 Dana: [Yeah. It
156 stays hinged and then it starts going like
157 that.

fig. 6

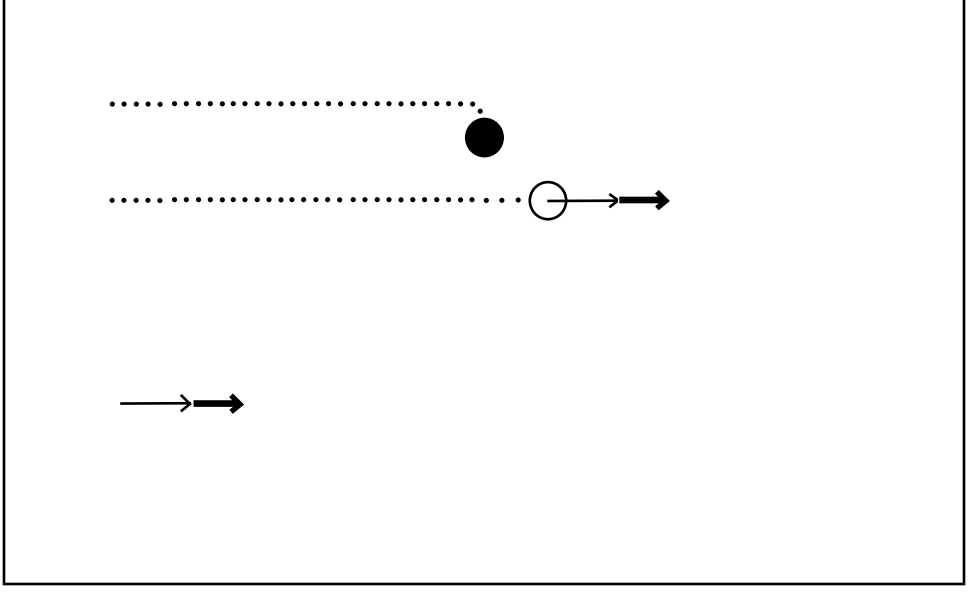


fig. 7

Appendix A: Transcription conventions

Timing		
Brackets	[ ]	Marks the beginning and end of temporal overlap among utterances produced by two or more speakers.
Equal sign	=	Indicates the end and beginning of two sequential 'latched' utterances that continue without an intervening gap.
Timed silence	(1.8)	Measured in seconds, a number enclosed in parentheses represents intervals of silence occurring within (i.e., pauses) and between (i.e., gaps or lapses) speakers' turns at talk.
Micropause	(.)	A timed pause of less than 0.2 sec.
Delivery		
Period	No.	Indicates a falling pitch or intonational contour at the conclusion of a turn constructional unit (TCU).
Question mark	No?	Rising vocal pitch or intonational contour at the conclusion of a TCU. An inverted question mark (¿) represents a half rise.
Exclamation point	No!	Marks the conclusion of a TCU delivered with emphatic and animated tone.
Comma	no,	Indicates a continuing intonation with slight upward or downward contour, as in the enunciation of an item in a not yet completed list, occurring (generally) at the end of a TCU.
Hyphen	yup-	An abrupt (glottal) halt occurring within or at the conclusion of a TCU.
Colon(s)	no:	A colon indicates sustained enunciation of a syllable vowel, or consonant. Longer enunciation can be marked using two or more colons.
Greater than/ Less than signs	> < < >	Portions of an utterance delivered at a noticeably quicker (> <) or slower (< >) pace than surrounding talk.
Degree signs	°no °	Marks speech produced softly or at a lower volume than surrounding talk.
Capitalization	NO	Represents speech delivered more loudly than surrounding talk.
Underlined text	yes	Underscoring indicates stress on a word, syllable or sound.
Arrows	↑ no	Marks a rise (↑) or fall (↓) in intonation.
Breath sounds	hhh	Audible expulsion of breath (linguistic aspiration) as in laughter, sighing, etc. When aspiration occurs within a word, it is set off with parentheses.
	•hh	Audible inhalation is marked with a preceding dot.
Other		
Parentheses	( )	Text enclosed in parentheses marks transcriber doubt. Texts separated by a slash represent alternative transcribings.
Double parentheses	(( ))	Transcript annotations (text italicized).

Appendix B: Steward Observatory, January 16, 1969

Multiple sources were used in constructing these transcripts. A digital copy of the original audiotape was obtained from the Niels Bohr Library of the American Institute of Physics. A working transcript for the whole tape produced by the BBC was obtained from the same source. Transcripts (and recordings) for some excerpts can also be found on the website of the Center for the History of Physics (2003). Some of this material was also transcribed and included as an appendix to the Garfinkel et al. (1981) article.

<u>Run #18</u>

Disney: (We've got a little bit of shape now.)
(0.4)
McCallister: We::ll,
(1.0)
McCallister: (It's) about like I saw in that sky: over
there, t' tell you the truth.
(0.5)
McCallister: Ther's a nice di(hh)p on the (hh) sid(hh)de of
that sky.
(0.5)
McCallister: Better turn this thing down.
(2.5)
Disney: We've got a bleeding ↑pulse <u>here</u>.
(2.0)
Cocke: ↑He::y.
(4.5)
Cocke: Wo::w!
(1.2)
Cocke: You don't suppose that's really <u>it</u> do you?
(1.8)
Cocke: It <u>ca:n</u>'t be.
Disney: (Sure) it's right bang in the middle of the
period. (Look), I mean right bang in the middle
of the sca::le. It really looks something to me
at the moment.
(0.8)
Cocke: Hmmm.
(3.0)
Disney: An' it's growing too!
(1.3)
Disney: It's growing up the side a bit too hmmh.
(1.9)
Cocke: God it (↑<u>is</u>) isn't it?
(2.4)
Cocke: Hhhm.
(6.3)
Disney: Look (at that) it's like a bleeding pulse?
(1.4) ⌈It's growing, John!

Cocke: ⌊Heh heh heh
McCallister: It is.
(0.6)
Disney: Look!
(1.0)
McCallister: It is. (1.3) He's right.
(3.0)
Cocke: Gaw::d!
(1.5)
Cocke: I hate to believe it right now (though)?
(1.5)
McCallister: Can't be done.
(0.9)
Cocke: CRrrg •Hih •hih •hih •hih.
(2.0)
Cocke: Well we're up to two thousand counts.
(1.0)
Cocke: We're now at seven fifty, seven hundred:,
(2.6)
Cocke: °( )° seven fifty (or something)=
Disney: =It's really building up. Look at that.
Cocke: It is, isn't it. Yeah.
Disney: There's not one left behind (now). (0.3) See
look, (0.6) not one of those dots left behind.
Cocke: Good God, yeah, uh huh.
(1.8)
Cocke: WOW, we'll stop we'll stop after ⌈(0.2) and
take it out of phase and start over again after
this run's over.
Disney: ⌊This (would
really favor) what we were expecting it
(1.6)
Disney: ↑Hmmm there's a second something over here look
Cocke: Well, we expect two (.) a small pulse and a
larger pulse remember.
Disney: Uh hmmm.
Disney: Right.
Disney: I wasn't too sure of this one, but that's a
bleeding pulse.
Cocke: It is isn't it.
(2.1)
Cocke: God.
(1.8)
Cocke: God damn it!
(0.4)
Disney: (Well) I don't believe it ⌈cuz I I'll wait
until we get a second one.

Cocke: ⌊hhsh hhsh hhsh
(>I know<)
Cocke: Yeah, I won't believe it until we get the
second one and until (.) the thing has shifted
somewhere else.
(3.4)
Cocke: But sure didn't do that on the sky, did it?
(0.5)
Disney: No no.
(3.0)
Cocke: God almighty! =
Disney: = Now it might get worse now as we're getting
as we're getting out of phase.
(McCallister): Ach(hh)ou!
Disney: But that ⌈look's a bloody good pulse! (0.6) to
me.
Cocke: ⌊Fine.
(1.0)
Cocke: Yes, isn't it.
Disney: >Come come< just come and look at it down here.
(Cocke): °Perfect! (try to).°
(2.4)
McCallester: Hha ha ha.
Disney: This is an historic moment!
(3.0)
Cocke: ↑Hmmm!
(1.8)
Cocke: I hope that it's an historic moment.
(1.0)
(Disney): Hhm hm.
(1.4)
Cocke: We'll know when we take another reading and uh
(.) if that (0.4) spike there is again right in
the middle see that spike's right in the
m:iddle and that scares me.

Run 22

Cocke: My Gaw:d! (0.4) It's a damned good thing you
remembered that correction hmm?
Disney: Eh hmm.
(0.7)
Cocke: Boy! (1.5) Son of a bitch! (2.1) °Jesus
Christ!°
(1.9)
Disney: (That's just moving) an' nothing like the pulse
we had before anyway. =

Cocke: = There’s something building (hh)up.
Disney: >(Now) you look at the bottom there< the dots
are quite (.) evenly around the bottom as well.
Cocke: Uh hmm.
(4.7)
Cocke: Yeah, now here’s some more coming up here.
(1.0)
Disney: Yeah:.
Cocke: And some more here oh: that’s just noise huh?
Disney: Um hmm.
(9.6)
Disney: Yeah that’s just noise >look at that<.
(10.2)
Disney: We’ll have to figure out what the hell this
means now.
(1.0)
Cocke: Ya::h. (0.5) HUH huh. (0.3) Theoretically?
(0.5)
Disney: Well- we- well- wa- we should be able to work
ou:t ⌈(.) how many photons are coming in per
second: to this pulse. (Correct)?
Cocke: ⌊(Yup.)
Cocke: Uh ⌈huh
Disney: ⌊The bloody size of the pulse.
Cocke: Well, we should be uh huh. =
Disney: = Uh:::: and that will should be and that will
give us some idear of the luminos:ity of this
object.
Cocke: Uh huh.
(1.4)
Disney: Won’t it.
(0.7)
Cocke: Right, uh huh (.) yeah.
(1.8)
Disney: Can we get the actual: number can we read off
digitally the number of photons in each
channel? (0.8) subsequent to this? =
Cocke: = Oh yeah!
Disney: We can?
(1.3)
McCallester: Well yeah I don’t see why (not)
Cocke: You’d haf’ to (0.7) essentially we would be
able to do this from the um (0.3) >well we can
do it< (0.4) >first of all< from the chart
recorder,

Some of the transcribed talk presented in Roschelle (1992) was not included on the recordings provided to us. Transcripts from those fragments are highlighted below. Clip timings are off of Roschelle's camera.

Clip #1: (3:26:31–3:26:42)

```
Carol:       O:kay.
             (4.9)
Dana:        ↑Wee:⌈↓ha:::
Carol:            ⌊Whoa::
             (0.5)
Dana:        >So we're gonna have to make it< (0.4)
Carol:       Go ⌈down
Dana:           ⌊veer
```

Clip #2: (3:29:14–3:29:27)

```
Carol:       Pretend we didn't see tha:⌈t
Dana:                                  ⌊So (.) what are we
             gonna do about this: (0.4) We're gonna make
             thi:s: shorter::
Carol:       Make it at a straight line too make it at
             ninety degree angle (1.5) just for the hell
             of it (0.4) there
```

Clip #3: (3:29:27–3:29:55)

```
Dana:        Wait well w- we didn't have it at a ninety
             degree
             angle befo::re (.) and it ⌈seems like the
Carol:                                 ⌊Okay  (take  the)
Dana:        same thing =
Carol:       = So we should go another (.) second: (0.8)
             °so:::°
             (1.5)
Dana:        YES it's beau:tiful
Carol:       Keep playing it's ⌈it's (       )
Dana:                          ⌊But it doesn't go down at a
             ninety degree angle I don't under⌈stand:
Carol:                                        ⌊Yea:h:
             mm mhm we'd better reset it.
```

Clip #4: (3:30:17–3:30:34)

```
Dana:        What I don't understand is ho::w (0.2) the
             (length thing/lengthening) (0.3)  the (0.2)
             positioning of that arrow::
             (1.5)
Carol:       (.hh)OU::H, you know what I think it is?  It's
             like the li::ne, (0.3) (that/fat) arrow is the
             li::ne, of where it pull:s that down >like see<
```

how that makes this dotted li:ne? .hh (0.2)
That was the black arrow:. (.) It pull:s it.

Clip #5: (3:30:32–3:30:57)

Dana: Now you're saying this is the black arrow?
Carol: Yeah.
Dana: And it pull:s (.) the other arrow ⌈on its
hinge.
Carol: ⌊On its
hinge. It pulls the other arrow on its hinge
down to the tip of the black arrow,
(1.3)
Dana: Making the line that you see here?
Carol: Right.
Dana: So if you were to have, like, this
Dana: ⌈⌈Who:a.
Carol: ⌊⌊Who:a. Put that back.
Dana: I, can't move that or, like, am I not allowed?
Carol: ((coughs)) I wouldn't mess with it
Dana: Damn. Okay so I guess. Okay so if you have
this arrow=
Carol: =The the black arrow, was like, was like,
right, I'm totally making this up, but, see the
black arrow was right ther::e But I'm assuming
it would pull the other arrow like right out to
⌈there
Dana: ⌊like, like
Carol: But this is completely made up no way so don't

Clip #6: (3:31:20–3:32:06)

Carol: Play. Are you ready for one second? >lemme
just<
(1.7)
Dana: This is slower when you push play (.) it
doesn't go as (0.5) >you know< ⌈quickly.
Carol: ⌊>It takes just
a second<
(0.8)
Carol: Hoohoh.
(0.8)
Dana: Um::. That was great.
Carol: ⌈⌈Hh(h)huh.
Dana: ⌊⌊It speeded up. (0.2) Did you see ⌈that?
Carol: ⌊He(hh)he
(0.5) •HHH Ours speeded up. (0.3) (•hhh)Ohh.

(0.6) Let's (0.8) re⌈set (0.4) play it for
three seconds,
Dana: ⌊Who:a.
(2.1)
Dana: Now watch the bottom arrow. Look it, it gets
lengthened. (0.9) But how::,
(0.6)
Dana: Look look ⌈it gets lengthened tah OH: ((slaps
table twice)) I got it!
Carol: ⌊(It gets speeded up.)
(0.4)
Carol: What?
Dana: When you add on this arrow (.) it's the length
of the total (.) that it it ⌈assumes
Carol: ⌊That's what I'm
saying (0.3) is that the black arrow pulls out
this arrow >that's just what I was saying<
(0.3) to its ⌈tip
Dana: ⌊Oh well I
Carol: But (0.2) you were doing it >saying it in a
different way.<

Clip #7: (3:32:10–3:32:29)
Carol: So if we wanted to pull this down to there,
we'd have to have this be like all the way
around:d or something like that.
Dana: No 'cause that wouldn't make this tip swing
around to that tip and make that angle?
Carol: What angle?
Dana: So I'm saying, Okay =
Carol: = I bet if I leave it like that it's going to
make this angle=
Dana: = right that's what I'm saying.
Carol: So we're going to have to swing all
⌈the way down here.
Dana: ⌊Oh my God! It's all so much clearer now!

Clip #8: (3:33:03–3:33:14)
Carol: Ri⌈ght it does.
Dana: ⌊That's per⌈fect!
Carol: ⌊It travels right along that
edg:e. (0.5) So we want it to travel along
that edg:e until (0.4) there. (0.6) Cuzz that
will make it come (.) down straight. See it
will travel along that edge =
Dana: = yeah =
Carol: = Until it's straight there =

Dana: = So, but what we didn't realize before.
Carol: Might have to make it a little shorter though.
Dana: Can't believe we didn't like think of this at
all, yesterday.
Carol: I know. Makes me feel quite stupid.
((interval not transcribed))
Dana: Well, before we didn't have this little picture
of what the arrow is doing.
Carol: Yeah.

Clip #9: (3:55:32–3:56:41)

JR: What did you figure out
Carol: We figured out ⌈what the black arrow ⌈was
Dana: ⌊Well ⌊yeah.
Dana: The black arrow, like, instantly made sense. I
don't know why we didn't get it yesterday. I
guess it showed on here, that helps you see,
like, where your black arrow was. And it
showed your other arrow moving to the tip of
that. So it, like, showed you what it wasn't
showing you yesterday.
Carol: Ye:ah:, (0.2) so =
JR: = So could you explain to me how it works:?
(1.0)
Carol: Yeah, I could show if: (1.2) you have the (0.3)
light arrow and the black arrow? (1.6) ahm:
(0.7) The light arrow's tip moves along the
line of the black arrow and stops (0.3) at the
end of the black arrow like
Dana: ⌈And then
Carol: ⌊(It hinges/like) it moves (0.7) like from the
ball like that if that was like an axes if that
was like (.) a hinge or something? And it moves
along the line of the black arrow and stops
(0.7)
Dana: ⌈And then like continues (0.6) as the path:
Carol: ⌊at the tip and then it goes that way (.) as
the (thick) arrow
(0.7)
Dana: It like changes the path: >like if< (0.4) this
is the black arrow and this is the light one
(0.4) it like goes up (0.6) and then when you
change it (0.4) when you put the arrow down it
like goes along ⌈that and it gets here =
Carol: ⌊yeah

Carol: = Yeah. It stays hinged to the ball ⌈>where
ever the ball is<
Dana: ⌊Yeah. It
stays hinged and then it starts going like
that. So if you wanted to change it to a
ninety-degree angle (0.5) you'd hafta put the
bla:ck (0.5) arrow so that it was at like the
right (0.4) angle
(0.5)
Dana: But ⌈(.) to git it (.) to go down (like that)
Carol: ⌊To go down it goes ninety
Dana: So even though you put the black arrow straight
down it's not really always ninety ⌈angle
Carol: ⌊That's what
we thought before so that if you put the black
arrow at a ninety-degree angle and then take a
(.) ninety-de⌈gree
Dana: ⌊But ⌈that's wrong you have to over
compensate.
Carol: ⌊You hafta make it like that
>like that< so it goes like that
(3.2)
JR: Sounds goo:d,
Dana: Sure.