High School Students Learning Science in University Research Laboratories

Robert E. Bleicher1, 2
Centre for Mathematics and Science Education, Queensland University of Technology,
Red Hill, Queensland, Australia 4059

Abstract

This article reports on a case study of a high school student working as an apprentice in a university research laboratory, part of a larger project aimed at evaluating a summer science program. The study examined communication between mentors (scientists) and student and how it constrained or supported learning. Narrative summaries of the context and range of activities in which the student engaged, transcripts of talk, and excerpts from field notes are reported to support the view of the laboratory as a cultural system. The student learned to participate in activities and discourse that were part of the everyday practices of members of a research laboratory. Mentors’ instructional styles affected both the manner in which the student learned and how he talked about science in public presentations. As programs involving students in research laboratories are becoming more commonplace, it is important to understand the educational opportunities afforded. Further, what high school students are capable of doing and learning in research laboratories has implications for expanding learning goals in the school science curriculum.

The 1980s and 1990s have seen a flurry of activity from the university and private industrial sectors aimed at involving K–12 students in summer science programs in research laboratories (e.g., the Argonne Summer Project, the Rose Tree-Widener University Program, and the Rockwell Engineering Mentorship Project). One of the major strengths of such programs is that they embed the K–12 learning experience in a bonafide science research setting. Instead of doing experiments in school laboratories, designed for practice-to-learn activities, students work in laboratories in which scientists are conducting ongoing research leading to publications and inventions of new technologies and equipment.

Little is known about how successful these programs have been, because there has been scant empirical educational research on them (Koballa, Butts, & Riley, 1995; Sirotnik & Goodlad, 1988). Such research would provide new insights into the characteristics of teaching–learning processes in actual science laboratories. These insights could have significant implications for student learning in school science laboratories.

Calls for models of learning in research laboratories are recurrent in the science education research community (Tamir & Shulman, 1973; Shymansky & Kyle, 1992). These researchers argue that we need a clearer picture of what goes on in laboratories as well as what and how students can learn in them. By recognizing the range of skills and conceptual understandings of which high school students are capable in context-rich research laboratory environments, we can begin to expand the learning objectives for students in schools, given the constraints of the different cultural settings (Roth & Roychoudhury, 1993).

© 1996 by the National Association for Research in Science Teaching
Published by John Wiley & Sons, Inc. CCC 0022-4308/96/101115-19
Purpose

The goal of this study was to begin to lay a foundation to help answer these calls for learning models in research laboratories. It examines the learning opportunities of a high school student working with scientists in a university laboratory. This research recognizes communication as the primary means of achieving such learning. Specifically, it attempts to answer the following questions:

1. What are the social and cultural characteristics of everyday laboratory work that affect a student’s participation as an apprentice?
2. What are the characteristics of the different styles of instruction across different mentors, and how do these affect the student’s strategies in giving a public science presentation?

Theoretical Perspective

Nature of Work in the Science Laboratory

A number of studies in science research laboratories have been undertaken within the disciplines of the sociology of scientific knowledge (for example, Woolgar, 1988; Latour & Woolgar, 1986; Knorr-Cetina, 1981) and ethnomethodology (for example, Lynch, 1985; Goodfield, 1981). Collectively, these studies support the notion that scientific knowledge is not a given. Rather, it is socially constructed by groups of scientists as they go about their everyday activities within specific laboratories, and as they communicate the results of that work to other scientists. The following excerpt from the study by Knorr-Cetina (1981), based on field observations during a year-long ethnographic study, illustrates this point:

If there is a principle which seems to govern laboratory action, it is the scientists’ concern with making things “work,” which points to a principle of success rather than one of truth. . . . The scientists’ vocabulary of how things work, of why they do or do not work, of steps to take to make them work, does not reflect some form of naive verificationism, but is in fact a discourse appropriate to the instrumental manufacture of knowledge in the workshop called a “lab.” (p. 3–4)

From such a description, science can be conceptualized as the result of human effort, making things work, and people making sense of what is observed. Whenever social scientists study laboratories, they report activities that are pragmatic in nature. The manner in which scientists conduct research just does not match up to the scientific method traditionally taught in school science courses.

The research outlined above suggests the need to observe how the scientists involved in this study work in their laboratory, to understand how they define science and what opportunity an entering high school student has to learn in that situation. Next, we need to consider what strategies a student might employ to learn about science and research in the laboratory.

High School Students Learning in the Science Workplace

Lave (1995) argued that rather than the individual, it should be the individual-acting-in-the-setting that should frame the way we view learning. The concept is that the activity and setting are bound together by the acting person, an individual “that is historically and socially constitut-
ed and that is engaged in relational activities with others and that becomes a self precisely through action in and on the world. Furthermore, this is not a disembodied self, but a whole self in which mind and body, thought and action are integrated through the embodied notion of person-acting-in-the-setting.” This view is supported by research carried out in diverse workplaces (Lave, 1977; Scribner, 1984; Schliemann & Acioly, 1989) that documents learning as an enculturation process through established apprenticeship models. The normal apprenticeship that takes place in university research laboratories is that of an adult graduate student participating in the research program under the guidance of a professor. In this study, high school students served apprenticeships in such laboratories. The apprenticeship model of learning in the laboratory can be applied to this situation insofar as it can be demonstrated that the students engaged in authentic workplace activities and that learning outcomes were evident in their actions and talk, both informal and formal.

High school students are normally accustomed to learning from teachers in school settings. They have expectations about how such interactions will occur, how to display knowledge, and how to communicate with their fellow students and the teacher. Once in the research laboratory, students in this study were faced with matching their prior knowledge and prior learning strategies with what they found in the laboratory learning setting. The students had multiple tasks to learn in first entering the world of the research laboratory.

One of their first tasks was to identify what counted as knowledge worth learning. For guidance, they observed what laboratory members counted as knowledge worth knowing to understand the research being done. This was fundamentally different from school-based learning experiences in which the teacher normally makes very clear what counts as knowledge worth learning. The school routine of weekly lectures, films, homework assignments, and quizzes was missing in the laboratory.

The tasks facing the entering high school students were to learn to do things and interact with scientists in the laboratory in socially appropriate ways—in other words, to learn to act like a member of the laboratory team. This involved moving through a progression of roles, from the initial role of a more or less quiet observer through more and more active roles as a participant observer in everyday laboratory activities. The goal was to move from viewing the laboratory as an outside visitor to gaining a deeper understanding of what science was and how it was done by scientists from their point of view within their local laboratory cultural frame.

Method

Design

Conceptualized from a cultural perspective, an interpretive methodology (Erickson, 1986) was employed to collect and analyze data. The study design was a qualitative case study (Bogdan & Biklen, 1982). The focus was on the communication between scientists and a high school student involved in specific laboratory activities.

This study took place in a summer science program for high school students at the University of California. A pilot study was conducted in the previous summer’s program. One of the requirements of the program was for students to give final presentations at the end of the program. Results of the pilot revealed that these presentations provided evidence of what the students had learned working in the laboratory (Bleicher, 1994). What was lacking was more detailed information about what the students had done in the laboratory. Such information needed to be based on direct observations of students in the laboratory over the course of the program. Therefore, in the more comprehensive study, it was decided to follow one student
through the entire program. The pilot also pointed to the need for the researcher to gain a clearer understanding of what scientists did in the laboratory and the nature of their research.

Based on this guidance, the more comprehensive study was designed in two phases. In the first, the researcher entered one laboratory prior to the start of the summer program, to gain insights into the activities of participants and their research agenda. This first phase, 4 months, also allowed negotiation with participants regarding the role of the researcher in their laboratory. This report will concentrate on the results of the second phase, which involved direct observations of a high school student in the same laboratory.

Participants and Setting

This study was carried out at the Center for Quantized Electronic Structures (QUEST) at the University of California at Santa Barbara (UCSB). QUEST is a Science and Technology Center funded by the National Science Foundation. Research at QUEST is focused on the physical phenomena of microscopically small quantum electronic structures, made primarily from semiconductor materials. Eventually the techniques and knowledge developed from this research will be used to create a new generation of electronic and optoelectronic devices.

The participants in this study were attending the Apprentice Researchers at QUEST (ARQ) program, a 6-week summer experience, which provides high school students with the opportunity to participate in the process of scientific research and inquiry. The students worked as apprentice researchers in collaboration with graduate student mentors, under the supervision of QUEST faculty. As apprentices, they worked in their mentor's laboratory in ongoing research projects and participated in the Center's schedule of seminars and meetings. The students were selected from three Santa Barbara high schools. The applicant pool included 58 Grade 11 students. Selection involved review of the initial written application (with special attention to the applicant's statement of why they were applying to this program), teacher input about the applicants, and interviews. The most important criteria was an indication of strong interpersonal skills (to work successfully in the small-group atmosphere of ARQ), an interest in doing science, and some indication that participation in the program would be a possible motivator for future involvement in science courses and/or careers.

One of the participants in this study was a 16-year-old boy, Tony, 1 of 12 students (5 girls, 7 boys), selected for the ARQ program. Tony was chosen for this study because of the groundwork done in the first phase of the study. He happened to be the student who chose to work in that laboratory. Also, Tony was representative of ARQ participants. He was a good student who enjoyed science as a school subject. He had no previous experience working in a research environment and had a limited understanding of the scientific workplace. Fortunately, after explaining the research to Tony, he consented to taking part in the study. The other 3 participants, Jon, Brian, and Yaz, were graduate student scientists who normally worked as a team in the laboratory in which Tony entered as an apprentice. They had agreed to be mentors to a high school student for the ARQ program. The researcher had already established a good working relationship with them during the first phase.

ARQ Program. The ARQ program had several components designed to prepare students for their work in the laboratories, as well as to explore their understanding of the scientific inquiry process and to provide exposure to a variety of research experiences. Participants met daily to discuss their activities in the laboratories and their perceptions about research. Students kept journals to record their personal impressions and their knowledge of the principles behind
QUEST laboratory research. Basic instruction in electronics, semiconductor physics, and computer programming were provided to give students the knowledge and skills necessary for successful laboratory work. They attended seminars given by QUEST undergraduate research interns to familiarize them with methods of scientific presentation and discourse, as well as to give them a greater scope of the work done at the Center. Students also went on field trips to a variety of research facilities in Santa Barbara and Pasadena so they could compare the approaches of scientists in different academic and industrial settings.

Students were required to give public presentations of the work they were doing in their laboratory apprenticeships. These presentations had the effect of focusing the pace and quantity of instructional activities in the laboratory. The public nature of these events served to motivate mentors and students to develop learning objectives for the apprenticeships. These objectives were aimed at helping students learn about the science being conducted in particular laboratories. Giving a good presentation was viewed by participants as a means of demonstrating a sound understanding of science.

Data Collection and Analysis

Role of the Researcher. The researcher assumed the role of a participant observer (Spradley, 1980). The participants understood that the researcher was in the laboratory primarily to document and study the learning experiences of the student. However, because of the groundwork of the prior 4 months, during which the researcher had participated as a member of the laboratory, there were some routine laboratory tasks he was able to undertake while still being present to observe and record the instructional activities of mentors with the student. On average, the researcher spent about 25% of the time helping with the science work. Because proceedings were videotaped, this did not interfere unduly with data collection. Furthermore, the researcher was usually able to suspend his science work whenever significant instructional events occurred. Having the legitimate status of helper in the laboratory resulted in reducing the intrusiveness of the observer in the study.

Data Sources. Sources of data included the researcher's field notes and video recordings of the activities and social interactions in the laboratory and other program activity sites. Participants were interviewed, both formally and informally, periodically during the program. Student journals were collected and photocopied.

Analysis. Videotapes and field notes were examined and triangulated with interview data to identify key instructional events that took place in the laboratory and other sites of the program. These key events were submitted to a three-stage discourse analysis: construction of transcripts, identification of analytic units, and construction of structuration maps. This procedure has been explained in more detail elsewhere (Bleicher, 1994). Briefly, it involves transcribing video recordings of talk and breaking them down into discourse analytic units smaller than whole sentences, called "message units." The sociolinguistic theory behind this analysis is premised on the notion that human communication occurs in fairly small chunks of both talk and nonverbal gestures as two or more people are interacting. Thus, an emphasized word, change in intonation, increase in speed of delivery, or nod could be significant signals from one speaker to another that communicate special and immediate meaning that become the basis for further talk and/or actions.

The discourse analysis was triangulated with other data sources to help confirm interpreta-
tions from emerging patterns in the data. As the researcher began to formulate interpretations, these were checked at the end of each day with Tony, Jon, Brian, and Yaz to establish some measure of confirmability (Guba & Lincoln, 1989). The aim was to develop an understanding of what and how learning was taking place in the laboratory and to check that participants themselves agreed with emerging assertions. Segments of videotapes and transcripts were reviewed each week for 4 weeks by participants to elicit remarks as to the kinds of activities and discourse they felt were pertinent to learning science in the laboratory.

Results and Discussion

The data that will be presented and interpreted have been selected to help develop a thick description of the cultural context of the laboratory in which Tony served his apprenticeship in the ARQ program. These data are organized in two sections pertaining to each of the two research questions, respectively.

Research Question 1: What Are the Social and Cultural Characteristics of Everyday Laboratory Work that Affect a Student’s Participation as an Apprentice?

Four aspects of the particular laboratory in this study had a significant effect on Tony’s apprenticeship, each of which is discussed in a following subsection. The first of these, induction of a new member, examines how the three scientists in that laboratory perceived their roles as mentors for a traditional incoming new member of the laboratory and how they translated this for the nontraditional induction of a high school student. The second, laboratory routine, describes the daily routine established to accommodate the student into the laboratory activity structure. The third, group meetings, describes the knowledge and manner of sharing results among related laboratory groups. Finally, the fourth section, laboratory as a multiple site for learning, provides a description of the laboratory as including several specialized work stations, each having the potential to offer a different aspect of science research that the student could learn.

Each of the four sections contains descriptions and interpretations of participants’ decisions and aims based on an analysis of field notes and informal interview recordings. The focus of the analysis was on examining the social and cultural aspects of particular activities or activity structures in terms of how participants perceived their respective roles as either mentors or apprentice. This focus was aimed at providing part of a thick description of the apprenticeship to help support claims that these had the potential to shape learning opportunities which the student might pass or take up in the course of his apprenticeship.

Induction of a New Member

One of the main virtues of the ARQ program was that Tony, as well as other ARQ students, was immersed in the day-to-day activities of a science research laboratory. In this manner, he gained firsthand experience of the uncertainty involved in doing science. Because his mentors were responsible for continuing their experiments, concurrently with hosting the high school student in the laboratory, the pressures of making things work to collect good data were always present and observable by Tony.

Tony entered a complex social and cultural system when he came to laboratory on the first day during the summer ARQ program. He had to learn to act appropriately in an environment that already had a complex system of roles and relationships, rights and obligations, and norms
and expectations among laboratory members. There were patterned ways of doing science and interacting with laboratory participants as well as with others outside the laboratory. Tony was entering a strange place to do new things with unfamiliar people. On the other hand, the social and cultural system of the laboratory changed in response to Tony’s entrance.

Much of the work that Tony had to do was to learn how to talk like a scientist as he saw it modeled by laboratory members. In addition, he needed to learn to act like a scientist. At the end of the ARQ program, he was required to publicly present what he had learned and done in the laboratory. Thus, the final task for Tony was to display convincingly to others what science and doing science was in his laboratory.

Jon, Brian, and Yaz were accustomed to having new adult, graduate school—level members join their laboratory from time to time. They expected a minimal level of conceptual understanding in mathematics, basic physics, and chemistry, as well as entry-level computing and mechanical skills. Tony, a high school student, was a strikingly nontraditional new member entering the laboratory. He entered this laboratory with the purpose of gaining more knowledge about science and learning how to work in the laboratory. While this purpose was the same as for a new graduate student entering the laboratory, the ultimate goal was very different. Tony’s educational goals were more immediate and modest compared to a graduate student’s 3- or 4-year down-the-track goal of completing dissertation research. As the apprenticeship progressed, Tony’s mentors were constantly reminded that his level of science expertise was much lower than the usual graduate apprentice.

The main work for Jon, Brian, and Yaz was to decide how to teach Tony both the theory behind the research they were doing in the laboratory, as well as instruct him in using the equipment. As this was not their only task for the summer, they had to integrate this instruction with their everyday research program. In the first week of his apprenticeship, Tony expressed his concern about being able to understand the hard theory upon which the experimental program of his laboratory was based. He was, however, fairly confident (and excited) about using equipment and undertaking experimental procedures.

All three mentors took an active role in Tony’s mentoring. Each developed his own unique approach. Jon took his responsibilities as a mentor very seriously. He often expressed his worry over whether he was teaching Tony well. Brian and Yaz did not overtly indicate such reflection upon their teaching role. However, from observation, it was clear that all three wanted to be good teachers.

Laboratory Routine

Tony learned by participating in laboratory activities. His three mentors employed the traditional laboratory apprenticeship model, but assuming no prior knowledge of techniques or theoretical engineering background. The concepts behind the research were usually explained in one-on-one tutoring sessions with individual mentors. Paper and pencil sketches, white-board diagrams, or actual pieces of equipment were employed as visual aids to what amounted often to minilectures on a particular aspect of a procedure or piece of equipment that was being introduced to Tony for the first time.

Learning took place in a rich social context. Considering that Tony was a high school student, he brought with him a history of doing science and learning in a school social context. A major task for him was to learn to operate effectively in the unfamiliar routine of the laboratory.

Tony also had to contend with the ARQ program routine. The laboratory experiences were embedded in the larger context of the ARQ program. This involved the student in attending
meetings and learning in other sites. A regular routine was established by the second week of the program: In the morning, there were activities involving the whole group of ARQ students, while the afternoons were devoted to individual apprenticeships in the laboratories with mentors.

The laboratory routine was established in a less explicit manner through negotiation between Tony and his mentors as the program unfolded. Mentors were sensitive to his needs, and vice-versa. Initially, as was natural because Tony was the new member in the laboratory, mentors took the lead in suggesting what and when to do certain things, when to take breaks, or when to go home at the end of the day. During the program, only the start and finish of a laboratory routine was evident: Tony would arrive between 12:30 and 1:30 p.m. and leave between 4:00 and 4:30 p.m. Between the start and finish times, one would be hard pressed to characterize any simple routine in the afternoon’s events. This, again, was understandable because the experimental nature of the laboratory’s work was dependent on supplies and equipment. These were subject to either running out or breakdown, and on any particular day the main activity in the laboratory might involve ordering or picking up supplies and parts. Other days might involve activities such as repairing equipment or discussing experimental designs. Yet other days might involve running an experiment or analyzing data.

Another consequence of this was that mentors might be more occupied with specific activities on some days than others. Thus, the time available and inclination of the mentors might dictate spending little time with Tony, tutoring him the whole afternoon, or involving him in hands-on activity with the equipment, or any mix of these. The routine constantly changed during the entire program.

Although there was no fixed laboratory routine, mentors held expectations about Tony’s routine of attending laboratory. If he arrived more toward 1:30 p.m. than earlier, Brian or Jon would often express concern. If he left the laboratory without saying where he was going, questions would be asked upon his return. Thus, there was an overall expectation that Tony should arrive at about a certain time each afternoon, stay for about the same amount of time each day, and leave at about the same time each day. There were consequences when Tony deviated from these expectations. They were generally reversed from what one would expect in a school setting, where a late student is usually reprimanded. In the laboratory’s case, Brian or Jon often reacted by involving Tony in more active participation. As for Tony’s reaction to this, several days would go by before he would perhaps be late again.

**Group Meetings**

As part of working in the laboratory, Tony attended weekly group meetings. Brian, Jon and Yaz worked in 1 of 4 laboratories that were involved in one professor’s research program. The professor (Dr. Harry Weiner) convened weekly seminar-style meetings at which one of his graduate or postgraduate workers presented their latest findings.

These meetings were an opportunity for Tony to see the bigger picture of how activities in his laboratory were integrated into a larger research project. It was also an opportunity to observe graduate and postdoctoral students giving private research group presentations of science. Aware of his own upcoming presentation, Tony often commented on the quality of graphics and presentation techniques he observed in these meetings. He was paying attention to detail.

Emphasis in group meetings was upon each team in the group getting “good, clean data” and reporting it as soon as possible. This helps explain why equipment was repaired and modified with such urgency. A good experiment was also characterized as one with elegant
simplicity or explainable complexity. If something was complex it was necessary for it to be explainable, else the group tended to count it as an artifact of another student’s imagination. Simplicity of design, and cleverness in methodology were valued by the group. The bottom line of any experiment was always whether it yielded clean data that could be convincingly interpreted and reported.

The questions asked at group meetings were for the most part about data interpretation. A graph was the most common representation for data. Generally, there were extended discussion, arguments, and disagreements over a particular graph in a seminar. Harry would often join in, and his comment, “That makes sense to me,” or “I can’t understand that” would have a strong influence over which direction discussion would take. Peaks on graphs, slopes of lines, and especially comparisons of two or more graphs would be the object of extended, sometimes 2-hour heated debates among group members.

What eventually came to be regarded as the right way to look at these graphs was certainly a group-constructed phenomenon. From the way the discussion unfolded and concluded, one got the impression that this same group later in time or another group of researchers might come up with a different interpretation of the same data. Of course, it was assumed that further experimentation would clear up controversies.

All of these views about what was good or right in terms of interpreting data and designing experiments made a deep impression on Tony. After the first group meeting, he began to model the group’s views, values, and even ways of talking about aspects of designing and performing experiments. This tendency for individuals to model a group understanding and view of issues was prevalent in mentors and scientists in other laboratories as well. It is a general feature of science groups that have common work goals (Latour & Woolgar, 1986).

Laboratory as a Multiple Site for Learning

The laboratory as a multiple site for learning was conceived in two respects. First, the laboratory contained several workstations that afforded different opportunities to engage in learning to use equipment. Second, because Jon, Brian, and Yaz all took on the responsibility at various times to help mentor Tony, there were three unique student-mentor social interactions sites creating different opportunities for learning.

Figure 1 shows a schematic of the layout of the laboratory, with positions of members’ desks and workstations. Circles representing the presence of Brian, Yaz, and Jon are placed near their respective desk work areas. Events that involved them as participants in key instructional events with Tony were located in several different sites within the laboratory. For example, Jon was involved in one key event at the mass spectrometer, another at the electronics cabinet near the electron energy loss spectroscope (EELS), a particular piece of laboratory equipment which will be explained in more detail later), and yet another on the lounge, critiquing Tony’s presentation overhead transparencies. Brian delivered many paper and pencil explanations at his desk, coinciding with the dotted circle on the figure. At other times, he demonstrated procedures at the EELS and the workbench area to the right. Yaz often used the white board above the lounge to draw figures during instructional events, as well as show Tony how to use the plotter at the workbench in the lower left of Figure 1.

There was a range of learning opportunities at the various workstations in the laboratory. For example, computer stations provided opportunities to practice graphic program skills. The mass spectrometer and EELS created situations for instruction in the use of tools and running of experiments. The book areas provided access to manuals and other reference materials to support learning how to repair or calibrate equipment.
Figure 1. Laboratory as a site of multiple learning.
Summary. Being gradually inducted into laboratory life and work, performing various tasks at different workstations, following a daily routine of activity, and attending group meetings that provided social cohesion among different laboratory teams provided a framework within which Tony engaged in science work as an apprentice. Because he was viewed as an apprentice, the three scientists assumed mentor roles they perceived to be appropriate for a complete novice and (even more so) for a high school student novice. Thus, the mentors viewed their most important role as providing individualized instruction for Tony to “get him to understand the theory behind their research.” To achieve this, each of the mentors developed his unique style of instruction. These variations in instructional style had different effects upon how Tony later demonstrated his understanding of science. The next section examines the actual discourse between the mentors and student.

Research Question 2: What Are the Characteristics of the Different Styles of Instruction across Different Mentors, and How Do These Affect the Student’s Strategies in Giving a Public Science Presentation?

Two important events took place during the summer program. In the first event, students gave a 10-minute public presentation of what they had learned in their respective apprenticeships during the third week of the program. Students gave a second 20-minute presentation in the final sixth week. These presentations provided an opportunity for Tony to demonstrate what he was doing and how well he understood the research in his laboratory. Tony’s first presentation centered on a type of vacuum pump used in the lab, the oil diffusion pump (explained in more detail later). His final presentation featured EELS, the major experimental technique that was the focus of the laboratory’s research program (explained in more detail later). Presentations were important for this study, as they provided an opportunity to examine how well students were understanding their apprenticeships. For this reason, instructional talk relating to Tony’s presentation topics will be highlighted.

Data are presented in the form of excerpts from transcripts of talk between Tony and his mentors. These particular excerpts were chosen because they (a) pertained to topics covered in these two presentations, and (b) provided a comparative illustration of differences in the interactions with different mentors and different work stations in the laboratory.

Data will are given and discussed in two parts. The first relates to the topic of Tony’s first presentation, the oil diffusion pump. The second relates to the topic of his final presentation, EELS. Each of these has been titled a “learning episode” to highlight that the purpose of the analysis is to examine the links between instructional discourse in the laboratory to the presentations for evidence of Tony’s learning.

Oil Diffusion Pump Learning Episode. The lab’s main research program demanded the maintenance of a very pure environment where chemical reactions could be studied. To achieve this, large stainless-steel chambers, much like pressure cookers with windows in them so that one could gaze inside, were constructed. All the air molecules needed to be removed from the chamber so that chemical reactions involved only the molecules being studied and few interfering air molecules. This was achieved by employing vacuum pumps.

One type of pump used in Tony’s laboratory was the oil diffusion pump. Air molecules were removed from the chamber by the action of fast-moving oil particles. Oil, originally in the bottom of the pump, was heated until it became steam and rose at extremely fast velocity up the pump body. The oil then shot out the top in such a manner that it caused air molecules to be
pulled down after it into the pump body. The principle behind this, called aspiration, was described by Yaz as a fast-moving stream of either liquid or gaseous material capable of pulling surrounding gas molecules along with it. This, in essence was what Yaz explained to Tony, but in much more detail and with more technical information. A typical transcript segment of Yaz’s first attempts at explaining the pump to Tony follows. Each line of the transcript represents one message unit.

Tony: it’s probably a stupid question is
   how does the air like flow towards that thing
   is that from the mechanical pump
   or how does it first start
   you know sucking toward the pump
   how does it do that
Yaz: actually what happen is that
   molecules go anywhere randomly
   if you look statistically what it says that
   if somewhere some volume in a space
   had less molecules right
Tony: yeah
Yaz: molecules flow into it
Tony: oh okay
Yaz: well what happens is that the
   that’s called equilibrium basically
   well what happens is that
   you think of that way
Tony: now you can start the direction
   because if you start the mechanical pump
   there will be less volume in there
   less molecules in there
Yaz: yeah
Tony: and so it will start traveling in that direction
   kind of
Yaz: that’s right yeah
   basically

This discourse took place as Yaz was handling a spare oil diffusion pump, dismantling it piece by piece, and pointing to parts of it as he explained how it worked. It took place near the white board in the lower right-hand side of the room diagram in Figure 1. At various points, Yaz would draw diagrams on the white board to support his explanations. This was typical of Yaz’s instructional style: talking about pieces of equipment at hand and drawing schematic diagrams to support his talk.

Tony’s Presentation on the Pump. Yaz’s style of talking about equipment at hand and supporting this with further schematic drawings was modeled by Tony and employed in his first presentation. Tony took the same oil diffusion pump to the presentation and used it to point to as he explained how it worked to the audience. He also used schematic diagrams predrawn on overhead transparencies to support his talk. The talk was not, however, a verbatim parroting of what Yaz had taught him. He added explanations of his own that indicated he had understood not just how the parts of the pump functioned, but the physical principles behind its operation.

Yaz and Brian attended Tony’s presentation. Both felt that Tony had presented his topic with
clarity and accuracy. There were a few minor points that he had not yet fully understood, but he had convinced them that he had mastered the basic concepts behind the oil diffusion pump and vacuum systems. They indicated that Tony's presentation skills could be improved.

**EELS Learning Episode.** The electron energy loss spectrometer is an instrument used extensively in surface science research. Its job is to characterize how molecules bond to metallic surfaces. Output from this instrument looks similar to electrocardiographs with peaks stretching out across the page. Interpretation of what these peaks meant was the main task of the scientists in this laboratory.

Jon used a tennis analogy to explain to Tony how the EELS worked. The following is a paraphrased version of the analogy given by Jon:

Visualize bouncing a tennis ball off a cement court: The ball is thrown, hits the cement, and reflects off with the no noticeable change in speed; now throw the ball on a grass court. The difference is that the ball will come off the grass with noticeably less speed (therefore less kinetic energy) than it was thrown: It loses energy to the grass as it bounces off it. With EELS, instead of a tennis ball, electrons are thrown, they bounce off a metallic surface, and when they come off, their speed (or kinetic energy) is detected and recorded on a graph called an EELS spectrum. Depending on what molecules are present on the surface, and the surface itself, the detected energies will differ in expected ways. These expected energy values are used by scientists to interpret what chemicals are present on the surface and how they are connected through chemical bonds to one another and the surface; this is called interpreting the spectrum.

A week after Jon had given this analogy to Tony, Brian explained more about how to interpret an EELS spectrum. He was trying to convey how electrons gave up energy to surface vibrations on both a practical and theoretical level. In the middle of this explanation, Tony volunteered his rendition of Jon's analogy, which he remembered from the previous week. Following is a segment of the transcript covering this instruction.

Brian: it's a characteristic of the molecule and how it's adsorbed
  what type of situation on the surface
Tony: Jon ever tell you about that tennis theory
Brian: tennis theory no
Tony: yeah
  Jon like told me this the first day
  you know like playing tennis
  and this ball would be like an electron
  this is like a clay court
  you know this is like a grass court
  you know all these are like different types of crystals
  and the ball like bounces off there
  and like you turn it off at like a certain amount of energy
  like say with the clay
  this is like the type of crystal
  this is the electron coming through
  this is the type of crystal
  each type of court takes off a uh different angle bounce
  kind of like a huge crystal
  it goes off at different angles
Brian: using angle
    is probably not a good thing to use
    they all come off
    at what is essentially the same angle
    electrons

This example gives some insight into how much Tony had understood Jon’s earlier instruction. The use of different court surfaces to help explain changes in tennis ball energy was the analogy chosen to help explain how electron energy changes in EELS electrons bounce off different crystal surfaces. Tony understood some aspects of the analogy correctly; others were fuzzy. Jon never checked with Tony as to how well he understood the analogy after the initial instruction. Brian appeared to be unaware of Jon’s analogy and chose not to incorporate it in his instruction. He never came back to it, and Tony, perhaps sensing that this was Jon’s instructional strategy and not Brian’s, never brought it up again. In his final presentation, which featured EELS, Tony never mentioned the tennis analogy.

Brian generally perceived his task as providing Tony with a technical understanding of both the theoretical and practical interpretation of an EELS spectrum. The following excerpt was typical of the kind of explanation given.

Brian: what can happen is an electron can come in
    and it interacts with the vibration
    what is does is actually see it takes energy away from the vibration
    and comes off with a higher energy
    but don’t worry about that
    don’t even mention that
    that’s too complicated
Tony: yeah
Brian: it’s not something we really use in the spectra analysis
Tony: hope I don’t get confused
Brian: see that’s the thing
    so don’t worry about it
    we’re just looking at loss features where it gives up energy

During such theoretical explanations, Brian would typically give short bursts of logical sequences in the physics or chemistry of what was taking place in the experiments, while Tony would sit attentively listening, taking some notes. Tony would usually nod and say “yeah” to show he was attending. Follow-up interviews immediately after some of these sessions revealed that Tony had understood only part of the explanation. He often said that he was getting the basic gist of it, but that he needed to study his notes and come back with some questions later for Brian. Sometimes he did follow up and sometimes not. Tony’s statement, “hope I don’t get confused,” was less typical in the corpus of recorded instructional talk. With Brian, these indicators that Tony was not quite understanding were generally not fully addressed. What was said previously got restated quickly in a similar manner. Then Brian would “get back on task” and introduce new material.

Jon and Yaz generally paid more attention to these admissions of not understanding and tried different approaches to reexplaining the problematic material. For example, Jon took up mentoring Tony the day after Brian’s explanation given in the example above. The context of this talk was that Tony was showing Jon some of the overheads he had generated for his final presentation about EELS and asking Jon’s help on some questions he had about the theory behind it. This example illustrates aspects of the discourse that contrast with Brian’s strategies.
Jon: we can derive say what kind of molecule on the surface
Tony: wait
   say that again
Jon: first we
   it's what we know and all we want to know right
Tony: yeah
Jon: all we know is the peak position mostly this one come into the surface do nothing it just bounce off right
Tony: and that some of them just lost energy this is a loss feature
Jon: yeah the intensity of a peak

Jon reacted to Tony's requests for more explanation by taking a fresh approach rather than simply rephrasing earlier explanations. In this example, when Tony interjects with "wait say that again," Jon does not actually say it again but decides to start back at the beginning with a new explanation, "first/it's what we know/and all we want to know right." The unique qualities of mentor-student discourse can have a large effect on what kind of information is given and how well it is understood in the face-to-face interaction of instructional events. Fresh, new directions to explanations can provide the student with new and extended conceptual understandings.

Tony’s Presentation on EELS. These examples were purposely designed to help Tony explain EELS in his presentation. To illustrate some connection with the discourse that occurred with Brian and Jon discussed above, a short excerpt from that presentation is given here. Tony is talking to an audience composed of 20 people, including his fellow ARQ apprentices, mentors, and other interested professors.

Tony: a low energy beam of electrons uh flows from a thermionic emitter and passes through an electrostatic energy selector which focuses on the crystal in the chamber the electron beam bounces off the surface with some electrons losing energy to surface vibrations and the scattered beam is then collected in the detector its given and uh an elec—electron energy loss spectrum

Those outside the laboratory who listened to Tony’s presentation were aware of some lack of deep conceptual understanding being developed in the talk. What they could not appreciate was just how much was missing. Tony had previously introduced and explained how the EELS equipment worked. His talk avoided fundamental explanations of the quantum mechanical theory behind it. That such knowledge was considered important was demonstrated by the extraordinary amount of time and effort spent by Brian and Jon in explaining it.

For example, fundamental to how EELS operated was the concept of energy loss—energy lost by electrons traveling from the EELS device, hitting the surface of interest, and coming back into the EELS device to be analyzed. How the electrons lost energy was explained by quantum mechanics. Tony never mentioned the word quantum or quantum mechanics, nor any
of the theory in his presentation. Brian had discussed quantum mechanics in relation to how EELS functioned at least 16 times, for an average of five message units each. Jon had discussed quantum mechanics eight times, for an average of four message units each. The scenario of electrons bouncing off the crystal and losing energy was discussed explicitly 33 times between the two mentors.

The point of this example is not to build a case of badly learned or badly presented science. The point is that what can be displayed in a presentation as conceptual understanding learned is usually judged by what can be seen and heard. The important things that may be missing may not be evident at all to those listening to such a presentation. The missing items may not be marked by contextualization cues or by interruption of the logical development of topic in the talk. This may not be a problem for a mentor or classroom teacher who has participated with the learner in co-constructing prior instructional activities. However, it can certainly be misleading to others listening to and perhaps charged with evaluating a presentation.

For example, one of the program organizers wrote evaluations of the presentations. She had a master's degree in engineering and a sound understanding of the research being conducted in Tony's laboratory. In her evaluation, she wrote, “Tony has absorbed a remarkable amount of information in his short apprenticeship. However, he was not able to develop a good grasp on the concepts. He was partially familiar with the experimental setup. In all, he presented an organized overview of EELS, and he understood the things that he spoke about. His explanations covered all the bases, but they were somewhat sketchy, and his understanding was not deep.” Although aware of the lack of a deep understanding, she was not able fully to evaluate how much Tony had missed owing to not having been party to the prior instructional discourse carried out in the laboratory.

**Summation.** The specific dyadic discourse between Tony and each of his three mentors had a large effect on how he was able to participate in scientific dialogue and laboratory activity. The instructional styles of different mentors had varying effects on how Tony chose to explain his understanding of the science theory behind the research in his apprenticeship. Taken together, the framework within which the apprenticeship operated and the instructional discourse he participated in largely defined how Tony talked about and displayed his understanding of science. It reflected the views and values of the members of the culture of the particular laboratory into which he had been inducted for his short apprenticeship.

**Conclusions**

As a student enters the science laboratory, she or he has to learn to use tools such as language, equipment, and procedures to begin to understand what is going on there. The manner in which members of the laboratory talk about science and explain the use of equipment largely affect both the rate and depth of such learning. This study supports the conceptualizing of learning in the laboratory as occurring through opportunities afforded to the student to do science that are created by communication between student and mentor. In this communication, mentors aim to explain their particular views of what it means to do science and be a laboratory member. In examining the learning opportunities of a high school student in a science research laboratory, there is a need to understand the culture of the particular laboratory in question—what participants do in their everyday work there that defines what they mean by science and scientific knowledge. Once this is understood, then learning can be defined as taking up the patterned ways in which local participants in the laboratory do science, know science, talk about science, and present science to those outside the laboratory (Knorr-Cetina, 1981).
In the case of a high school student, it is necessary to understand what level of expertise she or he brings to the laboratory. It is also necessary to determine how scientists perceive such a learner. In any research laboratory, a high school student will place specific demands upon the scientist-mentor which will interrupt the flow of work. In any laboratory there will be a range of opportunities for the high school student to engage in the doing and learning of science. In any laboratory, that student will take up learning in differing degrees along the three dimensions of doing, understanding, and communicating science.

From his laboratory experiences and the way in which mentors instructed him, Tony took up a vocabulary, a way of talking about it, and ways of representing it (particular charts, graphs, overhead transparencies). While aspects of what got displayed in presentation were uniquely attributable to Tony, parts of it were clearly related to the personal influence of the mentor’s instructional style.

Schematics and analogies used in the public presentations were often similar to those emphasized by mentors in the laboratory. The student employed communicative strategies similar to his mentor when explaining common items to the audience in a public presentation. When introducing such schematics or analogies, there was a noticeable change in the manner of delivery of the talk.

The structure of topic presentation also revealed modeling. Sequencing of topics in presentation generally modeled that of laboratory instruction. The student usually presented the sections of his talk in more or less the same order as they were presented by mentors in laboratory instructional events. This makes sense, because presentation involved the student in trying to explain some rather technical and difficult to understand science topics. Scientific conceptual instruction traditionally involves a pyramidal approach. Learning a fundamental concept leads to more complex concepts based on the previous ones. Because the mentors in this study received their science instruction in this manner, it is not surprising that this was their strategy of choice when instructing a high school student. The student reported that he was quite used to this same strategy in his school science courses. This sequential, pyramidal topic development was modeled by all the ARQ students in their presentations.

Results from analyzing the student presentations of science raise the question of just what is being seen in the activity of presentation. It is a performance in many facets. But is it a display of competence? Are the skills and conceptual understanding that the student actually possesses being demonstrated? The problem of performance versus competence is not an easy one. When evaluating student learning through any performance, caution must be taken as to what is actually being inferred about competence. Finally, students giving presentations afford an opportunity for further learning. This refers to an image of mentoring as a group process in which fellow students or groups of scientists helped by either comments or questions during the presentation or criticisms afterward, or in providing a sounding board and/or audience for students.

Implications for School Science

This study was designed as a foundational study in examining high school students serving apprenticeships in ongoing science research laboratories. ARQ program evaluation findings concur those from other similar summer enrichment programs—high school students in non-traditional settings such as university research laboratories are capable of learning both conceptual knowledge and hands-on laboratory skills far beyond the expectations of their teachers. In addition, they developed sophisticated ways of communicating that knowledge to others both informally and formally in presentations. This has implications for high school science situations.
Schools have a different purpose from university research labs—products of the two differ. The research laboratory produces reports in published journals to maintain credence for funding purposes. The schools are responsible to parents and society, who expect a new generation of scientifically literate citizens each year to graduate from our high schools. There cannot be a realistic match between these two purposes. On the other hand, both settings have an educational purpose: to help beginners become more experienced at doing activities and understanding how things work and why.

The most significant implication of this study to school settings is in matching those components of the instructional setting of the research laboratory that allowed open-ended inquiry to take place that are not limited to the difference in purposes or to the difference in resources available in the two settings. To distinguish exactly what those components are will require further research. It is clearly a worthwhile endeavor to pursue such research.

Notes

1Present address: CCTD, Board of Studies in Education, University of California, 1156 High Street, Santa Cruz, CA 95064. e-mail: bleicher@cats.ucsc.edu

2The author's area of expertise includes sociolinguistic discourse analysis, science teaching and learning, cooperative learning, and classroom ethnography.

References


Received April 18, 1994
First revision August 7, 1995
Second revision March 22, 1996
Accepted June 18, 1996