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ABSTRACT

The purpose of this study was to examine the activities and discourse between scientists and high school student apprentices (from Santa Barbara, California) in research laboratories and how these supported and/or constrained student learning of science. The study covered 3 consecutive years of a summer science program and included 32 high school student participants. Data were collected and analyzed within a multiple perspective research design composed of microethnography and interactional sociolinguistics. Student apprentices made noticeable gains in conceptual understanding of science as well as gaining new insights into the world of the scientist. Program experiences carried over positively into the classroom in the school year following the program. Results suggest that a cognitive apprenticeship model of science learning would be a worthwhile pursuit in school science instructional settings. Contains 27 references. (Author/MKR)

Conceptual Change Based on Laboratory Experience

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The purpose of this study was to examine the activities and discourse between scientists and high school student apprentices in research laboratory and how these supported and/or constrained student learning of science. The study covered three consecutive years of a summer science program and included 32 participants. Data were collected and analyzed within a multiple perspective research design composed of microethnography and interactional sociolinguistics. Student apprentices made noticeable gains in conceptual understanding of science as well as gaining new insights into the world of the scientist. Program experiences carried over positively into the classroom in the school year following the program. Results suggest that a cognitive apprenticeship model of science learning would be a worthwhile pursuit in school science instructional settings.

This study took place in research laboratories. The participants, however, were not the usual people one finds in such places - they were high school students. This paper reports on experiences these students had doing research and changes in their concepts of the nature of science and research. It also suggests connections to school science.

A large body of science education literature has established the importance of linking conceptual learning with practical experience (Yager, 1992; Wertsch, 1991; Brown, Collins, & Duguid, 1988; Rubba, 1987; Staver, Enochs, Koeppe, McGrath, McLellan, Oliver, Scharmann & Wright, 1989; Tamir & Shulman, 1973). Science curriculum developers have taken heed of research advice, recommending a strong laboratory component in the K-12 science education framework. This is a step in the right direction. As any student will tell you, laboratory is the fun part of the science class. It helps science come alive and clarifies what the text has been trying to explain. Most teachers, however, are not satisfied with the "cookbook recipe" nature of a great deal of high school laboratory exercises, and would really like students to be engaging in "wonder about" discovery type of investigation, that they envision scientists do. The problem is that research has not yet clarified the links between the science done in schools and the science done by scientists. Most students and teachers don't know much about the daily work of a scientist, and most scientists have little idea of what goes on in school science.

The research being reported in this paper does not claim to make a direct link between school and science workplaces. It does take advantage of an opportunity - with the hope that changes may come about in the school setting further down the track.

It is unusual to find high school students doing science in university research laboratories; it is unusual to find scientists involved in teaching high school students in their laboratories. This was the situation created in an innovative summer science program, which is the context for this study.

METHODOLOGY

Setting and Participants

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 brings high school students and teachers into the laboratory at QUEST to participate in the process of scientific research and inquiry. The high school students and teachers worked as apprentice researchers in collaboration with graduate student mentors, under the supervision of QUEST faculty. As apprentices, they developed specific laboratory skills on sophisticated experimental equipment, as well as first-hand experience of how science research is conducted.

The students were selected from three Santa Barbara high schools. The applicant pool averaged 60 for each summer. 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; face-to-face interview with nearly all the original applicants. Most important criteria dealt with indications of strong interpersonal skills (in order to work successfully in the small group atmosphere of ARQ); an interest in doing science; some indication that participation in the program would be a possible motivator for future involvement in science courses and/or careers.

The study took place over three consecutive summer programs. The participants included university research scientists (both post-doctoral and graduate engineering students, and a total of 32 high school students (3 females, 5 males in the first summer; 5 females, 7 males in the second; and 7 females, 5 males in the third). The students spent an average of 20 hours per week in the laboratory over the six week period, and 20 hours in other program learning situations.

Two high school teachers participated in the ARQ program, a chemistry teacher and a mathematics teacher.

There were seven faculty sponsors for the ARQ program from four different departments: Electrical and Computer Engineering, Chemistry, Chemical and Nuclear Engineering, and Materials. There were a total of twelve Engineering graduate students working under these faculty members who acted as mentors for the high school students in the laboratory.

Participants developed specific laboratory skills on sophisticated experimental equipment, as well as first-hand experience of how science research is conducted. Students had the opportunity to draw on previous knowledge in mathematics and science and recognize its application to the investigations of successful career scientists. Teachers had the chance to update their scientific knowledge of current developments in electronics, computers, chemistry and quantum physics.

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.

ARQ students met as a group for particular activities in three different locations: electricity laboratory; computer room; and the QUEST conference room.

The most important key instructional events outside of laboratory experiences, took place in the QUEST room: public presentations, Friday morning group meetings, Monday afternoon Intern seminars, and presentations. Nearly all the regularly scheduled events were recorded on audio-visual tapes. This allowed participants the opportunity of revisiting events, provided some entertainment value, and led to rich peer evaluation and deeper discussion of issues.

High school students entered the laboratories expecting to learn how to use a range of equipment and instruments, as well perform procedures and/or experiments. They were not disappointed: nearly all realized their expectations in their respective laboratory assignments.

Perspective

This research was conducted from a social constructivist perspective that is concerned with how social, cultural, and institutional factors support and/or constrain what is learned and recognized by participants as science. From this perspective, the subject matter knowledge of a particular scientific discipline is not taken as a given object, but rather one that is socially constructed moment-by-moment by participants, and subject to change over time (Lynch, 1985; Woolgar, 1988; Knorr-Cetina, 1981). The language used to discuss, present, and do science is socially constructed by participants (Santa Barbara Classroom Discourse Group, 1992; Carlsen, 1992; Cochran, 1990; Lemke, 1990). It is the circumstances of shared activity that shapes how participants view scientific knowledge and the learning opportunities available to students. The students participating in this study were viewed as serving both a laboratory participatory apprenticeship and a related cognitive apprenticeship as they learned science through doing science.

Design

The study design was a topic oriented micro-ethnography (Erickson, 1984) alloyed with an interactional sociolinguistic discourse analysis (Bleicher, 1994) of laboratory instructional talk. The researcher assumed an active participant observer role. Data included fieldnotes, videotaped recordings, student laboratory books, and ethnographic interviews.

DATA WINDOWS

Data will be presented through four windows: 1) Life in the ARQ, a summary of case study field observations to give a feeling for the range of activities and routine one representative student experienced in the laboratory; 2) representative examples of student views about learning in the laboratory; 3) students' views about scientists and research; and 4) student's views about relationships between the program experiences and their school learning experience. These data are representative of a rich corpus of naturalistic data from which emerged a socio-cultural learning model.

LIFE IN THE ARQ

Students worked on the following research projects: reactions of hydrochloric acid on gallium arsenide surfaces using electron energy loss spectrometry; the scanning tunnelling microscope to image surface states of conducting materials on the atomic level; synthesis and spectroscopy of mesoporous materials; computer simulations of crystal growth, in order to study the kinetics of surface reaction mechanisms; laser-assisted electrochemical etching of gallium arsenide surfaces; superconductivity in semiconductor materials by examining transport properties; characterization of high-temperature superconductor films grown under different conditions; quantized conductivity in gallium arsenide heterostructures; two students, as a team, worked on the processing and characterization of two-dimensional electron gas structures and silicon resistors; low-temperature gallium arsenide using conductivity measurements and electron microscopy; construction of ultra high vacuum equipment which is used in the growth and characterization of metal and semiconductor surfaces. To illustrate the range of opportunities to engage in science research, fieldnotes from this last laboratory situation will be summarized. Tony, the student in this laboratory was mentored by its three usual members - Larry, Sam, and Joe.

To help describe the range of equipment used, procedures done, and concepts taught in the laboratory, results of three domain analyses (Spradley, 1980) covering these will be given respectively in Tables 1, 2, and 3. A domain analysis is an ethnographic method of categorising objects, activities, and relationships between them. It begins to build a cultural inventory of what people do in particular social situations. In this study, it gives an idea of the tools, equipment, and experimental procedures that Tony learned in the laboratory.

Table 1 gives equipment/tools as the cover term, "is a kind of" as the relationship, and then a list of several items in the table as included terms. For example, a mass spectrometer is a kind of equipment used in the laboratory - a multimeter is a tool used in the laboratory. Table 2 lists several items that are kinds of procedures. For example, break vacuum is a kind of procedure done in the laboratory. Table 3 lists several kinds of concepts that form the theory behind experiments done in the laboratory. For example, ultrahigh vacuum is a particular atmospheric condition that is attained in the experimental chamber employing various procedures during experiments. The idea of constructing these domain analytic tables is to begin to build an inventory of what kinds of objects people use, their reasons for using them, and the significance of their activities upon their goals for working in the laboratory.

Table 1

Cover Term: Equipment/tools
Relationship: **is a kind of**

	Included terms	
mass spectrometer	multimeter	oscilloscope
parameter analyzer	lock-in amplifier	function generator
sealed chamber	upper chamber	lower chamber
mechanical pump	oil-diffusion pump	ion pump
turbo pump	back-up pump	cut-off valve
soldering gun	resistors	measuring devices
clean room	FTIR	EELS
optical mirrors	heating shields	cathode

Table 2

Cover Term: Procedures
Relationship: **is a kind of**

	Included terms	
break vacuum	check for leaks	run experiment
thermal desorption	mass spectroscopy	amplify signal
backfill chamber	processing data	make UHV clean
computer reads data	configure instrument	learning the language
debugging	saturate surface	change parameter
vary the waveform	measure resist	pull down window
acetone wash	characterize device	graph data

Table 3

Cover Term: Concepts
Relationship: **is a kind of**

Included terms		
ultrahigh vacuum	thermal conductivity	disassociates
adsorption	impinging crystal	actual code
rough vacuum	saturation	step values
vacuum	tearing molecules	CO-CO repulsion
plot curr-voltage	intensity per time	sticking probability
input-output (IO)	bridge site	program
data exchange	surface coverage (Q)	diffusion limited

The equipment was employed in various laboratory procedures. Tony learned by doing: his three laboratory mentors employed the traditional laboratory apprenticeship model, assuming no prior knowledge of techniques or theoretical engineering background. The concepts behind the research were usually explained in one-on-one, face-to-face tutoring sessions with individual mentors. Paper and pencil sketches, whiteboard diagrams, or actual pieces of equipment were employed as visual aids to what amounted often to mini-lectures on a particular aspect of a procedure or piece of equipment that was being introduced to Tony for the first time. All three mentors took an active role in Tony's mentoring. Each developed his own unique approach.

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.

Routine was established in two ways: a daily program routine; a laboratory 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: morning program, whole group activities - afternoon in the laboratory, one-on-one with mentors.

The laboratory routine was established in a less explicit manner through negotiation between Tony and his mentors gradually as the program unfolded. Mentors were sensitive to his needs and vice versa. Initially, as is natural since 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, 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 pm and 1:30 pm, and leave between 4:00 pm and 4:30 pm. Between the start and finish times, one would be hard pressed to characterize any simple routine in the afternoon's events. This, again, is understandable because the experimental nature of the laboratory's work was dependent upon supplies and equipment: these are subject to either running out or breakdown, and on any particular day, the main activity in the laboratory might involve doing nothing, ordering supplies and parts, repairing equipment, discussing the design, or running and analyzing the data from an experiment. 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.[1]

Although there was no fixed routine, mentors held expectations about Tony's routine coming and going. If he arrived more towards the 1:30 pm mark than earlier, Larry or Joe would often ask me where Tony was. If he left the laboratory without saying where he was going, the same question would be asked. So 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. There were consequences when Tony deviated from these expectations. They were generally reversed to what one would expect in a school setting, where a late student is usually reprimanded. In the laboratory's case, Larry or Joe often reacted by involving Tony in more active participation. As for Tony's reaction to this: several days would go by

[1]On a personal note, I reacted to this as a former teacher: there's no routine. This is not so revealing about the lab routine as it is to the expectation that time should be well structured to ensure learning objectives are attained: a very school-based cultural expectation on my part!

before he would perhaps be late again. An interesting form of reverse discipline.

Tony had an expectation coming into the laboratory that he would have Larry as his sole mentor; he had previously met Larry at a summer meeting before the program began. However, the first person he started working with in the laboratory was Joe. Joe continued throughout the program to mentor Tony. Yet, the expectation that Larry was his sole mentor was so strong that Tony continued throughout the program, and in follow-up interviews in the Fall to talk only about Larry as his mentor. He described Joe and Sam as other laboratory members and very helpful, but not formally as his mentors. In actuality, both Joe and Sam, as well as Larry, functioned as Tony's mentors.

Joe took his responsibilities as a mentor very seriously. He often expressed his worry over whether he was teaching Tony well. Larry and Sam also had this same attitude: they wanted to be good teachers.

STUDENT VIEWS ABOUT LEARNING IN THE LABORATORY[2]

Representative student responses to three of questions will be given here to give an idea of student attitudes to learning in laboratories.

Question 1.

What was communication like between you and your mentor?

Student responses:

My mentor and I talked about lots of things besides science, that is life in general. We got to know each other on a personal level.

My mentor explained things well and often. I would have liked my mentor to have defined long term goals a little better.

My mentor sometimes gave me a choice of activities for the day. He told me

[2]Acknowledgment to the work of Lui-Yen Kramer, an ARQ organiser who collated and reported the data in this section for program evaluation.

not to worry and to wait for assistance if I didn't feel comfortable with doing a certain procedure.

I would have liked my mentor to tell me more about the overall project early on. I should have asked more questions.

The best aspects were that at the beginning of the day we would go over what we would do that day and how the overall project was going. What I also liked was being able to talk to other mentors and asking them questions also so it was a group effort.

My mentor would gladly answer any questions I had even if they had nothing to do with the research.

My mentor always knew the answers to my questions and was eager to answer them. If she didn't know the answer at the time, she would go find out and tell me later.

My mentor was very open about everything and always quite candid, so it was easy for us to get along. He was very knowledgeable and always willing to explain things.

We were able to communicate openly, with no fears of feeling stupid or ignorant.

My mentor was able to interpret what was going on in the laboratory in a simple way, piece by piece.

Sometimes mentor used a technical term which he assumed I knew, although I had no idea.

I would have liked mentor to have checked on me more often than waiting for me to go to him with questions.

Question 2.

What kinds of activities did you do in the laboratory, and which were most productive for you?

Student responses:

I thought learning how the equipment worked was the most productive. By learning this, I was able to understand more about what was going on in the laboratory.

I think I did a lot better when my mentor gave me a structured activity to do.

My mentor and I talked a lot about the project, about why things were not working out as we planned. Besides these talks, I felt that I learned the most from doing projects on my own. It allowed me to make my own mistakes and learn by them, and later I discussed with her or others why or why not things worked.

I learned a lot just talking with my mentor about different things, EE [Electrical Engineering], special relativity, colleges, computers, etc.

The most productive thing for me was the hands-on laboratory work.

Doing experiments was most productive.

I felt that talking about my project was the most productive.

Question 3.

How comfortable did you feel working with your mentor, and how did you feel working in the laboratory in general?

Student responses:

I enjoyed talking with my mentor about all aspects of research.

I felt very comfortable working with my mentor. She treated me like a friend and not so much as a student. Other people in the laboratory were also very helpful to me when my mentor was busy with something else.

I felt that they everyone respected me. They understood that I was only a high school student with very little experience with what I was doing. They made it easy for me, only giving me basics.

I feel that my mentor respected me on a personal level rather than on a scientific level. So in way, yes, he respected me.

My mentor seemed to talk down to me, saying everything was "so easy"

I felt pretty comfortable working with my mentor, but I was sometimes afraid of messing up.

I would recommend my mentor to continue, as she has a lot of energy, enthusiasm, patience and makes a good teacher.

My mentor was very busy, but always ready to put aside his work and teach me something, or answer my questions.

My mentor was knowledgeable and able to communicate ideas into easily understandable, plain English sentences.

Probably the most important thing for the students was feeling comfortable with their mentors. Mentors who were relaxed and open to all types of discussion were able to establish good personal rapport in addition to good working rapport. The students enjoyed being respected as adults with legitimate concerns and opinions, which I think for many of them was a somewhat novel experience.

Students appreciated that they did not feel put down for asking "dumb" questions. This is something that is very important for students of their age. Many students are too afraid to ask questions in school, for fear of put-down from teachers or their fellow students. Because of this, students this age need active encouragement to ask questions. As a mentor, this sometimes required more than asking, "Do you have any questions?" Often, mentors needed to provide specific targets for questions (e.g., "Do you have any questions about this procedure that I just showed you?").

Students also appreciated their mentors being able to explain things in simple terms. This is not an easy thing to do, but it is very important. Students easily became frustrated and alienated when technical language was too prominent.

STUDENT VIEWS ABOUT SCIENTISTS AND RESEARCH

Students' views about what qualities a good scientist has and their expectations about what the research experience would be like were gathered from interviews during the first week of the program, before they undertook their apprenticeships. The aim of gathering these data was to try to get some idea of what they imagined scientists to be like and what kind of work they expected that they would be doing in laboratories. These 'pre'-views could then be used to contrast 'post'-views about their experiences at the end of the apprenticeship.

Two Questions on 'Pre'-views and Comparisons to 'Post'-views

(1) What qualities does a good scientist have?

Student responses:

Someone who is open minded, asks questions - you need to be organised in the way you want to go and be willing to often do the research so that you understand what you're saying -building up you own knowledge.

Good in maths and science - wants to see how the world works - someone who wants to know how the world works.

You have to read, have to do something yourself - must be creative.

Curiosity is crucial - a scientist needs to be really curious - needs to ask questions that will get him further in an area.

Has a desire to learn, not just for more money, but out of curiosity to know more, to find out new things that can benefit mankind.

A good background academically so that they can apply the knowledge.

open-minded, able to listen to everything that comes in if you are researching a certain subject - have to be able to work with other people - it's more a cooperation of ideas - education is important - it's not so much learning from text books as it is in listening to what others are saying.

Summary and comparison to 'post'-views.

Two aspects of what students viewed were important qualities of scientists were commonly identified by most students - open-mindedness and curiosity. Another ingredient to making a good scientist given was that of a good educational background. Although one example is given here (the last one), social qualities, such as the ability to cooperate with others and good communication skills, were seldom mentioned. Also, few students expressed the idea that scientists should be concerned more with service to humankind rather than for other more selfish motives for their work.

Post interview data clearly showed most students appreciated the intensely social nature of the work of scientists after their experience in research laboratories.

All of them repeatedly cited instances of how their mentors needed to communicate clearly with members of their laboratory as well as others in order to get their experiments going and especially in helping to interpret data from those experiments. They also commented on how good communication skills were essential to be a good scientist because they need to present their data to audiences and convince them that their interpretations of what those data mean are correct - this was the result of attending their mentor's seminars on a weekly basis, as well as other Centre events which featured scientists making presentations of their latest findings to an audience of fellow scientists. Finally, the students themselves were required to give two presentations of what they were doing and finding out in their own apprenticeships (one in the third week and one in the sixth week of the program). This brought the idea of good communication skills being necessary for becoming a scientist down to a personal level - it was a strong lesson.

The other aspect, about service to humankind, was not evident in post interview data. Either it was not apparent in the example given by their mentors (or other members of the Center's academic community) or it just did not make a noticeable impact on students in terms of priority to other matters that were part and parcel of the daily laboratory experience.

As for curiosity and being open-minded, both qualities were reinforced by laboratory experiences as evidenced by their frequent mention in post interviews. There was a very good match between the pre and post views about these qualities. Observations in the laboratory confirm that most mentors modelled both qualities frequently during the apprenticeships. The aspect of educational background was also reinforced by students' contact with graduate students and post-doctoral scientists and subsequent conversations with them about their past coursework and university training to do the work they were involved with in the laboratory.

One final point, a fine one, but one with some educational implications for school learning, was that the idea of a scientist as a person that "wants to now how the world works" was not particularly well borne out by the apprenticeship. Because the research being done in the students' laboratories was highly specialized, mentors talked about very specific interests, referenced to their own research projects. Scientist curiosity was largely confined to these specific problem areas, and reference to a more general curiosity for "how things work" was not evident on a regular basis as a topic of conversation with students. This is one possible explanation for the paucity of student remarks about this notion of figuring out how the world works as a quality of scientists in their post program interviews.

(2) What do you imagine you will be doing in the laboratory? What do you think you will get out of the experience?

Student responses:

I am going to be learning in a specific thing - I don't expect we'll get results or anything extraordinary is going to come out of the research - I'm looking to learn about the equipment and about what I am doing and I expect a lot of frustration and spending a lot of time just hoping and waiting for something to happen.

I'm expecting to increase my overall knowledge about sciences - I am looking for the experience and seeing whether in later life I would like to continue researching.

Just experience working with people and knowing what sort of problems there are and working them out.

Learn more about engineering - more answers to these questions, just to see if I really would like to go into engineering or if I'm interested more in physics or chemistry. What's more interesting to me or I guess to know whether or not I want to go into this field like science field.

Summary and comparison to 'post'-views.

The responses to what students' expected to happen in their apprenticeships elicited mostly vague and uncertain types of responses at first. Many simply said they had no idea what to expect, as they knew nothing about working in research. On face value, this seems like a logical and reasonable comment. However, the question was asking for what they "imagined" it would be like, and with many students, simply re-asking the question with this emphasis elicited a bit more imagination. Students appeared to be holding back, not so much from not knowing what they imagined, as from a reluctance to be seen to be ignorant about what would happen in the laboratory.

Taken in the light that most students could have very little idea of what goes on in research (this fact supported by program application data indicating what research experience students had had so far in their school careers), their expectations were of a very general nature - in terms of actual activities, or the social interactions with members of a laboratory that they might get involved in, there was no mention.

Many mentioned some idea of learning more science and/or engineering - it was notable that some students were making a distinction between a scientist and an engineer at their young age, a distinction that is confusing even for faculty members of the Center. Most expressed notions about getting work experience and learning about research in a general sense. Again, there was a notable lack of specific ideas about what they might be doing, with whom, and for what reasons.

Against the background of the vagueness of these responses, post interview responses are vivid and specific in recounting the activities and social interactions students experienced in the laboratory.

STUDENT VIEWS ABOUT RELATIONSHIPS BETWEEN THE PROGRAM EXPERIENCE AND THEIR SCHOOL EXPERIENCE

Students were asked three questions that indicated their opinions about the learning environment in laboratories and how it compared and might affect school learning. These data were collected from interviews with students at the end of the program, as well as written student journal entries.

(3) How did this summer's experience compare to what you have been doing in school?

Student responses:

Here I'm learning different things, you know higher stuff than what I learnt at school.

I was able to look at science in a different perspective instead of just a text book thing, you know, to be able to make experiments, analyse data and try to make some sense out of it

It was a lot of work, but a lot of fun - a very good learning experience - I'm learning a lot more physics than I did at school, like it comes alive for you here.

We didn't have as much time like in classrooms and lectures as at school, we learned a lot more because there was theory and you just learned the basics and then you used it and that was the difference because you hold on to things a lot longer if you're going to immediately have to use them and constantly looking back so you can use them, so in that way it was a lot more effective, I learned a lot more in a brief amount of time than I did at school where you just learn stuff and it has no application in school.

Totally different, here you remember things because we worked in the laboratory - we have hands on these machines, in school, we just read and write about things we've never seen before.

Summary

The main theme coming through the data was the practical nature of learning in ARQ. All theory was pertinent in that it had an immediate and obvious connection to practicai laboratory work at hand. Field observations concur that in almost every case mentors sat down to explain some theoretical point to students either during a break in an experimental procedure, or immediately before setting up the next stage of an on-going project. The learning of theory rarely occurred isolated from an immediate laboratory task. It was a common occurrence, however, that theoretical implications were discussed after an experiment. But even this was contexualized within the framework of puzzling over possible interpretations of specific experimental data output. The end result of these theoretical considerations was usually to redesign apparatus and/or to run a further of confirming experiments about the theoretical hunches of the mentor. There was a remarkable change in students' ability to participate in the theoretical discussion from their first entering the laboratory to the end of the six week apprenticeship. Many students were able to not only follow their mentor's theoretical arguments, but were able to make pertinent suggestions of their own as to what might be creating a particular pattern in data output. This was at the level of a conceptual understanding of the chemistry/physics involved, but lacking the depth of mathematical modelling skills mentors possessed to communicate their interpretations convincingly to other scientists and move to next steps in experimental planning.

Of course, the student responses must be understood in the context of what was evidently an exciting and high-tech experience as reported and exhibited by student responses both verbal (interviews) and written (journals). It is unrealistic to attempt to recreate the research center back in schools. Student comments about how interesting one environment was over the other need to be tempered by the obvious fact that they were in a highly stimulating and novel setting which, due to a change from former school routine itself would make life more interesting for most young adolescents. What could have consequences for the school setting, is the element of making clear and immediate practical connections between the textbook, often cited by students as presenting the theoretical side of science, and experimental work, interpreted by students as the application of theory - with the implication that this was the real essence of science. Most students expressed that hands on work in science had a value (although this was not always clearly separable from the fun element) and that theory was necessary to this work, but that theory on its own tended to be viewed as somewhat pointless. Clear and immediate connections between practical laboratory work and theory provide a strong motivational framework for the learning of science. The cook-book confirming type of school laboratory exercise does not make the right connection to theory that can be a true motivator for learning. Research needs to done that helps identify what kinds of experiments can be planned and carried out realistically in the more resource-limited school setting that can come closer to capturing the perceived correct practical-theoretical balance of science done in the research setting.

Next, given that students were thinking about connections between the ARQ and school settings, in terms of learning science, they were asked what they thought they might do differently when they returned to their schools.

(4) Do you think it will change the way you study back in the high school?

Student responses:

I think I'll start paying more attention to the application abilities of what I learn - I'll pay more attention to my English skills, because you have to be able to communicate fully and I'll focus on that.

I think I'm better focused on what actually needs to be studied

Probably now I'll ask teachers after the class for more information - it's good to have a better relationship with teachers.

Summary.

Many students used expressions like "pay more attention" and "focus" in their responses to this question. They indicated that they were thinking about how they approached learning in school. Compared to their initial responses in their application interviews before being selected for the program, they were expressing attitudes and awareness about their roles as learners with more detail. Later observations of the students back in their classrooms confirmed that they did seem to be developing a meta-awareness of the learning process, perhaps more than exhibited by some of their fellow classmates, though no hard data were collected for the comparison to be supported by this study.[3]

The last quote was a common one and holds a positive and refreshing hope for

[3]It would be the next step to collect such data. It is not obvious what the advantages might be of developing such a meta-awareness of the learning process while students are actually engaged in formal learning programs. However, such exploratory study might lead to interesting implications for instruction.

improved classroom interactions between students and teachers. It is usually the teacher that is often trying to encourage students to come to them for help more often. It would be one of the most significant steps forward for schools, if students began to take the initiative for their learning.

(5) What do you feel you got out of the program?

This final question, while originally asked to help evaluate the ARQ program, elicited responses that have implications for schools.

Student responses:

I'm definitely more driven than I was before the program - it will give me two years of definite focus and drive and harder work in school - it has given me a love and respect for science that I haven't had before and didn't realise the time that was going to be put into these things, definitely respect.

I was uncertain if I definitely wanted to go into science or biology - now I think that a science or engineering background gives you a really good foundation and you can always change into like humanities from that, if you want to - science helps you in your thinking.

You know what you're reading in an article, a basic vocabulary you feel comfortable with - this program help you understand and you are more confident after 6 weeks working here.

I guess I got to look at the other side of science and biology, you know and making me realise there are a lot of job opportunities - I learned that there's a lot of stuff you have to understand to do the work, so have to say learned a lot about humility this summer.

It felt great that a graduate mentor was trusting me with his thesis work, a lowly high school kid

Summary.

As might be expected, many responses related to career decisions. A few students were quite specific about which sub-discipline of science they were now thinking of going into. Certainly, some of the QUEST scientists were involved in the program with the aim of affecting such career choices. However, this was not the main intent of the ARQ program. The aim of immersing high school students in laboratory experiences in the research center setting was more to affect their attitudes to science and research, and even more broadly their attitudes to learning in general.

Most student responses to this question emphasized points that support this latter aim. Many listed specific skills they feel had been enhanced (e.g., ability to pick up important information from a scan reading of an article; to present information clearly and confidently to an audience; to ask better questions).

There was also an element of increased understanding and respect for what scientists do. The immense effort and work that goes into experimental science was not lost on the students. They also expressed a very clear increase in self-confidence, attributed not so much to being treated as equals, but as to being taken seriously for their reasoning ability and given a fair chance to show what they were capable of doing, given the time and opportunity. And this is, perhaps one of the most important implications to schools: is it realistic to expect to achieve such important confidence in students, given the imposed time constraints of short class periods and lack of a school infrastructure that allows secondary teachers more time to work with students. This is a quality versus quantity issue that needs to be seriously addressed in school reform issues.

DISCUSSION

The brief view through four windows into the experiences students had in the laboratory and changes to their concepts of the nature of science, research, and learning begins to develop the feeling of the rich social interactions in the laboratory. The cultural experience for the students was how these interactions affected their reflections about science, research, and, perhaps most importantly for this study, their attitudes towards learning.

The data support a socio-cultural model for learning in the research laboratory. It will be developed in three parts: the nature of the laboratory and laboratory work; the laboratory as a site for learning; and the relationship of the laboratory to other sites of learning.

The Nature of Laboratory and Laboratory Work

Accounts of studies carried out in different science laboratory[4] strike a common theme: a laboratory is not a laboratory is not a laboratory. In our quest to simplify the world, it is enticing to overgeneralize situations. The fact is that different laboratories have different purposes, different methodologies, and different effects upon policy and technology based on their findings.

Having said this, there is a subset of such laboratory that can be discussed generically: university laboratories. University laboratories are involved in basic research like many industrial laboratories. It is a common perception among those involved in such laboratories that there is an element of educational purpose to academic research laboratories that distinguishes them from industrial laboratories.[5]

These laboratories can be conceptualized as continuous learning environments founded upon a strong tradition of studentship: old hands nurture new hands in learning the ways of doing science in a particular laboratory. Entering graduate students select to work in the research laboratories of a professor usually based upon common research interests. Established laboratories generally have two or three scientists working in them at various levels of academic advancement: the newest recruit, more experienced pre-doctoral, and perhaps a post-doctoral scientist. All research is supervised by a professor, who takes responsibility for obtaining grants to continue research projects.

There is a minimal level of acceptable conceptual and laboratory skills competence required of new members. This is assured through a well-established academic system of qualifying screening examinations that must be passed after required coursework is completed. Current laboratory members expect that new members will be suitably qualified to undertake an apprenticeship in their laboratory

[4]For example: Latour & Woolgar (1986), Salk Institute lab-neurobiology; Lynch (1985), university lab-psychobiology.
[5]Personal communication with Jim Merz, Professor and Director of QUEST.

such that the present level of productive output will not be diminished, but enhanced.[6]

Laboratory as a Site for Learning

University laboratory participants are accustomed to having new adult, graduate school level members join from time to time. What happens when a non-traditional new member enters the laboratory? Specifically, how does the entry of an adolescent student without an undergraduate degree in science, much less graduate training, affect everyday life in the laboratory? Such questions could be considered by examining social interactions in the laboratory: an examination of the various activity and communicative exchange structures between participants. However, taking into account the purpose for the student's entering the laboratory gives a different scope to such an examination. The student enters laboratory with the purpose of gaining more knowledge about science and learning how to work in the laboratory. If one defines learning in the broad sense of the student trying to make sense of new science content knowledge/laboratory experiences/social situations, then one is asking for the cultural significance of the social interactions being examined. The theoretical understanding of cultural and social for this study is based on the following definitions formulated in Geertz' *Interpretation of Cultures*, (1973):

> One of the more useful ways of distinguishing between culture and social system is to see the former as an ordered system of meaning and of symbols, in terms of which social interaction takes place; and to see the latter as the pattern of social interaction itself. On the one level there is the framework of beliefs, expressive symbols, and values in terms of which individuals define their world, express their feelings and make their judgments; on the other level there is the ongoing process of interactive behavior, whose persistent form we call social structure. Culture is the fabric of meaning in terms of which human beings interpret their experience and guide their action; social structure is the form that action takes, the actually existing network of social relations. Culture and social structure are then but different abstractions from the same phenomena. The one considers social action in respect to it's meaning for

[6]Personal communication with pre-doctoral and post-doctoral scientists in Nuclear Engineering, Electrical Engineering, Materials Science, Physics, and Chemistry Departments at UCSB, 1992.

> those who carry it out, the other considers it in terms of its contribution to the functioning of some social system. (p. 145)

In light of this, the laboratory can be conceptualized as a mini-culture: a place where specific people come together to engage in common activities, for common purposes, and establish patterned ways of socially interacting over a period of time. These patterns construct systems of meaning and symbols. Laboratory as a culture is also characterized by social interactions. In this study, the learning site of the laboratory is viewed as one with established patterns of doing things, into which the student enters. The student learns to a large extent by observing the actions of laboratory members. When the student's actions disrupt the established patterns of laboratory life, a frame clash may occur which highlights those patterns for both laboratory members and the student.

Recent research has shown that the way instruction engages students in science influences access to scientific knowledge (Lemke, 1990; 1991) and the opportunities that students have to learn science (Cochran, 1990; Carlsen, 1992). This work shows that both the types of activity available to students and the ways in which the activity is accomplished through the teacher-student interactions define what is acknowledged as science and scientific knowledge; influence how students display knowledge in their actions and responses; the knowledge constructed about science. If we are to understand what students can and do learn about science, then systematic analysis across time is needed of events and the actions of teachers and students as they work together to meet learning goals. These findings have important implications for how we conceptualize learning in university laboratories. At the face-to-face level of engaging in science, particular views of what it means to do science, to be a scientist, are constructed through the opportunities students have.

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, how to communicate with their fellow students and the teacher.

In the summer science program, students selected a particular project from a written list of offered laboratory projects, though they did not have the opportunity of meeting laboratory mentors prior to laboratory entry. Due to the highly technical nature of these projects, the written descriptions only guided them in vague ways. Once in the laboratory, they 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 in order to understand the research being done. This was fundamentally different from school based learning experiences in which the teacher normally makes it very clear what counts as knowledge worth learning: a routine of weekly lectures, films, homework assignments, and quizzes were 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. Thus, the high school student's tasks were akin to those of the researcher entering a new culture. The goal was to move from viewing the laboratory as an outside visitor to gaining deeper understanding of what science was and how it was done by scientists from their point of view within their local laboratory cultural frame.

The laboratory scientists working during the summer program as mentors to the high school students were faced with dealing with two cultures in the same setting: the culture of everyday scientific work; the culture of teaching the high school student about that work. Mentors in each laboratory were unfamiliar with the pedagogical skills normally taught to high school teachers. They were also unfamiliar with many of the social and cultural demands of being a contemporary teenager. The high school student was perceived as a real novice both in conceptual knowledge and required entry level laboratory skills. Faced with the task of guiding the students towards some kind of understanding of what the laboratory's research was all about and involving them with hands-on experiences representative of normal laboratory work, these novice teachers were in a similar predicament as students in terms of unfamiliarity of how to approach the laboratory as a site for learning.

The major task facing the scientist mentors was akin to that of the ethnographer reporting findings to those outside the study site: how to make the familiar strange. The scientists needed to figure out how to take what was commonplace activity and ways of making sense of their work and help high school students understand it. They needed to make the unconceptualized nature of their scientific activity visible to both themselves and their students.

The learning situation in the laboratory was a challenging one: students who were unsure of how to student, and teachers unsure of how to teach. Yet, as the program progressed, it was evident that the students were learning in the laboratories: how did this get accomplished?

Relationship of Laboratory to Other Sites of Learning

The use of the term "sites of learning" provides a means of examining relationships between instructional activities in the laboratory setting with those occurring in other settings within the summer science program. Considering the activities of the students beyond the laboratory experience recognizes that every learning situation takes place within a larger context.

The learning experiences of the student in the laboratory were linked to other sites of learning in this study. Recognizing the large gap between students' school experiences of science and the graduate level expected for normal entry into the laboratories, other sites of learning were provided as support for the students participating in the summer program in this study. These sites were designed to support the laboratory experience. In all cases, time priority was given to the laboratory.

The model is one of the laboratory culture being embedded in a larger science summer program culture. This larger culture involved fellow students, class instructors, center administrators, and physical sites outside the laboratory where various types of learning tasks could take place. The laboratory within the program can be viewed as analogous to the classroom within the school setting.

One of the requirements for the students in the summer program was to make a final presentation of what they had learned in their laboratories to their fellow students, mentors, professors, interested teachers from their local high schools, and parents. Knowledge of this requirement influenced how student and mentor co-constructed the instructional context of the laboratory. Both the student and mentor viewed the presentation as an opportunity to display how much the student had learned, as well as how well the mentor had helped with that learning. Both were stakeholders in the quality of the presentations. A close analysis of some of these presentations from the first summer program is the focus of an earlier study (Bleicher, 1994).

Educational Importance - Implications

Students made noticeable gains in conceptual understanding following direct interactions with laboratory equipment and procedures and, most significantly, discourse with their scientist-mentors during practical work in the laboratory. Motivation to learn was extremely high. Student strategies for asking questions of their mentors demonstrated varying degrees of success in gaining the information being asked for during face-to-face laboratory interactions with mentors. Related to these strategies were individual differences in how students perceived their roles in their laboratory and their personal views of what constituted knowledge and expertise in this setting.

When observed in their respective school classrooms, during the subsequent school year, students were repeatedly reported to contexualize their classroom work in terms of their summer laboratory apprenticeship and to communicate laboratory "stories" to their fellow students in a confident manner. Students indicated new interests in collaborative learning environments, sharing ideas with school colleagues and teachers, and a growing respect for research. They expressed improved attitudes towards educational research, and a new awareness in thinking about teaching/learning processes. Comparison of entry and exit student data clearly demonstrated large gains in conceptual scientific knowledge, laboratory skills, written and oral communications skills, motivation to learn, interest in science, social awareness, and self-confidence. These gains were distinctly linked through the ethnographic audit trail to laboratory experiences that qualified as "legitimate peripheral participation" (Lave 1991).

Accounts of students working with scientists in laboratory can serve as operational models on the basis of which objectives for science teaching can be developed. Students learned firsthand: 1) that laboratory procedures and methods were not followed like cook-book recipes, but were creatively adapted to local needs in order to "get results"; 2) equipment breakdown, the redesigning of equipment, interfacing computers with other equipment, and improving data output formats were all approached by participants with the single-minded motivation of obtaining "good data"; 3) such data was highly valued and eventually became the basis for oral and written reports about the productive discoveries of the laboratory group.

School science laboratory.

There have been several models proposed for how school science laboratory should be structured, based on theoretical considerations. One of these will be briefly discussed here.

Advocates of laboratory-oriented science programs see learning as activity based, involving important elements of discovery and creativity (Tamir & Yager, 1992). This involves students in doing science, not just learning about science.

Based on day to day activity, the learner continuously brings prior knowledge to bear on new problems, making connections that lead to a clearer and better understanding of the phenomenon in question. The idea is to minimally guide the learner in order to maximize the development of critical thinking skills and a sense of student-owned problem solving.

The work of Joseph Schwab (1962), who identified three components of a laboratory learning situation, provides a useful framework for understanding minimal guidance. The three components are: 1) problems, 2) ways and means for discovering relations (methods), and 3) answers. In the model, the learner is supplied with all, one, or various combinations of these three components in a laboratory activity. Table 4 illustrates Schwab's four levels of guidance.

Table 4
Schwab's Levels of Guidance

	Problems	Ways & Means	Answers
Level 0	Given	Given	Given
Level 1	Given	Given	Open
Level 2	Given	Open	Open
Level 3	Open	Open	Open

Level 0 is a laboratory learning situation of full guidance, Levels 1 and 2 less, while Level 3 provides the least, or minimal guidance for the learner. Levels 0 and 1 are situations which Tamir (1992) terms verification laboratories, designed to validate the teacher's lectures or textbook materials. This is cookbook science, where the student is given a full explanation of the problem, how to do the experiment, and even the expected results in the case of Level 0. In Level 3, the student is presented with some phenomenon, but must pose her own problem or hypothesis, determine some method to test it, and use the data or observations to negate or lend support to that hypothesis. Modern approaches to science curriculum would be committed to working towards teaching-learning situations that are characteristic of Levels 2 and 3.

In a major review of science studies during the first half of the 1980's, Yager and Penick (1987) reported a major mismatch between the science laboratory model suggested above and that found in the schools. They found that, in many instances, laboratory activities were not offered to students, and if done, the activities were merely designed to verify the lecture or textbook. This finding was true across schools of varying philosophy including schools in which Inquiry and Discovery materials were being utilized (Watters, 1985).

Returning to Schwab's notion of Levels of guidance in laboratory activity, why do researchers report that most school laboratory science is at the Level of 0 or 1? Part of the answer to this question lies in the scant empirical evidence that would help guide teachers in engaging students in Level 2 or 3 laboratory activities. Though theoretically sound, the practical development of laboratory programs of instruction that actually achieve a high incidence of Level 2 or 3 laboratories are nearly non-existent in most American (Tamir, 1992) and Australian (Fraser, Giddings, & McRobbie, in press; Fraser, McRobbie, & Giddings, 1993) schools. The critical mass of model classroom examples is not there to support the widespread occurrence of the desired effect.

Another aspect to this problem is the lack of clear model of the range of activities and skills of which students are capable within laboratory settings; also, many high school science teachers do not have recent experience with research science. This study connects very strongly at this point in providing the foundation to build such a model. There is a huge gap between the purposes, equipment, and consequential funding systems that operate within university research laboratories and school laboratories. Merely reproducing the equipment and/or experiments does not solve the problem. Working out the practical details of simulating some of the socio-cultural aspects of university research laboratory in school settings will be a long, but rewarding road for future research and policy decisions.

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