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Discovering Work as "Experimental Demonstration" in School Science Labs

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Introduction

What gets discovered in school science laboratory work? A canonical answer, available in the professional education literature, would be that scientific concepts get uncovered and learned, along with (possibly) some technical skill in operating experimental equipment and even some elementary philosophical understanding of the practice of science. It is no accident that in school science, the use of laboratory-type activities became known widely during the 1960s and 1970s as "discovery learning," where students were to infer principles about how the natural world operates from manipulating everyday and scientific materials in particular ways.

To an education professional, 'what gets discovered?' could be quite easily heard as a normative question, synonymous with asking 'what should be learned?' In fact, a high-profile publication in the United States, *America's Lab Report*, has identified the following commonly accepted learning goals for school science laboratory work:

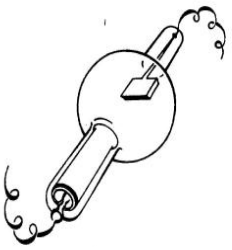
> "enhancing mastery of subject matter; developing scientific reasoning; understanding the complexity and ambiguity of empirical work; developing practical skills; understanding the nature of science; cultivating interest in science and interest in learning science; and developing teamwork abilities." (National Research Council [NRC], 2006:4)

Where the first goal – enhancing mastery of subject matter – especially is concerned, the NRC report acknowledges dismal success. Studies stretching from the 1960s to the present day have measured student science knowledge through pencil-and-paper tests, and found little evidence of the efficacy of lab work for improving this knowledge. Considered as an input variable, student laboratory work has been pronounced no better or worse at producing student science achievement than watching demonstrations or videotaped experiments performed by others (NRC, 2006).

I will approach the matter differently. Following the analytic perspective of ethnomethodology (Garfinkel, 1967; Button, 1991), 'discovery' in school science labs will be appreciated as an interactional achievement. In other words, rather than characterize 'what got discovered' using of tests of scientific knowledge, I will look closely at students' and teachers' practical actions in school science labs, recorded in real time, in order to develop some initial characterizations of the methodical work in which those students and teachers are engaged. This is to be done without irony (Garfinkel, 1967); that is without setting our professional analytic description of the interactional work of school science labs in opposition to professional educational accounts.

Re-specifying (Button, 1991) students' work in this way allows us to see the array of detailed, practical judgment constituting recognizable, but loosely stated, educational outcomes. In other words, the task is to describe and identify *just how* students might indeed "enhance mastery of subject matter" – or "develop scientific reasoning" or "understand the complexity and ambiguity of empirical work" – through their practical activities in school science labs.

Of course, discovery itself may be considered a matter of perspective. In this sense, one could anticipate that the discovering work particular to students has something in common with what the philosopher of science Norwood Russell Hanson identified as the acquisition of scientifically-trained ways of seeing:



> "A trained physicist could see one thing in [the Figure]: an X-ray tube viewed from the cathode. … [But, s]eeing is not only the having of a visual experience; it is also the way in which the visual experience is had. At school the physicist had gazed at this glass-and-metal instrument. Returning now, after years in University and research, his eye lights upon the same object once again. Does he see the same thing now as he did then? Now he sees the instrument in terms of electrical circuit theory, thermodynamic theory, the theories of metal and glass structure, thermionic emission, optical transmission, refraction, diffraction, atomic theory, quantum theory and special relativity." (Hanson, 1958:15)

In other words, we may expect that over the course of a career of being instructed in science, one discovers ways of seeing scientific concepts in otherwise non-evident places. Hanson's description surely has something in common with Lindwall's and Lymer's (2008) discussion of school science labs as places where the development of disciplined perception (see Stevens and Hall, 1998) of the world in particular material arrays can be arranged and instructed through teachers' and students' interactional work. The present study seeks to describe just this work.

University Introductory-Year Physics

The materials selected for this paper come primarily from a study of undergraduate science and engineering majors engaged in physics laboratory activities conducted at a large, Midwestern research university. Four classes of students and their respective Teaching Assistants (TAs) were selected, and approximately sixty hours of videotape of lab activities were collected during one academic quarter.

The classes were chosen so that each course in the three-quarter introductory physics series would be represented, along with one "honors" course (which covered the same topics as the first course in the sequence)[1]. Each of the four laboratory sections met eight times over the course of the 10-week academic quarter for the study. The laboratory activities were graded with and considered part of the larger course, which also consisted of lecture and discussion (recitation) components.

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[1] Students enrolled in the honors version of the course typically come from one of two populations: those designated "honors students" by the University, meaning that they would fall into (roughly) the top 10% of their academic class (based on grades and test scores); and students who have identified themselves as physics majors.

In this physics department, there was an active group of professors and graduate students whose research focused primarily on physics education, and through developing curricular materials for the University's introductory physics sequences, this group worked earnestly to try and minimize the negative effects of instructional conditions generally criticized in the education literature, such as large class sizes and monotonous lecture formats.[2]

Specific attention was also given to improving the laboratory portion of the introductory physics courses. The lab manuals for the videotaped courses were written by a professor at the university[3] (who was also a primary member of the physics education research group), and the lab activities were carefully designed to complement lecture and recitation activities. Graduate students in the physics education research group were also involved in teaching and designing labs and recitations.

The particular scenes described in this study come from a single lab investigation conducted by students enrolled in the second course of the three-quarter sequence, which is titled "Introductory Physics: Electricity and Magnetism." The classroom contained space for twenty-four students: three rectangular lab tables along each side of the room which were arranged so that one short end was against the wall, and the other facing an aisle in the center of the room. Each lab table was surrounded by at least four stools for two students to sit on each side. Computers and equipment were arranged so that each group of two students could work together.

Electric Force and Electric Charge as Practical Action

The analysis that follows makes use of tapes produced during the first formal laboratory meeting of the quarter, and captures the students' work on an activity titled *Electric Force and Electric Charge*. The activity involves the manipulation of relatively ordinary, everyday materials (e.g., cellophane tape, glass and plastic rods, wool, plastic wrap, aluminum cans, paper, Styrofoam) in order to demonstrate aspects of "electric charge," "electric force," "polarization," "conductors," and "insulators".

The activities occurring at two different lab tables in the classroom were videotaped and later transcribed for the descriptive analysis. Four students were gathered around each lab table to complete the lab tasks; the students worked in groups of two although they were free to discuss the laboratory activity with others in the room. The teaching assistant roamed around the classroom during the class time, visiting each lab table to answer questions and check student progress. This was the first lab activity of the quarter, so the students were "new" to working with one another; however, because they were not new to the Introductory Physics sequence, they knew something of the culture and expectations of laboratory work at this university.

The "Introduction" section of the *Electric Force and Electric Charge* lab written in the students' manual gives a brief conceptual overview of the science involved, as well as the students' practical task:

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[2] The department also regularly administered pre- and post-tests such as the Force Concept Inventory (Hestenes et al., 1992) to several hundred students each quarter to determine the effectiveness of their instructional efforts.

[3] All lab materials from this study (manuals, computer software) which were authored by faculty members are not cited in the bibliography to protect participants' anonymity.

> "Twenty-five hundred years ago, the Greek philosopher Thales found that when he rubbed amber, the hardened sap from a tree, it attracted light objects. A mere twenty-four hundred years later in the latter part of the nineteenth century, systematic investigations led to the formulation of a conceptual model of electricity that now allows us to understand Thales's experiments. During this lab, we will develop our own conceptual model for electricity by analyzing a series of simple experiments." (Lab Manual:1)

The next few paragraphs ask the students to consider "how a doctor could learn about your heart by attaching electrodes to your wrists and legs" and how a heart, "deep inside your body [can] produce those wiggly yet repetitive lines seen on an electrocardiogram." It gives some brief explanation of these phenomena, and ends with the question: "What is this stuff called electric charge?"

The subsequent portion of the lab manual – and the beginning of the students' instructions (the "activity" itself) – provides a striking contrast to the cheerfully-constructed, historical and application-based introductory accounts of electrostatic charge. In a brief paragraph, the students are asked to disregard the information they had just been given:

> "You have all heard about electric charge. There are two types, like charges repel, unlike charges attract, and so forth. Well for now, please forget everything you have heard. For the rest of this lab, you are only to write comments and make statements that are supported by the observations and analysis of the experiments that follow. If you do not see it, do not say it! In this section, the goal is to develop a meaning for the property of matter that is called electric charge." (Lab Manual:2)

The juxtaposition of background historical and conceptual information with the instructions for students to "forget everything" and become disciplined observing-reporting witnesses of whatever phenomena they encounter is fairly emblematic of science students' practical work, *as students*, in their laboratory activities. On the one hand, the students are to discover – as if for the first time – the orderly properties of whatever the scientific concept they are studying, using the materials provided. On the other hand, successfully seeing "electric force" in the interaction between pieces of cellophane tape and various everyday objects requires *some* notion of what one should be *looking for*.

It may not be surprising to a reader with any experience in science classrooms that "good" science students successfully learn how to traverse this oppositional set of expectations. Furthermore, these expectations appear to take shape in science classrooms at levels prior to that of the university students examined here (see Atkinson and Delamont, 1977).

For example, in another videotaped set of materials collected by the author, third grade students performing a laboratory activity were to scrape an ice-cube with grit frozen into it (a "mini-glacier") across a piece of sandstone, and respond to an imperative given on a worksheet: "What happens? Write your observations". Immediately after rubbing their ice cube across the sandstone, two students in one group of four began to argue about what they saw.

1. Amy: the glaciers sorta scratching the sandstone=
2. Dave: =Noo:::
3. Amy: Yea::h
4. Dave: Lookit the points ((*C takes the glacier and begins scraping the wood*))
5. Amy: (1.0) *A little bit*=
6. Dave: =Noo:: (1.0) ((*turns away to face his worksheet*)) too bad

One student (Dave) – who after some frustration literally held the ice cube in front of his detractor's eyes for her to see – insisted that what he observed was a *rock scraping a glacier*. The other student (Amy) confidently explained – several times, using analogies and scientific vocabulary words – that what the group has witnessed was a "form of erosion," and that most definitely, the *glacier has scraped the rock*. Whereas Dave faithfully produced a description of what he observed, Amy saw the materials as an evident "mock up" (Atkinson and Delamont, 1977; Garfinkel and Sacks, 1970) of what the teacher had been talking about in the previous days' science lessons.

Although we can expect that college physics students have long-since learned to deal with the task of "seeing science" in the school laboratory, the instruction to "forget what you know" and "just report what you see" often becomes itself an object of skeptical inquiry, and can lead them to second-guess their expectations and mount a special search for evidence to the contrary. For example, in one segment of the videotaped *Electric Force and Electric Charge* (*EFEC*) lab exercise, two pieces of cellophane tape are given electric charges by first flattening them on the lab table and then quickly ripping them off of the table. When two strips are placed directly on top of one another on the table, ripped off, and subsequently ripped apart, they acquire opposite electric charges – which the students learn by holding the tape strips near one another and observing them move towards each other: "oppositely-charged objects attract."

Once the students have created two differently-charged tape strips, they hang the strips from a dowel rod at their lab table, label them "t" and "b"[4], and proceed with a portion of the activity in which they are to charge various other objects at their table (by rubbing the objects with fur or cloth), hold them close to the tape strips, and determine whether the object is repelled by the "b" tape or the "t" tape. Students Bill and Gina reach a trouble spot when they note that the square cut-out of (blue) Styrofoam board they originally observed repelling from the "b"-tape began attracting it when the procedure was repeated.[5]

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[4] The "t" and "b" labels stand for "top" and "bottom" strips of tape. The students don't use "positive" or "negative" as labels, because they don't know which tape strip has acquired which type of charge.

[5] Line numbers reference sequential order in the larger study. Transcript conventions are taken from Sacks et al. (1974).

1709. ((*Gina is holding up the blue board to the hanging tape strips*))
1710. Gina: no its attracting now t'da bee
1711. Bill: well so- they might- they might have a typo in their thing
1712. itza piece uh tape (.) it could be either or (.)
1713. ((*reading*)) do all the free elect::-
1714. Gina: 'tsgot several typos then (1.5) I just needta be sure
1715. 'n this is the kinda stuff tha:t getschu a minus couple points
1716. in the la:b (.) that you should be getting a hundred in hhm
1717. (2.0) I mean you can go ahead an keep goin
1718. Bill: mmhmm:: i- i- itsa la:b- itsa la:bratory result (.) whatever site ya
1719. git- 'ts gon- it doesn't make a difference
1720. (2.0) I mean (1.0) expect stuff ta go screwy
1721. (2.0) hmhmm thissus a lab (.) this isn't- hmm (.)nothing's perfect

The transcript is interesting for its coherence with the exchange between the third grade students noted above: Bill is ready to accept the task of "reporting what we observe," whereas Gina worries about the intended curriculum of the science exercise. Student Bill offers an account of the problematic observation that shifts the relevant field of inquiry from the observation field to the lab manual ("they might have a typo in their thing"). But Gina is clearly uncomfortable with Bill's proposed account. For Gina, the possibility of typos doesn't resolve an apparently anomalous pair of observations – not solely because of the apparent conflict in the scientific principles involved, but because of the implication for her grade in the laboratory, and her assessment of how classroom physics 'works'.

Bill takes up a similar theme, and provides his own assessment of their accountability as students: "they told us to write what we see, and strange things happen in lab" (including, apparently, "a typo" in the lab book). In both accounts, there are thus multiple observational fields at play, and the students are consulting and/or invoking each of them.

Experimental Demonstrations

With these orienting descriptions in hand, I want to return to the question posed at the outset of this study: *What gets discovered in school science laboratory work?* In professional science, "discovery" is associated with experimentation; with formal, deliberate inquiries into the workings of the natural world intending to uncover some news about that world. In school science, however, laboratory activities are not expected to produce findings novel to science (although the findings may be novel, in part at least, to students).

Collins (1988) notes that historically, the scientific "'experiment' was done to find out something about the natural world, whereas a 'demonstration' was intended to reveal that something to an audience" (p. 727), and argues for the continued relevance of these distinctions today. This distinction suggests that rather than consisting of *experiments*, school science lab activities might be considered *demonstrations* of scientific concepts affiliated with an instructional curriculum. Furthermore, these activities are essentially *self*-demonstrations, where students must serve simultaneously as audience *and* exhibitor.

The self-demonstration character of school lab activities poses a unique challenge to the science student. Collins (1988) credits Gooding with developing the experiment-demonstration distinction in his historical accounts of Faraday's nineteenth century habit of "practic[ing] the art of experimenter in the basement of the Royal Institution but only [bringing] it up to the lecture theatre *once he had perfected it in the case of each novel effect*" (p. 727, emphasis added). He continues

> "The hallmark of demonstrations is still preparation and rehearsal, whereas in the case of an experiment one may not even know what it means for it to work – the experiment has the capacity to surprise us…Wherever possible, experiments are still done in private because, the initiated aside, confidence in 'the facts' will not survive a confrontation with Nature's recalcitrance." (ibid., p. 727)

The students in school science labs do not generally have an opportunity to practice or rehearse their self-demonstrations. As a result, they are typically given instructions with which to work to produce an intended result. And it is finally here that we can locate science students' discovering work:

What gets discovered in school science labs is a practical course of action for turning instructions into an evident demonstration of a defensible scientific character.

In other words, the students' demonstration work shares with the natural discovering sciences some aspects of experimentation, in that through its enactment, students are continually experimenting with ways of seeing and saying the science that is to be found around them. The school laboratory activity self-demonstration, in tandem with the required written accounting of it, serves as the thoroughly cultural "potter's object" (Garfinkel et al., 1981) which emerges from science students' lived work in the classroom laboratory[6]. The third graders' witnessing of erosion in an ice cube's movement across sandstone is such a feat, as is university physics students' accountable production of electric force and charge in assemblages of cellophane tape and Styrofoam boards.

The task remains to articulate just how a practical course of action for producing a self-demonstration develops in the science laboratory. I will consider science students' work in this regard along two broad categories: *Following Instructions* and "*Fitting*." I'll define the latter as the students' attempts to fit together their instructions with what they expect to be the relevant scientific ideas.

Although the *EFEC* lab materials are used as exemplars for this study, they are in many ways emblematic of the practices undertaken by students across the videotaped corpus of introductory physics labs. The physics students in each laboratory course engaged in various activities recognizable across scientific (and everyday) practices – for example, "observing," "measuring," "calculating," "accounting," etc.

These practices are useful examples of the "epistopics" which organize Lynch's (1993)

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[6] H. Garfinkel, M. Lynch and E. Livingston describe Cocke and Disney's 1969 discovery of the optical pulsar using an analogy with the potter's object (and in contrast to the work of, say, a coroner providing a cause of death): "The analogy to the oscilloscopically displayed pulse is the developingly observable object of the potter, where the pulse takes 'shape' in and as of the way it is worked, and *from* a place-to-start with *to* an increasingly definite thing." (Garfinkel et al., 1981:137)

call for building a post-analytic corpus of science studies. As Lynch details, many aspects of the labs studied and described are no doubt features distinctly attached to and shaped by the setting and occasion. Yet, there may be features of these undergraduate physics labs that are also recognizable as more or less general features of school science lab work.

I will revisit the nature of this "family resemblance" (Wittgenstein) – as well as the implications of students' work in following instructions and fitting – in the concluding remarks.

Following Laboratory Instructions

In the end, most of what students are asked to do in a school science laboratory is directly related to enacting a set of instructions.

Previously, Amerine and Bilmes (1988) studied third grade students' performance on following the instructions given in several classroom learning activities. As relative beginners to following instructions for the kinds of activities given to them, the students often failed to follow their directions competently.

After observing the students' difficulty, Amerine and Bilmes argued that, in following instructions, the

> "meaningfulness and coherence of instructions is grounded in the perceived relationship between course of action and projected outcome." (1988:338)

In other words, one requirement — perhaps the most fundamental — for competently following instructions is an ability to recognize that the intended outcome of enacting instructions is suggested in the instructions themselves[7].

Amerine and Bilmes also argued that the course of action in following instructions be understood reflexively; that is, action is not only shaped by the instructions but shapes them, as well. With these noticings in hand, Amerine and Bilmes characterized four features of following instructions that seem to be necessary for their successful enactment:

> (1) recognizing "the essential and unessential features" of written or verbal instructions;
> (2) being able to "fill in the gaps," or, remedy the indexicality of these accounts, "both conceptually and through practical activities;"
> (3) determining "the relevance of particular acts;" and
> (4) producing "practical classifications of phenomena" in order to "reduce [the] ambiguity" of the task at hand (ibid.).

We needn't treat their account as a prescriptive one in order to take interest in the work of following instructions in our undergraduate physics lab, and whether it includes practical actions of the kinds which Amerine and Bilmes found. The work of (practically) remedying ambiguity and indexicality and classifying materials at hand might take on a specific and interesting flavor in the case of the *EFEC* lab.

In the context of a school science laboratory activity, the instructions provide a practical guide for the students caught between the task of performing a science demonstration

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[7] Of course, as we have noted, an added complication for the university physics students (and many other school science students) is that they must pretend *not to know* all that they have learned about school science and what their lab is supposed to come to…

and the reality of working within a more experimental context. The students in these science laboratories build their next-course-of-action from instructions provided by various sources: the lab manual; each other; the teaching assistant; the textbook; and other ad hoc places. Enacting the instruction seems to involve two continual processes: fixing a field of view, and determining the relevance of the instructions in terms of what and how to see in this field of view.

These processes of "field-fixing" and "determining relevance" are also related to practical aspects of producing a witnessable demonstration.

Lynch and Macbeth's (1998) ethnomethodological study of elementary classroom science demonstrations (performed by instructors) characterizes the classroom science demonstrations they observed by referencing four themes:

> (a) positioning and disciplining witnesses;
> (b) managing and orchestrating an observing assemblage;
> (c) securing and shaping descriptors; and
> (d) upgrading commonsense explanations (p. 277).

"Positioning and disciplining witnesses" refers to the teachers' "orchestrated management" of the scenes:

> "the discipline of the classroom is a concerted ordering of eyes, ears, hands, entire bodies, and discursive actions, all of which are brought into focus on a materially witnessed phenomenon." (ibid.)

Similarly, the teachers must manage the unfolding of the demonstration act. Thus,

> "managing and orchestrating an observing assemblage" entails performing an activity while "'narrating the scene' with hands, eyes and voice pointing to the 'missing what' of the demonstration." (p. 281)

By selecting and shifting between particular registers of talk, the teachers "secure and shape descriptors" and "upgrade commonsense explanations." Through directing, questioning, and answering students, teachers produce the evident science of the display. Thus, relevant vocabularies are brought into play, and ways of speaking scientifically appear on the scene, where both are tied to material displays and actions.

Lynch and Macbeth's (1998) study of classroom science demonstration shares a clearly overlapping interest with the present study. Their analysis seeks to understand how teachers and students interact to produce "science" out of equipment — beakers, droppers, bulbs, carts, or whatever materials are marshaled for the display — and out of communicative practices — talk, gesture, silence, intonation, and so forth. Of course, in the present study of university physics labs, the challenge for students is to essentially "play teacher" on their own; using their instructions as a guide, they must establish pertinent explanations and descriptors, find the "missing whats," and do their own upgrading of accounts, as the work of producing an observable display of the phenomenon, perhaps for the first time.

Fixing a field of view

In the following scene, four students (B, G, P and Q) are working around the lab table, about halfway through the allotted lab time in the *EFEC* activity. In this segment, students P and Q are getting ready to begin a portion of the activity in which they will be holding up different types of materials (glass rods, plastic rods, etc.) to some charged strips of cellophane tape which are suspended from a wooden dowel on a ring-stand in front of them. Here are the students' literal instructions for this part of the activity[8]:

> "You have other objects at your lab table. Try rubbing some of these objects together (for example, a glass rod with silk or a plastic tube with wool) to see if after rubbing they have a 't-type' electric charge or 'b-type' electric charge. List only those objects or types of materials that are clearly t-type or b-type." (Lab Manual:3)

The transcript below notes the interaction between P and Q as they begin to follow those instructions.

1159. P: Therez: (0.5) a glass rod wi' silk
1160. (1.0) plastic tube ((*looking toward black rod*))
1161. Q: w'got plastic tube right here
1162. ((*Q picks up white rod and black cloth*))
1163. P: or iz this the plastic tube?
1164. ((*P reaches across Q and picks up the black rod*))
1165. Q: uhmm::
1166. P: uh 'is iz:
1167. ((*Q hits rod on table twice*))
1168. P: *'ats plastic, isn't it?*
1169. Q: 'at sounds like wo:od
1170. ((*Q hits the other rod on the table three times*))
1171. P: ( ) *ben:ding* ( )
1172. Q: 'is iz wool right here
1173. ((*P holds out the black cloth*))
1174. Q: *hmm:* ((*P takes black cloth*))
1175. P: *wool?* so:: (.) d'we have a-
1176. d'y' have a glass rod over there?=

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[8] Note again that "t-type" and "b-type" refer to the charged pieces of cellophane tape the students are using in this experiment. The lab manual does not write of the tape as being "positive" or "negative" in terms of charge, but instead asks students to refer to the laboratory equipment as having "t-type" charge (the same charge as the "top" piece of tape) or "b-type" charge (the same charge as the "bottom" piece of tape). The instructions are part of establishing the "missing what" of the demonstration that the experiment is to reveal.

This segment of transcript captures a mundane practice of science laboratory students; it's akin to "taking stock," and students routinely do this in preparation for performing an experiment.

They identify relevant pieces of equipment in accordance with the instructions, and in doing so, they "fix" a field of view for gauging their scientific observations. But here, they do so not on a field of docile objects. It's not a mere inventory. Rather, the question repeatedly shows itself as "just which object is this?" whose answer is tied to practical courses of action, e.g., hitting a rod on the table and listening to the sound it produces.

Although the lab manual's instructions almost *casually* mention "other materials" on the lab table, and parenthetically mention some of the materials, the students focus very intently on determining "what's what" on the table in front of them. These students are quite serious about identifying pieces of equipment (glass, wood, plastic, wool), and inspect the materials in vernacular ways to decide the matter.

Examples of students fixing or anchoring their view of the lab activity to the equipment occur throughout the lab session. For example, the students carefully consider the scale markings on a ruler before attempting to measure a piece of tape; they compare sketches in the lab manual with the materials in front of them, and they discuss the meaning of the instructions in the lab manual on a regular basis. Even the meaning of the term "lab bench" is brought up (lines 1029-1030 and 1033 below):

1027. B: We're supposed to like hang these things up, aren't we?
1028. (19.0) ((*B attaches the strips of tape to the dowel on the ring stand*))
1029. G: (hhh) 'to the wooden dowel (2.0) ((*reading*)) Now tape a new schtrip with
1030. the huh-handle to the lab bench (1.5) what's the lab bench?
1031. B: piece uh tape (.)
1032. wooden dowel (.) ((*reading*)) (piece uh strip new tape)
1033. thisis the lab bench ((*hits table with elbow three times*))

The students' closely detailed reading of their instructions renders even seemingly obvious terms as "lab bench" as in need of coordination with the material field of view.

But note, another common form of "field-fixing" may be reading lab instructions aloud – my transcripts are replete with instances of this practice. The reading sometimes signals that it is time to "move on," and other times might serve to call attention to a place where observations and instructions stand in puzzling relation, but saying the written words has the effect of disciplining group members to consider the same spatial field – to get everyone "on the same page," so to speak.

In the professional and education research literatures, lab activities in science education are often critiqued for adopting a "cookbook" approach. In other words, by relying too heavily on procedural instructions they are said to allow students to miss the scientific principles behind the activity. In looking closely at the way students orient to lab activities in real time, however, it is apparent that a very close orientation to detail seems to be part and parcel of following instructions during such an activity.

And so, despite the fact that science educators may try to direct their students' attention to the *science* of a laboratory activity by only casually mentioning the details of the materials and equipment or by requiring "supposition-less looking," the students, it seems, must establish some sort of practical reference to what they're working with and how it is to be handled.

Seeing relevance

A second aspect of following instructions that students regularly enact in the science laboratory is learning to see the relevance of the instructions for the task at hand. Recall that instructions provide a guide for students to pull the scientific demonstration relative to a particular lab activity into view. In order to "see" the science of a laboratory activity, the students must know where to look.

For example, the students at another table (W, X, Y and Z) were closely oriented to measuring 10 cm of tape, as their laboratory manual instructed them to do:

> "Remove two 10-cm long pieces of regular clear tape from a roll of tape. Curl the ends of the tape over to make handles (see the sketch at the right). Press the sticky sides of the tape to the top of the lab table and rub them so that they make good contact with the table. Then, quickly pull the strips of tape off the surface and bring the non-sticky sides of the tape near each other. Record your observations. Does it matter which side of the strips face each other? How does the distance between the strips affect what happens?" (Lab Manual: 2)

The students consequently spend quite some time and effort working out exactly what the marks on the ruler mean before they begin removing the tape (note: the aspects of "fixing the field of view" described above are involved here as well).

X: is that ten cennimeters?
W: (cennimeters) *I think so*
(2.0) ((*X and W are looking at the ruler*))
X: is that cennimeters? No that's half the size
W: that's ah that's half scale there
W: (3.0) *ten cennimeters*
X: what side's metric? ok that's-
W: *that's ten cennimeters*
X: 'sthat a hundred an fifty?
so ten cennimeters is <u>there</u>?
W: mmm hmm
(9.0) ((*X holds the ruler next to the tape dispenser as he pulls off one*
strip of tape and puts it on the edge of the table; W, Y and Z watch))

Despite their careful measuring, having exactly ten centimeters of tape was not a critical piece of the instructions for this laboratory activity. The students were only to observe the two pieces of tape attracting and repelling each other; ten centimeters was ultimately just the suggested and approximate length necessary. In fact, after watching W and X work so carefully with the ruler, students Y and Z sitting across the table proceeded to remove their tape strips, as well; however, they chose to forgo the use of the ruler and remarked about the need only for an "approximate" length of tape, since "our observations are gonna be qualitative."

In other words, this second group of students was able to determine the (lack of) practical importance of measuring ten centimeters of tape for their lab activity in order to demonstrate attraction and repulsion between the tape strips. They saw the "10 cm" instruction as a matter of approximation, and quite rightly so, for the purposes at hand. However, the advantage of "going second" – having something of the intended results of their instructions in clearer view – may have had much to do with their assessment.

Incidentally, after the scene above, W and X never again used the ruler to measure strips of cellophane tape. So while these undergraduates might not immediately recognize the relevance of a particular instruction, they were generally able to modify their use of an instruction like the "10 cm" one to fit their practical purposes. In fact, this ability to determine the relevance of instructions seems to be constitutive of the work of following them.

In their study of third graders, Amerine and Bilmes (1988) noted that students were not necessarily able to determine the relevant aspects of their instructions for seeing the science spectacle contained within them. Instead, the students turned a lesson about fluid pressure into a game involving "lucky pans."

In contrast, the students in undergraduate physics labs are much more successful in seeing the practical relevance of their instructions for producing a demonstration of the science. And they can be forgiven if, in light of not necessarily knowing ahead of time what they might be looking for, they assume all instructions are relevant until proven otherwise.

Fitting Instructions to Science

Students' work in finding the relevance of particular instructions is tied closely to the second general aspect of lab work mentioned above: "fitting."

In conjunction with their practical decision-making about the intended outcome of their instructions, students must set about assessing whether or not they have witnessed the science spectacle as it was meant to be seen. Accordingly, the students begin a practical process of "fitting" their observations to (what they believe to be) the expected scientific results of the lab activity. Essentially, "fitting" is the work of bridging the gap between "naïve observer" and producing the "intended answer" in a school science activity.

Jane French (1989) used ethnomethodological analysis "to consider and to describe some of the interactional practices used by participants in accomplishing scientific instruction." (p. 11)

Her study is of British first-year secondary students performing basic chemistry experiments. She characterizes the teacher's instructions to the class as pre-experimental descriptions of scientific "facts" that should be observed during the experiment and as post-experimental explanations of problems encountered by the students in trying to observe these "facts." After the activity, and in light of the students' performance, the teacher gives the class examples of human error (primary causes) and instrumental error (secondary causes) to account for deviations from the expected observations. The teacher essentially provides her class with a model for making observations "fit" within an expected scientific outcome. Since these students are relative novices in the science laboratory, the teacher leads her class through this process.

Unlike the novice students in French's study, the students in the undergraduate physics laboratory are capable and quite good at accomplishing this type of "fitting" work on their own. Essentially, the task might be described as a practical sort of "troubleshooting," where the students generate reasons for unexpected occurrences during the lab activity and attempt to remedy those occurrences. For example, in the *EFEC* activity, the students often find themselves faced with less-than-apparent results.

In some instances, the tape strips which are supposed to be visibly "attracting" or "repelling" instead hardly move. In other cases, the students might expect to see one thing (for example, oppositely-charged strips should act in a different manner), but instead, they see something else (the oppositely-charged strips behave in the same way). When things like this happen, the students go about suggesting alternative strategies and acting on them, until they produce a more desirable result, or until they decide to "move on" to another activity.

When faced with unexpected results, the undergraduate students in this study had no trouble identifying possible corrective strategies. For example, the students altered their means of operating or handling the equipment: they adjusted their way of holding the charged materials toward each other or tried re-charging the various materials involved.

When these efforts failed, the students also consulted each other or the teaching assistant for suggestions. Students would often repeat a procedure, "just to make sure" that their observations were accurate. Some students would eventually attribute a "bad result" to a mistake in their lab manual or other mistaken instructions.

In the scene below, students X and W rub a blue Styrofoam board with a cloth in order to produce a static charge on the board. They then hold the board next to some oppositely-charged strips of tape (labeled "t" or "top;" and "b" or "bottom") which are hanging on a wooden dowel in front of them. Their task is to determine whether the tape is attracted or repelled by the board. At first, the students don't see any attraction or repulsion from the tape, and so they adjust the position of the board. When this still doesn't produce results, they decide to re-charge the board (line 2209):

2200. X: ((*reading*)) vigorously lu- vigorously rub a white soft cloth against
2201. a blue Styrofoam insulation board
2202. (31.0) ((*X picks out the white cloth and blue board and rubs the board*
2203. *with the material, then holds the board up to the hanging strips of tape*))
2204. X: **hold it on this side**
2205. W: that's the sticky side
2206. (6.0) ((*W and X watch as X holds the blue board up to the hanging strips*))
2207. W: ** 'it the opposite side**
2208. X: thinkso? ((*turns the board around and holds it on the other side of the*
2209. *ringstand*)) (4.0) doesn't do much more (.) maybe I need (.) more charge

At first, the students don’t see any attraction or repulsion from the tape, and so they adjust the position of the board. Student X narrates his actions – “hold it on this side” – and thus produces a candidate place for repair when the result is not in evidence. Student W’s comment “that’s the sticky side” is thus interpreted as a call to move the board to interact with the non-sticky sides of the tape. When this still doesn’t produce results, they decide to re-charge the board (line 2209).

X still don’t see attraction or repulsion of the tape to the Styrofoam:

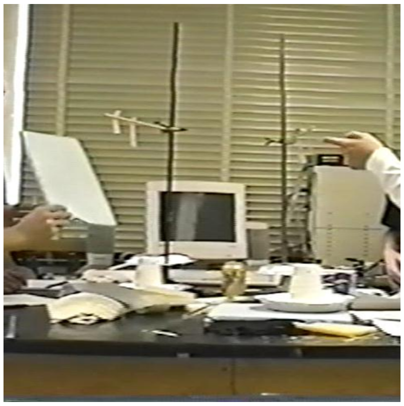

Fig. 1 Laboratory set-up showing ring stand and dowel rod with hanging strips of cellophane tape

2215. w- I don’ know (.) I can’t tell if it’s the air pullin it er-
2216. (7.0) ((*W and X watch closely as X hold the board to the strips*))
2217. W: think ‘ts pullin that one
2218. X: maybe its repellin t- y’know what I think we need? (.) I think we need
2219. new- two new strips uh this one ((*points to the hanging strips*))
2220. ((*X puts the blue board down on the table and lifts some wax paper*))
2221. X: you got the tape? ((*W picks up the tape and pulls a strip from the roll,*
2222. *then puts the roll down; X picks up the roll of tape and rips off a strip*))
2223. X: think we messed up the charge uh those somehow (don’ know)

In this scene, students W and X can be seen focusing intently on the tape and the Styrofoam board, but seeing such slight movement that they can’t be sure whether what they see is due to electric charge, or to “the air pulling it” (line 2215). After patient observation with little observable results, X suggests that perhaps they should re-charge the “top” and “bottom” strips of tape (line 2219), saying that they probably “messed up the charge [of] those somehow” (line 2223).

Student X re-charges the strips of tape and carefully places them on the dowel rod for a re-run of the process.

2229. X: bottom (11.0) an:d (2.0) top
2230. ((*X places a tape strip on the wooden dowel, removes the two strips which*
2231. *had been hanging there, and places the second new strip on the dowel*))
2232. ((*X picks up blue board and begins rubbing it with the white cloth*))
2233. X: (5.0) did she say use the white cloth on this one?
2234. W: ( )
2235. Y: (4.0) ((*looks up from across the table*)) I think so
2236. X: *ahright* ((*continues to rub the board*)) (6.0)

Note that X fixes the field of view by narrating and thus emphasizing the position of the “bottom” strip of tape and the “top” strip of tape as he hangs them on the wooden dowel (lines 2229-2231). He then re-charges the blue board, and a new candidate explanation for the trouble of the ambiguous display is offered: is he using the right cloth to charge the Styrofoam board (line 2233)? Earlier in the class period, the Teaching Assistant announced to the students that while they were free to rub any combination of materials together to produce an electric charge, she noticed that some combinations of materials worked better than others, and she announced various pairs of objects in non-specific and non-technical terms: “I found that for this rod the best thing was plastic wrap, for this rod, the best wrap is the woolen one, for the board the white one.” When his lab partner (Student W) is unable to confirm the Teaching Assistant’s directions, Student Y working with a different partner across the table offers his assistance (line 2235).

Upon repeating the procedure with new strips of tape and a freshly-charged Styrofoam board, students X and W get a different result, but one that is just as problematic. It seems that now, instead of doing nothing, both strips of tape are moving toward (or “attracting”) the board.

2237. X: uhkay lets try it now ((*holds the board up to the hanging strips of tape*))
2238. W: oh yeah big time ((*pointing to the tape strip on the right*))
2239. X: obviously attract- whoah ((*laughs and moves the board*
2240. *back and forth in front of the two hanging strips*))
2241. is that- that’s not right is it? ((*laughing*))
2242. W: its attracting them both
2243. X: yeah (1.0) buh’ aren’t these opposites? ((*laughing*))
2244. wait a minute ((*X laughs and puts the board down, then lifts one strip of*
2245. *tape off of the dowel and holds it near the other strip, watches the strips*
2246. *move toward each other, then puts the strip back on the dowel*)) (4.0)
2247. X: hhhhh u::hh ((*laughing*)) I don’ know (3.5) I’m confused
2248. W: *that’s weird*
2249. X: ((*looks around*)) where’s the tee ay?

What is immediately-expressed relief at the sight of a witnessable result (“oh yeah, big time,” line 2238) is almost as quickly identified as a new source of trouble (lines 2239-2241). The students assume that this result – both the “t” and “b” strips of tape apparently attracting the blue board – is problematic, since the strips of tape should have opposite charges and therefore behave differently (lines 2242, 2243, 2248)[9]. They adjust the position of the board (lines 2239-2240), check to make sure that the two strips of tape do in fact “attract” each other and thus can be considered oppositely charged (lines 2244-2246) and then ultimately look to the teaching assistant (TA) for an answer (line 2249).

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[9] For the reader who is curious, what has probably happened is that the students failed to produce a static charge on the blue Styrofoam board. When a neutral object is brought near a charged object, the neutral object can be polarized, such that either positively or negatively charged materials can be attracted to it.

The teaching assistant is not immediately available to these students, and so they must devise another course of action. When students Y and Z on the other side of the lab table repeat the same activity with the blue board and the strips of tape, they *are* able to see one of the strips being attracted to the board and the other strip of tape repelling it. Students W and X look to Y and Z for help. But although W and X try to make adjustments to their technique (for example, by holding the board behind both strips of tape at once, rather than behind one strip at a time), they ultimately get the same result: both strips of tape seem to be attracted to the board.

"Fitting," as a kind of practical trouble-shooting procedure these students use to deal with "infelicitous results" (French, 1989) in the laboratory, is quite orderly and accomplished.

In the school science lab, despite instructions to the contrary, there is an understood moral imperative to figure out what went wrong in light of an expected result rather than to just write what was observed. And in fact, the "fitting" process itself can be seen to have a moral order; students in the university physics labs I observed would almost always attempt to modify their own procedure or fiddle with equipment before assuming an error in the lab manual. Looking to others for help was certainly acceptable, but it typically seemed to be an option only after one tried to make the corrections on her own in the first place. Likewise, asking the TA for assistance was considered more of a "last resort" than a first one. Often, "fitting" resulted in a new, improved outcome for students, who could then get on with the work at hand.

Other times, as in the case above, the students are unable to resolve their dilemma; then, it is not unusual for students to "let it pass" (Garfinkel, 1967), in light of time constraints or related factors.

Discovering Work in School Science Labs

Revisiting the characterization of student science lab work given earlier – the experimental demonstration – and considering the description of these students' activities in light of it, we might see the practical work of being a science student for its interactionally-accomplished character.

We can appreciate the work of following instructions, and the sophisticated way in which these undergraduate students were able to establish a visual frame of reference and determine the practical relevance of their instructions for completing the task at hand.

We could also appreciate that the students who were "fitting" their answers to an expected result were not just trying to "get the right answer," or ignoring their instructions to be naïve observers, but were able to attempt a practical problem-solving routine to effect a demonstration of the relevant science for their own eyes.

While the characterization of university students' work in physics labs is undeniably local and tied to materials, persons, spaces, and circumstances, it is possible to see this work for its overlapping with and resemblance to other practical classroom activities, such as students' and teachers' interactions in elementary school science lessons (Amerine and Bilmes, 1988; Lynch and Macbeth, 1998); high school science lessons (Atkinson and Delamont, 1977; French, 1989) and other university physics labs (Lindwall and Lymer, 2008). One may even see congruence with the work of research scientists (Lynch, 1985), appreciating that it may just be through the disciplined and repeated work of producing an experimental demonstration that third graders grappling with ice cube erosion might eventually and naturally see Hanson's "theory-laden" x-ray tube.

This way of describing students' work in the school science laboratory may be unfamiliar to professional educators who see students' "discoveries" in labs as cognitive conceptual ones synonymous with their performance on paper-and-pencil achievement measures. And yet, our description re-specifies the ways in which the education profession's goals for lab activities – learning about science concepts, reasoning and practice – are realized through students' experiences, and specifically through their discovering work.

The advice is not, however, to treat any of our descriptions – of experimental demonstrations, fixing fields of view, finding relevance or fitting – as objects of theoretical judgment about students' school performance. Rather, it is to appreciate science students' myriad abilities in producing a practical course of action for seeing the science in a material worldly array, given limited and morally-ordered resources for instruction, and how this discovering work informs our understanding of both schooling and scientific practice.

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