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Doing Science at the Elbows of Scientists:

Issues related to the Scientist Apprentice Camp 97

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> Telling children how scientists do science does not necessarily lead to far-reaching changes in how children do science; indeed, it cannot, as along as the school curriculum is based on verbally expressed formal knowledge. (Papert, 1991, pp. 10-11)

Introduction

Apprenticeship has a long history as a powerful educational strategy. Recent work in anthropology and education has suggested that apprenticeship learning has the potential to provide a useful model for designing meaningful learning environments (Brown, Collins, & Duguid, 1989; Collins, Brown, & Newman, 1989). Rather than "telling" students about a discipline, students are immersed within a community in which they engage in practices "at the elbows" of more competent peers, teachers, or scientists. Leading science educators have distinguished active learners doing scientific investigations from passive learners receiving science instruction (Ruopp, Gal, Drayton, & Pfister, 1993; Solloway, Krajcik, Blumenfeld, & Marx, 1996). *Instruction* includes the performance of exercises or activities designed to illustrate a single science concept. While an *investigation* is a comprehensive perspective focused on actively engaging learners in authentic scientific inquiry, apprenticeship goes one step further and places this *investigation* in the context of the well worn path of a scientist's research agenda, where the apprentice is under their tutelage, using their lab and equipment, doing the science that contributes to the scientist’s work and thus has a vested interest. This experience allows student’s to gain insights in to the circumstantial nature of science and facilitates students’ adoption of a *gaze* (i.e., way of perceiving and interacting with the world) that is consistent with that of real scientists.

Historically, scientists were considered to make use of rational principles that were somewhat distinct from everyday thinking and acting. More specifically, scientists employed the scientific method, which required applying special cognitive skills so that the scientist may define and solve problems that occur in the natural world. Recent advances in the philosophy and social studies of science have pointed towards a different image of scientists and their practices. The “work of scientists” is one that is socially constructed and fundamentally situated (Latour, 1993; Roth & Bowen, 1996). Scientists develop situationally dependent procedures, with projects taking shape because of contextually available equipment often in relation to unexpected findings (Knorr-Cetina, 1981, 1992; Latour & Woolgar, 1979); all of which “give rise to emergent facts that harden as scientists construct arguments to convince their peers” (Roth & Bowen, 1996, p. 75). In other words, within the laboratory, resources (facts, heuristics, theories, models) and practices (laboratory skills, application of concepts) are continually negotiated and transformed based on the situations in which they are being applied (i.e., the circumstantial nature of science). This allows students to gain a rich appreciation for the situated nature of resources and practices, both of which are continuously transformed through embodied laboratory practices in relation to the community-based goals (Roth, 1996). In contrast, within the context of schools, resources and practices are (all too often) introduced as objective facts, creating the misconception for students that these are immutable, existing independent of the social situations in which they were created, formalized, and continually re-negotiated.

Drawing on the advantages of apprenticeship learning and to provide students with an opportunity to engage in “authentic” science practices, the Scientist’s Apprenticeship Camp (SAC) was established. During this past summer, six groups of inner city, middle school students attended SAC and selected an apprenticeship in which they worked with one practicing science teacher and one mentor scientist. The SAC was designed to match inquisitive, highly motivated middle school students and teachers with researchers in the School of Science at Indiana University/Purdue University Indianapolis. Participants worked in groups of four with the expert guidance of a practicing scientist as they conducted scientific research. Students were presented with an authentic research problem and had hands-on experience with state of the art instrumentation and equipment. They learned how to state a hypothesis, conduct experiments, collect and process data, and integrate their findings into a presentation suitable for a scientific conference.

Findings and general perception of the previous year, SAC 96, were that simply putting students into scientist labs did not take full advantage of the apprenticeship experience. Scientists focused on mastering basic factual knowledge and therefore tended to lecture to the campers during the initial days of the camp. Scientists, it was found, often talked or demonstrated science, providing students with less opportunity to engage in scientific practices. This year adjustments were made, including an Apprenticeship Electronic Notebook introduced to lessen the scientist’s need to lecture students during lab time and a more formal evaluation of the camp was requested.

This Study

For this report, both naturalistic and quantitative data are reported to gain a holistic vision of SAC (Guba & Lincoln, 1983; Scriven, 1983; Stake, 1983). An evaluator was present for all ten days of the camp, and for the final presentation day. In addition to the data directly collected by the evaluator, two other researchers also collected field notes, videotaped students while working in the laboratory, and conducted interviews. Teachers were equipped with beepers, and at random times during the day they were beeped and expected to fill out a questionnaire designed to evaluate how active students were. Students also filled out questionnaires intended to measure their engagement, enthusiasm, and how important the camp was to them. The electronic notebook, which recorded all student, teacher, and scientist entries, provided another means of gathering data. The presentations themselves and pre-post assessment measures administered to students represented a final source of data for this report.

In daily meetings among the researchers, field notes, student interviews, and teacher observations were discussed so as to generate assertions used to direct data collection efforts the following day. In particular, these meetings illuminated pertinent issues with respect to the successes and challenges of SAC. The issues most prominent at the end of the study (and which structure this report) are:

- Did students spend more time listening about or engaging in scientific activities?
- What were student’s goals for learning in the various apprenticeships?
- What was the role of technology in supporting the apprenticeships?
- Did students find the apprenticeships personally engaging?
- Did students find the apprenticeships personally meaningful and motivating?
- What did students learn?

The issues were refined during fieldwork, group meetings, and increasingly focused data collection and analyses. Lincoln & Guba (1986) recommended triangulation as one means of increasing the credibility of interpretations derived from naturalistic interpretations. Data were triangulated using multiple methods; including interviews, fieldnotes, videotape analyses, student debriefing, and analyses of referential materials.

The Context

The camp consisted of six different apprenticeships organized around various content. Drawing on the scientist's postings as displayed in the electronic notebook, the following descriptions of each apprenticeship are offered:

- Rat Group - During this project, apprentices studied adult rats that were exposed to methamphetamine during the first week of life. In particular, apprentices were determining if exposure to methamphetamine during development changes the rat's sensitivity to the drug in adulthood. Students calculated drug doses, balanced scales, collected data, set up data files on the computer, looked at differences, and interpreted data.
- Bat Group - During this project, apprentices used signal processing methods to analyze echo signals to study and understand how various information about a target (e.g., an insect or a Lego block) is represented in an echo signal. This information provided insights to how bats used bisonar signals for navigation, communication, and hunting insects. Students used high-end computer workstations and advanced modeling/visualization software to represent, analyze, and interpret echo signals.
- Moth Group - During this project, apprentices analyzed the effects of various insecticides for inhibiting the growth of the Juvenile Hormone in moths. Students applied topical assays of the treatment insecticide and controls and then observed the differences in growth of the moths. Students performed dissections, weighed moths, inputted data to a computer, analyzed and interpreted data.
- Watershed Group - During this project, apprentices determined the sediment and nutrient concentrations in a local creek and

evaluated the effectiveness of the wetlands at filtering these pollutants out of the water. Apprentices viewed current land use practices, measured stream velocities to estimate surface water discharges, and collected and analyzed water samples to assess water quality upstream and downstream of a specific data.

- Color Group - During this project, apprentices used computational chemistry to study the relationship of molecular properties to observed color. Apprentices used molecular modeling software on a high-performance workstation to build computational models of these molecules and calculated some of their physical properties. The values of these properties were compared to predicted values to validate the reliability of the computational model.
- Laser Group - During this project, apprentices examined the potential of using lasers to make “logic gates,” which are necessary for the operation of optical communication and computing technology. However, there are several pressing problems that must be addressed before the potential of optical computers using lasers can occur. Apprentices were apprised of some of the concerns and given open questions. They then engaged in a series of experiments to find the answers to some of these questions.

Each day began with a brief discussion as groups (consisting of four students and one classroom teacher) met to talk about their expectations during their time with the scientists. Students and teacher then spent two hours directly apprenticing with the scientist in his/her laboratory. During this time students took pictures using a digital camera, collected notes on the research, carried out laboratory practices, engaged in discussions with the scientist and each other, collected data, and eventually submitted data for analyses. Following this laboratory time students had lunch as a group.

The second half of the day consisted of the separate groups meeting to discuss data, followed by an approximately two hour period in which students used an electronic notebook designed for this study. Using the electronic notebook, students entered data (including pictures and field notes), posed questions to scientists using a chat interface, searched the World Wide Web (WWW) for relevant data, read scientist notes, and worked on their final presentations. Occasionally, a portion of this time was used to teach students how to use presentation software, prepare presentations, speak publicly, search the WWW effectively, and pose and respond to scientists' questions electronically. On the final day, parents and siblings, university personnel, the scientists, and other interested members of the surrounding community were invited to watch each group engage in a 15 minute presentation regarding their experiences and findings.

Various Roles

Scientist. The scientist's assigned role was to empower the learner to conduct "real science experiments." Scientists defined the experiment, methodologies, tools, lab, resources, conceptual frameworks, data to be collected, equipment (diode lasers, digital oscilloscopes, optical modulators, or computers), data collection methods (current meters, water quality sampling equipment, water chemistry probes and data loggers, colorimetric field tests, or lab spectrophotometer) or the data itself (bisonar echo signals from bats), sites of the experiment (Crooked Creek watershed), subjects for experiments (lab moths or rats), experimental treatments (methamphetamine or a Juvenile Hormone-based insecticide), tools for data collection (computerized activity monitors, molecular modeling software, or signal analysis software), and informational resources (rat brain atlas).

The scientists had the primary responsibility of defining the "research environment," which, in this case, was also the learning environment and curriculum. Scientists had clear ownership of the data that students' collected, because it was their data. Thus mistakes of procedure were often monumental to the scientists. For example, the scientist mentoring the Rat Group was allocated only so many rats by the university and only so much methamphetamine for her study. If students made mistakes at any step with the experiment, the scientist loses the hard fought resources that are at the center of her research and often career.

Teacher. There was one teacher assigned to each of the six groups. These were in-service science teachers from local high schools and middle schools. They undertook multiple roles in SAC. The first role was to serve as a liaison between the students and the scientists. This involved both in-lab and out-of-lab roles. In the lab, teachers served a scaffolding or, more accurately, interpretative role in both directions. This role would be enacted if scientists would explain concepts or ask questions and it was clear that students did not understand—the teacher would then paraphrase the scientist for the learner. This method served a number of functions. First, it promoted effective communications. Second, it promoted connection between the scientist discourse and the learner discourse in a way that was both sensitive to the real problem and performed an educative function so that students could learn the discourse of the scientist (it did not dumb down all the communications, just confusing ones). Third, it performed an educative function for the scientist so s/he could learn how to better communicate with middle school learners. The paraphrasing also occurred in the opposite direction—when the student asked questions of the scientist. Here the teacher served basically the same function; that is, aided communications, modeled phrasing questioning to students, and was educative for the scientist.

The teachers' roles outside of the lab were more diverse. Over the custodial roles of getting apprentices to and from lunch, going to the labs, and back to the computer room; teachers played three roles in SAC. The first role was one of preparedness for the group’s time with the scientist. It was stressed to the scientist, teachers, and campers that the most important and critical time they had during the week was their time with the scientist and that the teachers should have the apprentices ready to "hit the street running." There were specific times set aside for teachers to help apprentices prepare for their time with the scientist. The second major role of the teacher outside the lab was to reflect on and process the experience with the scientist for the students. This included times in which students went over what they did and learned during lab time, as well as, times where they processed data that they collected (measurement, pictures, graphs, etc.). Finally, the most time consuming role the teachers had was the facilitation of the apprentice research presentation that was the culminating event of SAC.

The research presentations were the most emphasized outcome of the apprentices' two weeks at SAC. Directors put direct pressure on apprentices and teachers to create a high quality 10 minute, PowerPoint presentation of their research. Teachers facilitated the organization of the presentation, collection of resources, technical aspects, and accompanying speeches. Apprentices had "dress rehearsals" on the day prior to the final presentation that were critiqued by the directors and scientists.

Learner. Learners had two distinct categories of roles in SAC. The first and primary role was as the scientist’s apprentice and the second was as a presenter of scientific research. These two roles were conceptually related both in the minds of the students and in the directors of the camp; they were markedly distinct in terms of what the learners did, who facilitated them, the legitimacy of what they did, and the outcomes.

In the scientist apprentice role, learners had little control over the primary research question, basic goals, assumptions, parameters, practices, and resources that were used. They entered the on-going practice of science by conducting research experiments that were a part of the scientist’s actual research agenda. The role was clearly as an apprentice (new-comer) working with a master (old-timer) in a very structured community of practice where the practices that they engaged in were extremely well defined. Their roles were to quickly understand the conceptual framework of the master and then participate in tool-related practices. These tool-related practices were exacting and nonnegotiable. Apprentice had no latitude in changing their technique, instrumentation, site, or subjects. Learners engaged in these tool-related practices through a process of watching the masters perform the practice and then a slow appropriation of the individual steps of the practice. Once the tool-related practices where performed to the master’s satisfaction, both the scientist and the teachers would often engage learners in discussion of, "Why do we do it this way?" Some steps in these practices may not even be appropriated by the apprentices because of difficulty, time constraints and/or other issues (i.e. injecting methamphetamine into the rat). The apprentices role when they were in the lab working with the scientist were strictly defined by the scientists.

In the secondary, but related role, learners engage in the practice of modern day scientific presentations. This involves the practices of PowerPoint presentation development, WWW searching, public speaking, producing visuals, journal writing and delivering scientific presentation. Learner’s roles in this apprenticeship were markedly different. There was a mixture of relatively passive lecture/demonstration instruction with active presentation development and practice times. The lecture/demonstration instruction times were often lead by non-scientists that presented in one hour shots. Thus the learner's role was to take in the information or skill and apply it to their presentation. In their active presentation development roles, learners had almost complete control over their work. Within the time frame determined by the directors, the confines of the PowerPoint, and the requirement that each member of the group have a public role in the presentation, they were in control of the presentation. There was some mentoring by the teachers and the scientist, but this was markedly different than the mentoring that was done in the lab. This mentoring took the form of gentle facilitation, not strict adherence to a particular practice. Ownership was clearly in the hands of the learners. Doing poorly would reflect on both the scientist and the teacher; however, in stark contrast to the lab work, it would not impact the scientist's research in the slightest.

Findings and Discussion

The results of this study—the findings and data selections supporting them—are presented in six sections organized around each issue, which focused efforts and which were continuously refined by new data and analyses.

Activities of Apprentices

Issues:

- Did students spend more time listening about or engaging in scientific activities?

Findings:

- On average, the camp seemed to strike a balance between listening about and doing scientific activities (M = 5.39, SD = 3.12), with “1” being primarily listening about and an “11” suggesting doing scientific activities. The Moth and Color groups were the most active in doing scientific practices, while the Water and Laser groups spent more time listening about practices.
- Resource use of the camp members was limited, involving few resources, and primarily defined by the scientists (M = 4.35, SD = 3.12); a “1” suggests using few resources that were primarily defined by the scientists, and an “11 suggests the inverse. The Moth and the Laser groups were most active, with the Bat, Color, and Laser having the lowest scores.

The Context questionnaire (see Appendix A) was designed for this study and intended to measure whether students were *listening* about or whether they were *doing* activities that the researcher deemed as important in apprenticeships. Data was collected as the teachers in each group were randomly paged (using beepers) twice daily. On these two occasions, and once at the end of the day, teachers filled out the Context questionnaire. An exploratory factor analysis using oblique rotation was used to determine the number of factors from the 9 items in the Context questionnaire necessary for explaining the variance in item scores. Results suggested two factors (with item loadings of .4 and above) explaining 63% of the variance. Factor one consisted of items 1-5, 8, and 11, and was intended to measure whether students were <u>listening</u> <u>about</u> or whether they were <u>doing</u> scientific activities. Factor two consisted of items 6 and 7 and measured whether students were using a few resources that were specified by the mentor or using multiple resources beyond the laboratory setting. Internal consistency estimates for the listening-doing apprenticeship activities ($\alpha = .91$) and the resource use ($\alpha = .87$) factors suggested that both were reliable. The scores ranged from 1-9 with a lower number for the first factor suggesting students were listening about the use of scientific activities and a higher number suggesting increasing levels of scientific activities—a "6" indicates a balance between listening and doing. A lower score on the second factor (resource use) suggests limited use of resources and that this use was primarily defined by the instructor, and a higher score suggests the inverse.

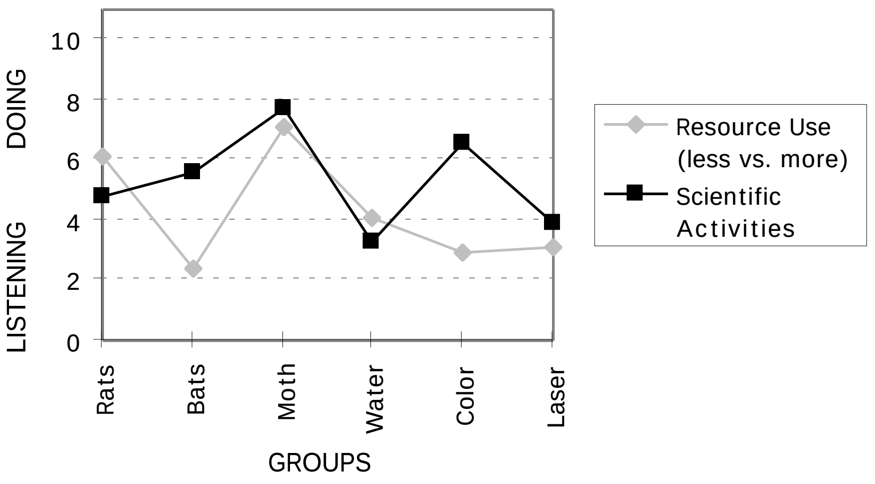

Figure 1. Means for and Scientific Activities (listening vs. doing) and Resource Use (less vs. more) for Apprentices in the Six Groups

A multivariate analysis of variance was carried out to determine if there were significant differences among groups with respect to the multivariate composite of scientific activities and use of resources. With the use of Wilks' criterion [*F*(5/386)= 57.03, p<.001], there were significant differences between the six groups, accounting for 73% of the variance; following Cohen’s (1988) guidelines this represents a very large effect size. Discriminant function analysis (DFA) was used as a follow-up because, unlike analysis of variance, it examines which variables are significant in the company of others. Results from the DFA revealed that the *F*-to-remove was significant at the .01 level for apprenticeship activities (*F* = 82.09) and resource use (*F* = 69.46).

The **Rat** Group, on average, seemed to strike a balance only slightly favoring listening about opposed to doing science activities (M = 4.8, SD = 1.38), with the members using multiple resources some of which they defined (M = 6.00, SD =2.27). The **Bat** Group spent approximately 50% of their time listening about and 50% of their time doing scientific activities (M = 5.58, SD = 1.93), however, they only used limited amounts of resources and those were primarily defined by the scientist (M = 2.20, SD = 2.11). The **Moth** Group was clearly the most active apprenticeship context (M = 7.73, SD = 2.37), with the members using multiple resources many of which they defined (M = 7.11, SD = 2.52). The **Water** Group mostly listened about the use of scientific activities (M = 3.34, SD = 1.31), and used the fewest resources most of which were specified by the scientist (M = 4.11, SD = 2.60). Members of the **Color** Group appeared to spend more time doing scientific activities than listening about their use (M = 6.63, SD = 2.37), however, their resource use was minimal and was primarily defined by the scientist (M = 2.95, SD = 3.60). The **Laser** Group appeared to spend more time listening about the use of scientific activities (M = 3.89, SD = 2.12), and their resource use was minimal, again, being primarily defined by the scientist (M = 2.95, SD = 3.60).

Student Goals

Issues:

- What were student’s goals for learning in the various apprenticeships?

Findings:

- Apprenticeships clearly differed in their reasons for participating in the activities of the camp. While apprentices in the Rat, Bat, and Moth groups valued the research as the primary reason, students in the other groups placed more emphasis on getting ready for their presentations.
- Camp results, collapsed across groups, indicated that 49.8% of apprentices were doing the activities because they were “collecting data for the experiment” and 23% for “the presentation.”
- 66 % of the students indicated that they were doing the activity they were engaged in when beeped because they wanted to do it, opposed to 34% who stated that it was required.

Apprenticeships differed in terms of learner goals for participating in the activities when they were beeped, X^2 (20, n = 241) = 92.35, $p <$ .001. It was the goal of the camp that students would value the research they were doing both for the sake of the experiment and in relation to the presentations. For example, the most common reason for students in the Color and the Laser Groups was “for the presentation,” while students in the other groups chose “to collect data for an experiment,” with water being almost equally divided (see Table 1). It appears that the Water, Color, and Laser groups were not able to establish research questions that were as compelling to students as the presentations. Whether this validates the role of the presentations or suggests a need for improving the experiences in these groups is up to individual interpretation.

Reasons for Doing Activities	**Rat Group**	**Bat Group**	**Moth Group**	**Water Group**	**Color Group**	**Laser Group**

Required for camp	0	1	0	2	0	0
Data for Experiment	31	24	34	17	7	7
Data for Presentation	5	7	3	14	22	13
Teacher/Scientist made us	3	5	0	1	4	0
Other	4	4	2	6	15	10

Table 1. Group by reasons students selected for participating in the camp activities when beeped.

Camp results, collapsed across groups, are displayed in Figure 5 and suggest that 49.8% were doing the activities because they were "collecting data for the experiment." Twenty-three percent chose "needed to get data for my PowerPoint presentation," 19.9% chose "other," 5.4% chose "the teacher made us do it," and the remaining 1.2% chose "required to be at this camp." These results, specifically that 50% engaged in the activities to gather data for the experiment, suggests that students did indeed adopt the goals of the camp. As a matter fact, when one student misinterpreted that the scientist already new the results of the data, he became so frustrated that he wrote a disgruntled electronic message to the scientist: "Why are you having us analyze data that you already know the results. I have been working hard and thought I was doing this work for a real reason."

Students were also asked if they were doing this activity because "it was required" or "wanted to do it." Sixty-six percent of the students indicated that they were doing the activity they were engaged in when beeped because they wanted to do it, opposed to 34% who stated that it was required.

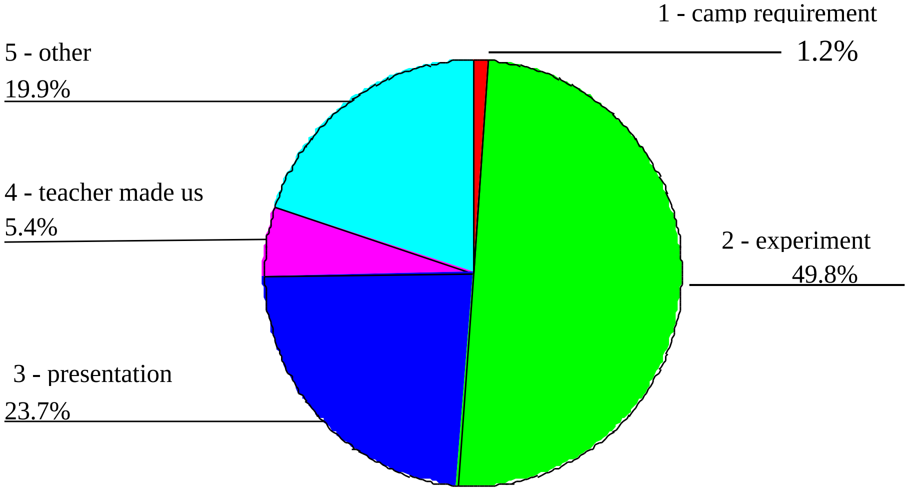

Figure 2. Individual Choices With Respect to Reasons for Doing the Activities That They Were Doing

Role of Technology

Issues:

- What was the role of technology in supporting the apprenticeships?

Findings:

- The Electronic Apprenticeship Notebook created alternative avenues for information that can be conveyed through didactic instruction and would have used valuable lab time.
- The Chat section created a "reflective zone" that was away from the excitement of the lab allowing students could reflect on the lab experience with each other.
- The Notebook section created a powerful support system for the scientific presentation. Although not without initial glitches, the notebook did allow students to store and retrieve digitized pictures, field notes, scanned in graphs, and scientists’ comments for later use in preparing the presentations.

The Apprenticeship Notebook section created a powerful support system for one of the driving goals of the camp, the scientific presentation. Drawing on Schon’s (1987) distinction of reflection *on* practice versus reflection *in* practice, the Apprenticeship Notebook facilitated both reflecting back on the previous activities and encouraged students to reflect while they were engaged in the activities. Apprentices used the Notebook to gather all of the data, pictures of instrumentation, field surveys, test animals, and data analysis graphs and charts. The Apprentice Notebook was partly introduced in an attempt to lessen the scientist’s need to lecture students, and maximize students’ time with the scientist. In terms of maximizing the benefit of the limited time the students had with the scientists, the results indicate three benefits of the Apprentice Notebook. I will briefly describe these benefits and use illustrative examples from the Bat Group to solidify these findings. The three assertions follow.

1. Creating alternative avenues for information that can be conveyed through didactic instruction. As pointed out previously, one of the major waste of mentor/lab time is lecturing to the campers. The Links section of the Apprentice Notebook was designed to facilitate distribution of basic fact to the campers and Chat section was a vehicle to ask questions and elaborate on that information. The evidence of the first is derived be references in the Chat.

What is a rotation vector and periodic function? Jackie

Do the bats send out the sonar signals voluntarily or not? Pat

Do all clear solutions absorb the same amount of light??? Tom

Scientists also used the Chat room for asking probing questions, often playing off student questions, to test student understanding. Similar to what a teacher would do in a lecture setting. For example, as a follow up to Tom's "clear solution" question (above), Dr. R asks,

> What do you think happens to color or transparency of a solution that absorbs light form all regions of the visible spectrum (still clear) but absorbs more white light than ... say water?

The important observation here is that this didactic instruction is being conducted outside of the lab and at the conveyance of the scientist. Thus maximizing the hands-on work were they need to be physically with the scientist.

2. The Chat section also created a "reflective zone" that was away from the excitement of the lab where students could reflect on the lab experience with each other. For example:

Q: *What are some of the differences between lasers and flashlights? Tony*

A*: ... a flashlight spreads its light out from a long distance. A laser has a small concentrated beam of light... Fred*

A: *... a laser light is much more concentrated... Pat*

A: *...Lasers take the same amount of light and puts it in a smaller area... Tom*

Q: *What do you think our hypothesis is going to be? Rob*

A*: Our hypothesis will be about the watershed and how the wetlands will clean it up.*

And after time to think and formulate question, this reflective zone gave student opportunities and a comfortable social distance to ask the scientist difficult questions that were not simply factual that could have been looked up or clarification of factual information, but extensions into the heart of the scientific practice. For example:

Q*: How can a cube come out looking like two mountains on a sonar graph*? *Tim*

Q*: Wouldn't the sonar signal you recorded have to send out several of these signals to get the full picture of the object instead of just one? Terry*

Q*: If we had phase information, do the 3D or 2D graphs look like the target image?*

It should be noted that Tim's question goes to the very heart of the bat sonar question. That is where the bat sonar is a replacement for our vision or a totally different way of perceiving the spatial world. His confusion is an attempt to say, "why don't the graphs look like a cube?"

3. The Notebook section create a powerful support system for the driving goal of the camp, the scientific presentation.

Apprentices used the Notebook to gather all of the data, pictures of instrumentation, field surveys, test animals, and data analysis graphs and charts. This was combined with ongoing lab observations, hypothesis, plans, outlines and conclusions. One of the teachers was so impressed with the Notebook he stated that the Notebook "put us light-years ahead of last year in the preparation of the presentation."

Personally Engaging

Issues:

- Did students find the apprenticeships personally engaging?

Findings:

- Students reported to be engaged during much of the apprenticeship, with over 85% of the students scoring 6 or above on a scale of 1-9.
- Students indicated that their skills to complete the activities exceeded the challenges of the activities.

Using the beeper technology students were beeped twice each day and expected to complete a Flow Questionnaire (see Appendix B), adapted from Czicksentmihaly's work. Over the last two decades Csikszentmihalyi (1990) has been researching the conditions that promote individual engagement or what he has called "optimal experience" or *flow*. His flow theory predicts that "the experience will be most positive when a person perceives that the environment contains high enough opportunities for action (or challenges), which are matched with the person's own capacities to act (or skills)" (Csikszentmihalyi & LeFevre, 1988, p. 816). Optimal experiences were reported to occur when individuals had clear goals, the situation offered nontrivial opportunities for action, and the activities were well matched to the skills of the individual. If the challenges of the activity were too simple, boredom would result. If they were too complex or if the individual did not have clearly defined goals, then apathy would occur. Csikszentmihalyi hypothesized that in the face of complex situations, the clearly structured demands of flow activities provide order to consciousness, and ultimately, help individuals build more complex identities.

Item 7 was added to the Flow measure so that students' main reasons for participating in the activities could be determined. The internal consistency estimate for the 10 items (excluding items 1 and 7) was $\alpha = .87$ and suggested that the instrument was reliable. Figure 3 depicts the percentage of individuals who had scores of 0-9, with a score of "0" suggesting little student engagement, while higher numbers suggest increasing levels of flow. Results are positive in that over 85% of students averaged "6" or above n the nine-point scale.

However, students indicated that the challenges of the activity (M = 4.25) was well below their abilities (M = 7.01). Csikszentmihalyi (1990) has found that a good match between these is a requisite to optimal experience for students in the United States. The lack of match in this research could indicate that students were not being optimally challenged or that they overrated their abilities with respect to the scientific activities. However, rather than finding the students to be bored, results indicate that the students found the apprenticeships highly motivating and personally meaningful.

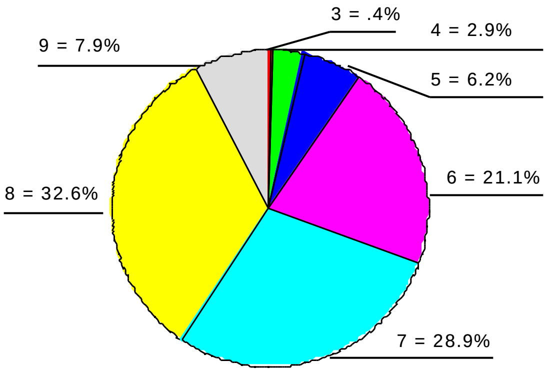

Figure 3. Percentages of Individuals Who Scored 1-9 on the Flow Questionnaire—Higher Numbers Suggest Increasing Levels of individual

Meaningful and Motivating

Issues:

- Did students find the apprenticeships personally meaningful and motivating?

Findings:

- With respect to enjoyment of the activity, approximately 85% of students selected "6" or above on a scale of 0-9.

- With respect to personal importance of the activity, approximately 93% of students selected “6” or above on a scale of 0-9.

In addition to student overall scores with respect to flow, items 4 and 10 were analyzed individually to determine if students were enjoying what they were doing and if the activity was important to them. The percentages are displayed in the Pie Chart in Figure 4, with the former on the left and the latter displayed on the right side. Results were positive with respect to enjoyment in that approximately 85% of students selected “6” or above, with a “0” indicating not-at-all and a “9” indicating very much. Similarly, with respect to importance of the activity, 93% of students selected “6” or above on the same 0-9 scale.

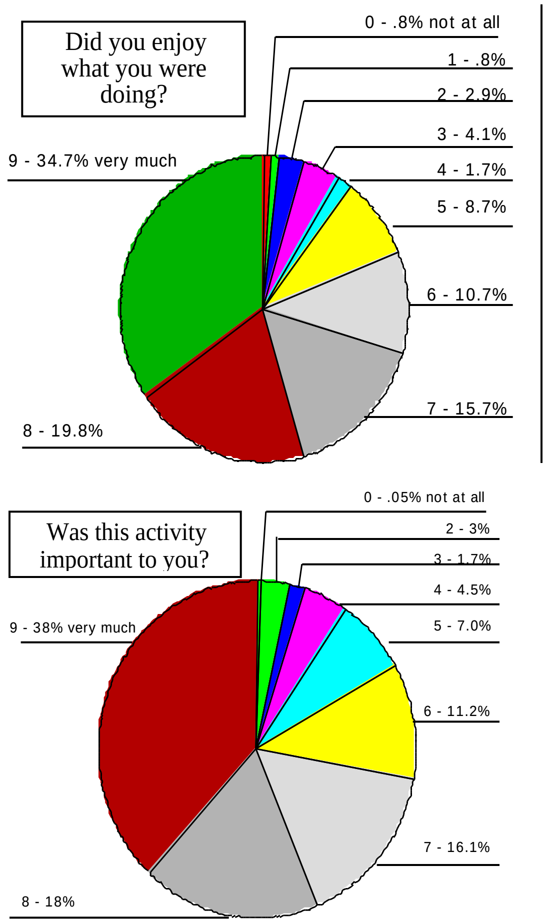

Figure 4. Percentages of Individuals Who Scored 0-9 on Item 4 (Did you enjoy what you were doing?) and Item 10 (Was this activity important to you?)

Learning

Issue:

- What did students learn?

Findings:

- There was a statistically significant difference between students pretest and posttest understanding of the scientific method. In the posttest students used more of those terms that are central to the scientific method (hypothesis, results, analysis, problem) than in the pretest.

· Student presentations were complex and scientific, with all groups scoring 10 of 11 possible points. All groups included graphs, digitized photos, and explained in detail the methods used in their experiments. The only limitation of these presentations being that 5 of the 6 groups failed to discuss the broader implications of their study.

Learning was first evaluated by examining differences in students *understanding* of the scientific method before the camp started and after it was completed. Specifically, students were asked what the scientific method was, with all answers being evaluated using the rubric depicted in Appendix C. Interrater agreement was .98 for the pretests and .91 for posttests. Significant differences were found between pretest ($\underline{M}$ = 1.19, $\underline{SD}$ = 1.49) and posttest ($\underline{M}$ = 1.88, $\underline{SD}$ = 1.36) scores, $\underline{t}(20) = 2.73$, $\underline{p} = .011$. These results suggest that students' knowledge of the scientific method did increase over the course of the camp.

It is important to note that these gains did not result from didactic lectures in the classroom. Rather, students understanding resulted from engaging in practices alongside, and under the guidance, of the more knowledgable scientists—within the context of practice. One of the real benefits of SAC was that their was no separation between *doing* science and *learning* science, both occurred simultaneously with student practices informing learning and student learning informing practices.

Learning was also evaluated by examining differences between students' *application* of the scientific method both before the camp started and after it was completed. Students were asked to read and respond to a scenario and then apply the scientific method to the situation (see Appendix D—the left scenario served as the pretest and the right scenario served as the posttest). Interrater agreement was .91 for the pretest and .90 for posttest. Significant differences were not found between pretest ($\underline{M}$ = 1.24, $\underline{SD}$ = .76) and posttest ($\underline{M}$ = 1.66, $\underline{SD}$ = 1.39) scores, $\underline{t}(20) = 1.88$, $\underline{p} > .05$. These results suggest that students' ability to apply the scientific method did not increase over the course of the camp.

Although SAC did provide an environment in which students did science, SAC had the additional opportunity to support students' appreciation of the fundamentally *situated* nature of science; that is, the evolution and adaptability of the scientific method when applied within the context of varying situational demands. The fact that students did not improve their ability to apply the scientific method, coupled with interview and fieldnote data, suggests that students may *not* have developed an appreciation of the circumstantial (situated) nature of science (i.e., the use of the scientific method). This may have resulted from the fact that in SAC much of the problems were well-defined and it was the scientists, not students, who had the primary responsibility of defining both the problem and methods used in trying to understand the problem. Furthermore, the circumstantial nature of science was minimized, in that directors, teachers, and scientists wanted to provide as much of a tightly controlled experience as possible. Although this emphasis increased the possibility that students experienced applying *all* of the steps of the scientific method, it may have had the undesirable effect of preventing students from applying their own problem frames and appreciating how one adapts the scientific method to varying conditions. Alternative explanations for the non-significant results is that students had become fatigued with respect to filling out questionnaires, or that students did not find the question personally meaningful.

Learning was also evaluated using the authentic outcome measure of student presentations and pretest-posttest scores with respect to their understanding of the scientific method. Presentations in all groups were complex and scientific. They provided evidence of students skills in using the presentation software, understanding and implementing the scientific process, and the skills of presentation. Presentations included digitized pictures that the students had taken, as well as those already taken by the scientists. They also included self-produced graphs representing analyses of data, and in some cases illustrative drawings of students' work. All presentations were distributed across group members, with each apprentice having a particular set of slides and content for which he or she was responsible. However, students were involved with all aspect and when one of the students was absent on the day of the presentation, another student stood up in front of the audience (including a local television station) and delivered the missing section without the benefit of notes.

All student presentations had over a dozen slides, which illuminated the steps of the scientific method. A rubric was designed to analyze the completeness and quality of students' presentations (see Appendix C). With 100% rater agreement between the two raters, average scores were "10" out of "11" possible points. In fact, one of the raters who had a Master's degree in Physics continually commented on how impressed he was with the quality of the presentations. Student pride and ownership was evident both in terms of developing and in terms of giving their presentations. In fact, one of the parents told this researcher: "He has been talking about this presentation for the last three days. He is very proud and excited." All groups presented their data clearly and completely, with the only limitation being the lack of discussion regarding future implications.

Strengths of SAC

From the perspective of the students and the goals of the project directors, SAC was an overriding success. The SAC directors designed the camp with the intention that students would carry out authentic scientific practices using resources alongside experts. The apprenticeships were authentic, and engaged students in meaningful experiences in which they performed practices that were similar to those performed by scientists. All too often, students learning science are expected to appreciate content implicitly framed by the culture of schools, but whose value and function is explicitly attributed to the cultures of scientists (Brown et al., 1989). In these contexts, grades as opposed to authentic practice becomes the primary impetus for learning. In contrast, students at SAC did not receive grades and their was no separation between that which was learned, their reasons for learning, and the communities that valued and used the work they were doing; in other words, the ability to perform scientific practices defined what was learned and, additionally, served as the primary motivation for learning.

Students at SAC were clearly involved with doing, opposed to listening about, science. In fact, there were almost no occurrences of scientists simply lecturing to students. The discussions that took place between scientists and students almost always took place within the context of the laboratory and focused around issues emerging in relation to understanding/performing scientific practices. This was partially facilitated by the Apprenticeship Notebook, which served as a powerful support mechanism for promoting interaction and dialogue between students and the scientist, for reflecting on the practice, and as a medium for storing data, pictures, and field notes to be used in student presentations. The Apprentice Notebook, although designed for SAC, is a tool that could be incorporated within the context of schools. It could then be used as one means of introducing new students to the SAC scientists and maintaining contact with previous apprentices. Other students not participating in the camp could also view student-scientist discourse and gain insights on this community. In this manner the Apprentice Notebook could serve as a tool (or resource) allowing “outsider’s” to gain an “insider’s” perspective.

The scientists and teachers at SAC were well chosen and clearly committed to making the project work. The scientists were extremely willing to work with students—sharing their time, equipment, and resources so that students would have a meaningful experience. The teachers of SAC had many diverse roles, which required them to learn and adapt on the fly. These roles included serving as a bridge between students and the scientists, linking scientist and learner discourse and practice in a manner that was both sensitive to the real problem and to the abilities of students. Other useful facets of SAC included the fact that students were also free to select which apprenticeship they would participate in, possibly giving them a sense of ownership and matching personal interests with learning context. This was apparent as students participated in the community of scientific practice and used phrases like “our research,” “my data,” and “we tested.” Too often, student ownership and personal interests are minimized when students learn in the context of schools (Cordova & Lepper, 1996). Results of the flow measure suggest that the camp was personally engaging, with over 85% having an average score of “6” on a scale of 1-9. Further, 85-90% of students found the camp to be exciting and personally important, indicated by an average score of “6” on a scale of 1-9. Also, over 50% of students stated that their primary reason for participating in laboratory practices when beeped was to gather data for the experiment. These findings are impressive when one also notes that students significantly improved their understanding of the scientific method (a procedure not explicitly taught), and were able to develop quality, scientific presentations.

Strategies for Improving

According to current researchers in science education (Roth, 1996), educational psychology (Collins et al., 1989), and anthropology (Lave & Wenger, 1991), advantages of learning within the context of an apprenticeship environment include: (1) individuals are actively doing science; (2) learning occurs in a motivating environment where students are challenged and appreciate the uses of what they are learning; (3) learners are doing science “at the elbows” of more competent peers, teachers, or scientists; and (4) learners gain an appreciation of the situated nature of science. With respect to SAC, the active contexts in which the apprenticeships occurred and the high engagement levels of the students was previously discussed. However, the challenges of the apprentices, as well as points 3 and 4 above deserve further elaboration.

On average, results from the Flow measure did not indicate that there was a good match between the challenges of the apprenticeships and their abilities to complete the activities of the apprenticeships, with most reporting that the apprenticeships were not challenging enough. Although it is difficult to tell if students were over-exaggerating their abilities, one might explore putting more responsibilities and greater expectations on the apprentices in the coming years. This could include more reading at night as well as ownership in directing the experimental process; finding a balance in which the experimentation remains "authentic," yet more determined by the students is clearly not a simple issue.

Apprentices did learn about doing science under the expert guidance and mentoring of the scientists. In these contexts, learning was a seamless part of the environment with students actively engaged in practices to which learning was a result. Much of student time was also spent in the context of preparing their presentations. Students worked hard to produce, what they perceived to be or were told by their teacher was, a "scientific" presentation. In one student's words, "this is our only chance to share our data ad prove our experiment was a good one. Dr. Sehn [*the group's scientist*] will be there, and she is counting on us." However, there was less expert models for students scientific presentations. In the coming year, SAC could have more examples of scientific presentations in evidence, having students working side-by-side with scientists to produce these presentations, or using the Apprenticeship Notebook to provide examples of authentic presentations.

Lastly, apprentices could be given an opportunity to see more examples of applying the scientific method to other problems, helping them gain an appreciation for the situated nature of science as they uncover what changes and what remains the same. This could include the development of lessons building on notions of anchored instruction discussed by the Cognition and Technology Group at Vanderbilt (1990; 1993). In these lessons, students are immersed within a macrocontext or story in which a problem (the anchor) emerges and which students are expected to solve. These lessons could be specifically designed by the teachers, and may even include movies (e.g., The Young Sherlock Holmes) in which students would either evaluate the application of the scientific method or, in teacher-prepared lessons, actually be expected to apply the method to a realistic problem scenario.

Conclusion

SAC provided a new and exciting means for students to learn/participate in authentic science. Although apprenticeship learning is currently receiving much academic discussion, SAC actually established a context for this type of learning to occur. The resources, including personnel, equipment, laboratory time, planning, were extensive and a testimonial to the dedication of the project directors. It is clear that this investment helped to establish an extremely rich learning context. I praise the current work and judge the camp as truly successful. As scientists, educators, and researchers continue to understand learning in such rich apprenticeship situations, we can develop a more complete understanding of what it means to know and learn, and the types of environments that best promote authentic and transferable knowledge.

References

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. Educational Researcher, 18(1), 32-42.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. In L. B. Resnick (Ed.) *Knowing, learning and instruction: Essays in honor of Robert Glaser* (pp. 453-494). Hillsdale, NJ: LEA.

Cordova, D. I., & Lepper, M. R. (1996). Intrinsic motivation and the process of learning: Beneficial effects of contextualization, personalization, and choice. *Journal of Educational Psychology*, 88, 715-730.

Cognition and Technology Group at Vanderbilt. (1990). Anchored instruction and its relationship to situated cognition. *Educational Researcher*, 19, 2-10.

Cognition and Technology Group at Vanderbilt. (1993). Anchored Instruction and situated cognition revisited. *Educational Technology*, March Issue, 52-70.

Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience*. NY: Harper & Row.

Csikszentmihalyi, M., & LeFevre, J. (1989). Optimal experience in work and leisure. *Journal of Personality and Social Psychology*, 56, 815-822.

Guba, E. G., & Lincoln, Y. S. (1983). Epistemological and methodological bases of naturalistic inquiry. In G. F. Madaus, M. S. Scriven., and D. L. Stufflebeam (Eds.) *Evaluation models: Viewpoints on educational and human services evaluation* (pp. 311-334). Boston, MA: Kluwer-Nijhoff Publishing.

Latour, B. (1987). *Science in action: How to follow scientists and engineers through society.* Milton Keynes, England: Open University Press.

Latour, B., & Woolgar, S. (1979). *Laboratory life: The social construction of scientific facts.* Beverly Hills, CA: Sage.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* New York: Cambridge University Press.

Levin, J. A., Riel, M., Miyake, N., & Cohen, M. (1987). Education on the electronic frontier: Teleapprenticeships in globally distributed educational contexts. *Contemporary Educational Psychology*, 12, 254-260.

Knorr-Cetina, K. D. (1981). *The manufacture of knowledge: An essay on the constructivist and contextual nature of science*. Oxford, England: Pergamon.

Knorr-Cetina, K. D. (1992). The couch, the cathedral, and the laboratory. In A. Pickering (Ed.), *Science as practice and culture* (pp. 113-138). Chicago, IL: University of Chicago Press.

Papert, S. (1991). Situating constructionism. In I. Harel & S. Papert (Eds.), *Constructionism: Research reports and essays*, 1985-1990 (pp. 1-11). Norwood, NJ: Ablex.

Roth, W.-M. (1996). Knowledge diffusion in a grade 4-5 classroom during a unit of civil engineering: An analysis of a classroom community in terms of its changing resources and practices. *Cognition and Instruction*, 14, 170-220.

Roth, W.-M., & Bowen, G. M. (1996). Knowing and interacting: A study of culture, practices, and resources in a grade 8 open-inquiry science classroom guided by a cognitive apprenticeship metaphor. *Cognition and Instruction*, 13, 73-128.

Scriven, M. S. (1983). Evaluation methodologies. In G. F. Madaus, M. S. Scriven., and D. L. Stufflebeam (Eds.) *Evaluation models: Viewpoints on educational and human services evaluation* (pp. 229-260). Boston, MA: Kluwer-Nijhoff Publishing.

Solloway, E., Krajick, J. S., Blumenfeld, P. & Marx, R. (1996). Technological support for teachers transitioning to project-based science projects. In T. Koschmann (Ed.) *CSCL: Theory and practice* (pp. 269-306). Hillsdale, NJ: Lawrence Erlbaum Associates.

Stake, R. E. (1983). Program evaluation, particularly responsive evaluation. In G. F. Madaus, M. S. Scriven., and D. L. Stufflebeam (Eds.) *Evaluation models: Viewpoints on educational and human services evaluation* (pp. 287-310). Boston, MA: Kluwer-Nijhoff Publishing.