Optical Pulsars and Black Arrows: Discovery's Work in 'Hot' and 'Cold' Science

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Abstract: Prior research in science education has explored differences in professional scientific inquiry and classroom science, what has been characterized as *hot* and *cold* discovery. We compare here two previously analyzed instances of 'doing discovery.' The first is the discovery of an optical pulsar reported by Cocke, Disney, and Taylor (1969) and analyzed in some detail by Garfinkel, Lynch, and Livingston (1981). The second is an example of practical reasoning performed by two students working in a microworld analyzed by Roschelle (1992). One can observe differences across the two cases in the nature of the things discovered and in the practices of inquiry that led to their discovery, though the interactional work of doing discovery is remarkably similar. It is a work of noticing, of directing partners' attention, and of seeking, negotiating, and securing ratification of an understanding. We propose further inquiry into the interactional organization of discovery's work.

Educational researchers have long demonstrated an interest in the processes by which students are introduced to the procedures and reasoning of scientific discovery. Atkinson and Delmont (1977) in an early report, argued that classroom science is structured to provide "concrete display[s] of the warranted production of factual science" (p. 100). They made a distinction, however, between what they termed *hot* discovery, the outcome of situated inquiry into some question for which no answer is current available and *cold* discovery, the result of inquiry directed toward reproducing an answer for a question that is already settled (at least for the teacher). They concluded, on the basis of this distinction, that classroom discovery is in its form and purpose a "mock-up" of actual science.

Lynch and Macbeth (1998) observed that classroom experimentation does indeed differ from professional science on a variety of dimensions including scale and timing, division of labor, witnessability, the competency of the participants, availability of equipment, and considerations of cost and safety. While conceding that classroom science *is* designedly a mock-up of canonical, laboratory science, they entreated the reader not to take their findings as contributing to the conventional critique of science education as lacking in authenticity. Instead of presenting classroom science as a deficient version of professional science, Lynch and Macbeth analyzed science lessons as possessing "(a) orders in their own right, (b) assemblages of equipment, embodied practice, witnessing relations, descriptions, and explanations; and (c) developing organizations of competency" (p. 276). They argued that "there is no great divide between the academic and ordinary settings, but only different articulations of no less situated knowledges" (p. 294).

But if discovery's work is to produce new articulations of situated knowledges, how is this actually accomplished as an ordered form of contingent practice? We will examine two previously analyzed instances of discovery, one a paradigmatic example of professional scientific inquiry, the other inquiry in a pedagogically-arranged situation. The first is the discovery of the optical pulsar reported by Cocke, Disney, and Taylor (1969) and later analyzed by Garfinkel, Lynch, and Livingston (1981). The second is an example of practical reasoning performed by two students working in a microworld analyzed by Roschelle (1992). Our purpose in bringing the two together is not to highlight differences between them, but rather to address the following question: if both constitute legitimate instances of discovery, what is it about them that makes this recognizably so?

We approach this question from an ethnmethodologically-informed perspective. Ethnomethodology is a social-science discipline that focuses on a specific kind of practice, the practices of sense-making. It begins from the assumption that the sense or intelligibility of a situation is not given *a priori*, but is instead methodically built-up locally through the actions (i.e., "sense assembly procedures," Garfinkel & Sacks, 1970, p. 343) of local participants (the "order production staff," Garfinkel, 2002, p. 102). Ethnomethodological research, therefore, is directed toward documenting the methods through which intelligibility is produced *in situ*.

DATA

Discovering the Optical Pulsar

Cocke et al. (1969) began their published account with the following declaration: "We wish to report the discovery on January 16, 1969, 03h 30m UT, of strong optical pulses from the pulsating radio source NP 0532 in the Crab Nebula" (p. 525). Beyond its contribution as a scientific report, the paper has attracted much attention owing to the fact that their interaction at Steward Observatory on the night in question was preserved on an audio recording. This serendipitous development has transformed the work of that particular night into an historically-important example of discovery in professional science and it has been studied on this basis by a variety of social scientists. For the analysis reported here, we have examined the following materials: the original Cocke et al. (1969) report, partial transcripts of the Steward Observatory recording included as appendices to Garfinkel, Lynch, and Livingston (1981), and the transcripts and audio clips provided on the website of the American Institute of Physics (Center for History of Physics, 2003).

Radio pulsars had only just been discovered a year prior to the publication of the Cocke et al. paper and had generated enormous interest in the astronomy community (Center for History of Physics, 2003). What actually caused these emanations was unknown, though there were various theories (e.g., white dwarfs, neutron stars). The discovery of an optical pulsar would have important implications, both for theories about the mechanisms of pulsar behavior and the fundamental characteristics of stellar bodies. To find an optical pulsar, however, an astrophysicist would need certain things: access to a powerful telescope, the availability of a device for accumulating light emissions at a tuned frequency, the practical skills to operate such apparatus to gather scientifically-useful data, and a very good guess as to where (and at what frequency) an object emitting optical pulses might be found in the vast regions of the charted universe. Cocke and Disney traveled to Arizona to do their observations because they were able to secure time on a mid-size telescope there and because Don Taylor, an engineer at the University of Arizona, had developed a photometric device (the "Computer of Average Transients") for measuring frequency-tuned photo emissions. Though Cocke and Disney lacked practical experience in operating telescopes, they were aided on the night of the discovery by Robert McCallister, a technician working at the observatory. Based on others' prior findings and their own calculations, Cocke and Disney organized their labors into a series of *Runs*, each sampling photo emissions at a particular frequency from a particular point in space. At the most practical level, their work that night consisted in jointly making sense of the representations produced by Taylor's photomultiplier.

Garfinkel et al. (1981) focused on the status of the thing discovered, what they termed the "Independent Galilean Pulsar" and its relationship to the researchers' embodied ("vulgarly competent," p. 139) practices. Our focus, on the other hand, is on the interactional features of doing a discovery. In particular, we are interested in how participants interactionally and methodically navigate from an occasioned noticing to a ratified understanding. Early in Run #18, we find the following exchange:

<u>Excerpt 1</u>

```
1 Disney:   We've got a bleeding pulse here.
2            (2.0)
3 Cocke:    He::y!
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Disney’s announcement does not constitute a discovery. In measured terms it directs the attention of his interlocutors to something noticed. His assertion is more specific than a simple, ‘Hey, look!’, however. The use of the membered term, a *pulse*, adopts a certain position with regard to what they are seeing on the oscilloscope (see Fig. 1). After a studied pause, his announcement elicits a non-committal response from Cocke. Cocke registers the noticing, but withholds endorsement of its status as a ‘pulse.’ Both Disney and Cocke subsequently state conditions that must be satisfied in order for the thing observed to represent evidence for an optical pulsar (Disney: there needs to be a secondary peak, Cocke: the primary peak must shift or disappear when they change the parameters). The runs that followed were designed as tests to determine if these conditions could be satisfied.

Their efforts culminated in an exchange that then occurred during Run #23:

<u>Excerpt 2</u>

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1 Cocke:     Well it’s there all right
             >isn’t it.  Look at it.<
2               (1.7)
3 Cocke:     Gaw:d!
4               (3.9)
5 Disney:    ⎡⎡Look John there's
             definitely two pulses see=
6 Cocke:     ⎣⎣(         )
7 Disney:    =look they're ⎡split by a
             half-cycle.
8 Cocke:                   ⎣yeah (.)
             yeah Uh huh. Yeah. (1.0)
9            Right.
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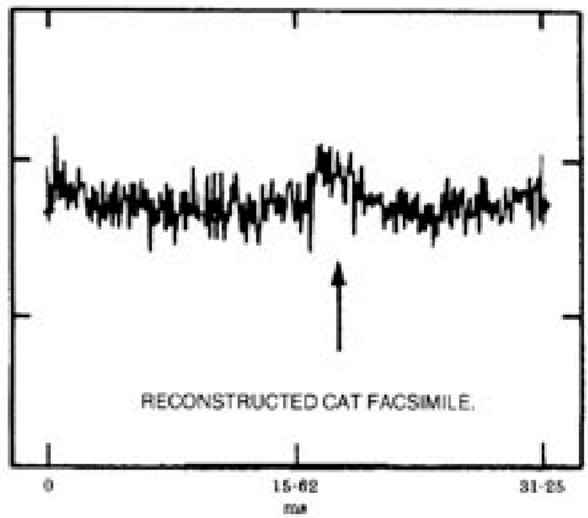

<u>Figure 1</u>. The first observed pulse from the optical pulsar as collected on Taylor’s “Computer of Average Transients.” (Adapted from Cocke et al., 1969)

Cocke’s utterance marks an arrival of sorts. The prospective nature of Disney’s earlier identification has given way to a proposal for a ratified understanding. Cocke concludes with a perceptual directive (“Look at it.”) to which Disney responds with a series of directives of his own (“Look John …”, “See look …”). They provide instruction one to the other in how to regard the accumulating evidence of the oscilloscope display.

We lack the space here to describe the details of how the transition from initial noticing to a resolved and ratified understanding was organized interactionally, but we can make several summary observations. First, the ‘discovery’ emerges from a background of situated knowings. It is this background that provides for the intelligibility of Disney’s opening announcement (“We’ve got a bleeding pulse here.”) and allows for its parsimony. Second, the pulse is presented here and treated subsequently as a jointly-held possession (“we’ve got …”), reflecting the participants’ orientation to discovery as a collective activity. It is not sufficient for Disney or Cocke to unilaterally accept the pulse as warrant for an optical pulsar; they must collectively adopt a view of the accumulating data as a certain kind of evidence. Finally, discovery’s work is conducted using a set of sequentially-organized, contingent practices.

“It pulls it”: Representing the Physics of Motion

Roschelle (1992) described the interactions of two high school students, ‘Dana’ and ‘Carol,’ working together at a computer. They were volunteers in a study in which subjects worked in pairs to complete a series of 18 problems (called “EM Challenges”). They used a program known as the Envisioning Machine (EM), “a direct-manipulation graphical simulation of the concepts of velocity and acceleration” (Roschelle, 1992, p. 239). 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 challenge up to and including its solution. Clips #4 and #5 involved reflection after having completed this challenge. 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. The last clip contains an interview conducted later in the day.

In an EM simulation run, two objects are made visible on the screen—a darkened circle labeled by Roschelle as the "ball" and an open circle he designated the "particle" (see Fig. 2). Both objects left a trail of dots when they moved. The students took as their task to make the dot trace produced by the particle match the dot trace produced by the ball. This involved interactional work by the students to 1) discover, through sequential and coordinated actions of inquiry, that the two arrows associated with the particle, described by the students as "light" arrow and "black" arrow, could be manipulated to alter its behavior, 2) to produce manipulations of the arrows that would properly produce desired movements of the particle, and 3) to produce systematic descriptions of those reproducible methods that produced predictable behavior of the ball. The camera was directed toward the computer screen throughout the first eight video clips providing no direct view of the participants. Based on gestures performed and Dana and Carol's respective positions in the interview clip, however, we can infer that Carol sat to the left (looking toward the screen) and Dana to right. They appeared to take turns operating the mouse and we occasionally saw one or the other point or gesture in front of the screen. Their activities and actions were coordinated in ways that displayed a joint orientation to this work as a team task, imparting both benefits and responsibilities to the participants.

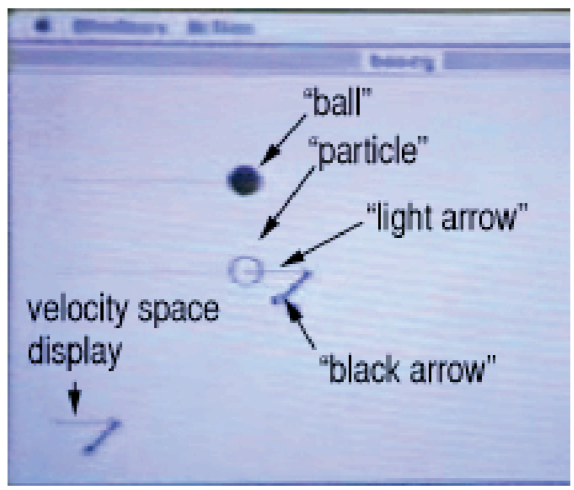

Figure 2. Screen grab showing the components of an IM challenge within the EM microworld.

The two challenges described in Roschelle (1992) were both IM (Impulse Machine) problems. In non-IM challenges, the trajectory of the particle was based solely on the starting position of the particle and the length and direction of the two arrows set by the students at the beginning of the simulation. In IM challenges, on the other hand, the length and direction of the black arrow could be reset for one sec. intervals at pre-specified times in the simulation. A special graphic designed to "animate the process of vector addition" (Roschelle, 1992, p. 240) was also provided. As a simulation run began, this "velocity space" graphic displayed a stationary version of the "light" arrow attached to the particle. During the intervals in which the black arrow had been reset, a dark arrow was also displayed in the velocity space display with precisely the same length and direction as the black arrow in the simulation (see Fig. 2). As the simulation advanced, the origin of the light arrow in the velocity space display was fixed but its length and direction were changed as its tip traveled along the length of the dark arrow. When it reached the tip, the dark arrow disappeared but a dot trace persisted (see Fig. 2 in Roschelle, 1992). Those who have had a course in Calculus-based physics might recognize this animation as geometrically computing the resulting velocity (the light arrow after the reset) given an initial velocity (the light arrow at the beginning of the reset) and a change in acceleration (the dark arrow). Dana and Carol did not discuss the graphic in such terms, however, and displayed no evidence that they recognized it as such.

Figure 2 captures a moment near the conclusion of Clip #7 when Carol was setting parameters for a simulation run. At this moment Dana declared "Oh my God! It's all so much clearer now!" This statement would presumably index some sort of discovery, but what is the referent of *it* and how did it manage to become so much clearer? Just 35 sec. earlier, she had dramatically announced a change in her understanding of the situation. Her use of *now* linked her current assessment to that prior announcement.

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Excerpt 3
1 Dana:      Now watch the bottom arrow.  Look it gets lengthened.
2 Dana:      But how::?
3 Carol:     ⌈⌈It gets speeded up.
4 Dana:      ⌊⌊Look look it gets lengthened until OH: (.) I got it!
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Dana's utterance in progress in line #4 was suspended to deliver this proclamation. Heritage (1984) has described how *oh* in some circumstances can be used as a *change-of-state-token*, that is as an element used in talk to "propose that its producer has undergone some kind of change of state in his or her locally current state of knowledge, information, orientation or awareness" (p. 299). The interaction proceeded as follows:

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Excerpt 4
1 Carol:     What?
2 Dana:      When you add on this arrow (.) it's the length of the total
3            (.) ⌈that it assumes
4 Carol:         ⌊That's what I was saying is that the black arrow pulls
5            out this arrow >that's just what I was saying< ⌈to its tip
6 Dana:                                                     ⌊Oh I
7 Carol:     But you were doing it >saying it in a different way<. So
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Roschelle (1992) noted parallel situated pointing during Dana's (line #4 in Excerpt 3 and line #2 in Excerpt 4) and Carol's (lines 4 and 5 in Excerpt 4) respective explanations. Carol treated Dana's explanation here as a recasting or a formulation of her own explanation provided 2½ min. earlier.

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Excerpt 5
1 Carol:     .hh Ooh you know what I think it i:s↑ it's like the li::↑ne
2            (0.3) that arrow it's the li::↑ne of where it pu::lls that
3            down >like see< how that makes this follow the line↑ .hhh
4            that was the black arrow (.) it pu::lls it.
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In line #1 of this excerpt, we see Carol producing an oh-prefaced announcement of her own. The explanations are deeply indexical and employ an *ad hoc* vocabulary. One could question (as Roschelle [1992] does) whether or not Carol's description is indeed a prior statement of Dana's explanation offered in Excerpt 4. Our interest here, however, is in how the work of noticing, formulating, and ratifying of an emergent understanding are organized.

Both Dana and Carol's announcements of changed understanding (in Excerpts 3 and 5 respectively) were offered as if marking an event, a psychological change-of-state, but in both cases they served as pre-announcements (Terasaki 2004), that is they set the stage for something that followed, in this case the delivery of an explanation. The work of conjointly producing a situated understanding as evidenced in the data involved the sequential unfolding of particular and occasioned activities according to an emergent sequence that provided for the production of specific descriptions/explanations of the observed phenomena. The participants' understandings were occasioned as and evidenced by their work practices with respect to the tasks at hand. Our analysis of Dana and Carol's discovery rests on two key assumptions.

The very fact that Carol produced a description of the observed behaviors of the relevant objects on the screen relies on the assumption that these observed behaviors were discoverable, accountable, predictable and reproducible. In part, this assumption derives from the work they had already performed to observe the outcomes of their own manipulations of the simulation environment. This assumption can also be seen to inform the actions of the participants based on the apparent and obviously designed nature of the activity which Carol and Dana were performing. Furthermore, this assumption provided a warrant for their ongoing inquiry into the relationship of the dark arrow in the velocity space display and the black arrow and the relationship of the black arrow to the motion of the particle. Finally, and essential for the very notion of discovery, we recognize that actors can and do assume that the relations governing observed behaviors are discoverable, accountable, predictable and reproducible without having to 'understand' or articulate what those relationships actually are.

A second assumption is that participants can articulate these relationships in mutually intelligible ways. This assumption allows participants to treat the organization, design and achievement of this simulation as a collaborative instructional activity that makes relevant conjoint and collaborative sense-making work. This was an activity in which 1) observable and reproducible behaviors were exhibited and 2) participants could manipulate objects in the scene to change those behaviors in reproducible and predictable ways. Participants' task as embodied in the design of the activity was to produce accounts and explanations of these behaviors that could be used to reliably reproduce observed behaviors using explanatory procedures and resources to which they already had access. It is apparent from the circumstances, methods and the material resources of the simulation as well as the achieved sense-making by Dana and Carol that they were already capable of making use of explanatory methods and procedures that were adequate for the task at hand.

Discussion

Hall (1999) conducted an analysis in which he held side-by-side two fragments of interaction, one a dinner table discussion with a seven year-old boy and the other a bit of diagnostic reasoning carried out by a cohort of 2nd-year medical students in a tutorial meeting. Such a contrast presupposes that both events can be seen as instances of some more general interactional category. The category, in the case of Hall's paper, was 'having a theory.' In this same way, the current paper takes Cocke and Disney's discovery of an optical pulsar and Carol and Dana's joint articulation of the significance of the velocity space display to be two instances of a more general category, the interactional category of 'doing discovery.'

One might, of course, observe differences across the two cases in the nature of the things discovered and in the practices of inquiry that led to their discovery. For example, the discovery in the case of Cocke and Disney was provided for by their prior calculations and planning; one might say they set out 'looking for it.' In the case of Dana and Carol, the participants proceeded to dutifully carry out the task set for them and discovered something along the way. Here, as in the Cocke and Disney example, the discovery was primed, but the agency of the priming was different. The priming in this case was provided not by the participants themselves but rather by the designer of the microworld. Despite this difference, however, the interactional work of discovery is remarkably similar. It is a work of noticing, of directing partners' attention, and of seeking, negotiating, and securing ratification of an understanding and the primary finding of this paper is that the ways in which this work is organized in these two instances is remarkably similar. Other similarities can also be seen. For example, both instances were organized around cycles of manipulation and observation (i.e., the sampling runs of the Cocke et al. study and the simulation runs in Roschelle's report). Both also involved discovery related to a representation—the CAT display in the Cocke et al. study and the EM screen in the Roschelle study. Though our focus here has been primarily been on the interactional organization of producing a discovery, the participants' use of representation and practices of inquiry are also clearly important to understanding these different case studies as qualified instances of 'doing science.'

Cartoonists represent discovery as a light bulb suddenly illuminated above the subject's head. Is discovery, then, to be understood as an intra-cranial phenomenon? As Garfinkel (2002) has observed, "There is nothing in heads but brains" (p. 211). Looking for discovery there, as a consequence, would seem to be an analytic dead end. As we have attempted to document here, a discovery can be better understood as the intersubjectively-negotiated production of a ratified understanding. Seen in this way, a discovery is not a mental event, but an interactional accomplishment, like a conversation or an argument. As to the question of whether cold discovery equals hot or whether discovery in school emulates discovery in professional science; we take this to be an empirical matter. The answer will not be found in detailed examinations of curricular design or in exogenous evaluations of students' understandings of scientific method. The answer, if it is to be found at all, must be located in the details of the participants' actions when carrying out the necessary work of these two settings. Regardless of whether the practices of inquiry in 'hot' and 'cold' science turn out to be different or the same, it might seem reasonable to expect that the interactional methods by which the doing of discovery actually gets done are likely to be recognizably similar. We need more work, however, to better understand what these methods might be.

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Acknowledgements

We are especially grateful to Jeremy Roschelle or making available the digital recordings upon which his 1992 publication was based. Preparation of this manuscript was supported in part by two grants from the National Science Foundation (EHR #01-26104 and EHR #03-13990). Any opinions, findings, conclusions, and recommendations expressed are those of the authors and do not necessarily reflect the views of the funding agency.