

Doing Science at the Elbows of Experts: Issues Related to the Science Apprenticeship Camp

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Received 19 July 1999; accepted 31 July 2000

Abstract: The purpose of this paper is to synthesize literature related to apprenticeship learning, the sociology of science, and K-12 science education to develop a set of characteristics for designing/evaluating participatory science learning experiences. Following this discussion, we further clarify and illuminate the value of these characteristics for science educators by using them as evaluative criteria for characterizing the experiences of 24 middle school learners who embarked on a 2-week long camp with “real” scientists engaged in “real” research. We also describe how middle school science teachers supported both reflection-in-practice and reflection-on-practice during the camp, and how an electronic notebook was also leveraged to support both types of reflection. Implications of these characteristics for science education more generally are discussed. © 2000 John Wiley & Sons, Inc. *J Res Sci Teach* 38: 70–102, 2001

Telling children how scientists do science does not necessarily lead to far-reaching changes in how children do science; indeed, it cannot, as long 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 have suggested that apprenticeship learning can provide a useful model for designing meaningful learning environments (Brown, Collins, & Duguid, 1989; Collins, Brown, & Newman, 1989). Rather than “telling” learners about a discipline, apprentices are immersed within a community in which they engage in practices “at the elbows” of more competent peers, experts, or “old-timers.” This is consistent with the recommendations of science educators who have advocated for *active learners doing scientific investigations*, instead

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Contract grant sponsor: School of Education, Indiana University (PROFFITT grant).

of passive learners receiving science instruction (American Association of Science, 1993; NRC, 1996; Ruopp, Gal, Drayton, & Pfister, 1993; Solloway, Krajcik, Blumenfeld, & Marx, 1996).

While an *investigation* is a comprehensive perspective focused on actively engaging learners in authentic scientific inquiry, apprenticeship goes one step further and situates this *investigation* in the context of the well-worn path of a particular scientist's research agenda. Here, the apprentice is under an expert's tutelage, using the scientist's lab and equipment, doing the science that contributes to the scientist's work, and doing the science in which the scientist (and potentially the apprentice) has a vested interest. This experience allows the learner to gain insights into the communal nature of science and may facilitate the learner's adoption of ways of perceiving and interacting with the world that are consistent with those of real scientists.

In its second year, the Science Apprenticeship Camp (SAC) was established on the time-honored principles associated with apprenticeship (intense relationships with a mentor, learning through doing authentic activity, using authentic tools, and learning as part of a community that values the practices). The SAC was designed to match middle school learners with scientists in the School of Science at a large Midwestern urban university. Participants worked in groups of four as they conducted scientific research and developed a scientific presentation under the expert mentorship of a practicing scientist and with the guidance of a middle school teacher. As a research project, the SAC created a unique opportunity to understand a learning context that embodied many of the characteristics of apprenticeships and that worked with the traditional clients of education (in this case middle school children), but in the environment where scientists carry out their practice. This is in contrast to the literature related to apprenticeships that has been framed either in making the classroom more apprenticeship-like or studying apprentices working for extended periods of time directly within a community. In contrast, at SAC, participants who were not qualified to become "real" scientist apprentices (these were eighth graders, not graduate students), but were immersed in a 2-week learning experience in which they worked with a scientist in his or her laboratory.

The purpose of this manuscript is to synthesize literature related to apprenticeship learning, the sociology of science, and K-12 science education to generate a set of characteristics that can guide educators in both the design and evaluation of participatory science learning experiences. The SAC provides a useful framework from which to apply these characteristics as evaluative criteria, thus, illuminating their value for researchers as well as instructional designers. More generally, this research has implications for the evaluation and construction of apprenticeship-like experiences, and for the design of classroom experiences that incorporate key characteristics of participatory science learning.

Theoretical Framework

Our evaluative framework cuts across various bodies of literature all of which have jointly informed our perspective of what characteristics constitute a rich environment for participatory science learning. More specifically, these characteristics are developed through examining the literature of apprenticeship, the sociology of science, and K-12 science education.

Apprenticeship Learning

Over the last century, we have seen formal schooling emerge as the predominant means of educating the young. One of the most common features of relegating education to schools is that "skills and knowledge have become abstracted from their uses in the world" (Collins et al.,

1989, p. 453). This movement toward the teaching of skills and knowledge as abstract entities is predicated on the belief that knowledge can be described in terms of specific objectives and imparted without recourse to the communities of practice who value it (such as scientists, mathematicians, and journalists who use the knowledge as part of their everyday activities), or the situations in which it is valued (see Anderson, Reder, & Simon, 1996). As a result, individuals learning in the context of the classroom are not exposed to the mature field of practice that uses the information being learned (e.g., communities of physicists or mathematicians), or to a cultural identity (e.g., becoming a scientist) other than that of a school-based student, or to those authentic situations in which becoming knowledgeable skillful is useful (e.g., researching cures for diseases). This process undermines the value of the content being learned and fosters a situation in which learners are expected to appreciate content implicitly framed by the culture of schools but whose use and value is explicitly attributed to the cultures outside of schools (i.e., mathematicians, writers, scientists, and so on) (Barab, 1999; Barab & Duffy, 2000; Brown et al., 1989).

Before education became the responsibility of schools, it was learning through participation in apprenticeship experiences that served as the most common means of learning (Lave, 1988, 1993; Lave & Wenger, 1991; Rogoff, 1990). Although the importance of learning by doing was central to discussions being advanced by Dewey (1938/1963), it is the anthropologist Jean Lave who has brought a renewed interest for apprenticeship learning to educators. Lave began her research on craft apprenticeship among the Vai and Gola tailors in Liberia over 25 years ago, and has developed and expanded her notions of apprenticeship learning in multiple contexts (Lave & Wenger).

Lave and Wenger (1991) used the term “communities of practice,” to capture the importance of activity in fusing individuals to communities, and of communities in reproducing individual practices. Within the context of these communities, learning is conceived as a trajectory in which a newcomer moves from *legitimate peripheral participant* to *core participant* within the community of practice. While participating in this trajectory, newcomers’ primary motivation for learning involves participating in *authentic activities* of the community and in doing so, the newcomer moves toward becoming more central to the community of practice. For example, in the case of the Vai and Gola tailors, apprentices learn concepts and skills fundamental to creating a suit in the context of participating in creating a suit as part of a community of tailors who create suits (Goody, 1989). Or, in the case of recovering alcoholics, alcoholics learn about concepts, practices, and skills central to staying sober, within a communal context of people trying to stay sober (Cain as cited in Lave & Wenger, 1991). In these apprenticeship situations, the learner is initially positioned within a community of practice as a legitimate peripheral participant, and it is participating effectively in this context and, in turn, becoming central to the community that serves as the prime motivation for learning.

Collins et al. (1989) introduced the idea of cognitive apprenticeship as one means of realizing the learning potential of apprenticeship in the cognitive domain. The notion of cognitive apprenticeship includes: (1) the development of learning contexts that model proficiency, (2) providing coaching and scaffolding as students become immersed in authentic activities, (3) slowly removing scaffolding as students develop competence, and (4) providing opportunity for independent practice so that students gain an appreciation of the use of domain-related principles across multiple contexts. Collins et al. are not simply advocating the application of principles successful in apprenticeships to the classroom. Instead, it is their intention to actually transform the culture of schools so that students: (a) can appreciate the purposes and uses of the knowledge they are learning, (b) will actively use knowledge as opposed to passively receiving it, and (c) will learn the varying conditions in which the knowledge can be used.

Lave (1993, 1997), comparing in-school versus out-of-school learning, has contrasted what she characterizes as “the culture of acquisition” with “understanding in practice,” or so-called “context-free” versus “context-embedded” notions of learning. Central to the former perspective is traditional schooling (Resnick, 1987), which is frequently “viewed as the institutional site for decontextualizing knowledge so that, abstracted, it may become general and hence generalizable, and therefore transferable to situations of use in the ‘real’ world” (Lave, 1997, p. 18). In this model, the instructional process involves “transmitting” decontextualized knowledge and skills to the learner who will acquire these as generalizable entities (Rogoff, 1990). In contrast:

Those interested in an apprenticeship approach, or more generally in theories of learning-in-practice, assume that processes of learning and understanding are socially and culturally constituted, and that what is to be learned is integrally implicated in the forms in which it is appropriated, so that, for example, *how* math is learned depends on its being *math* that is learned, and how math is learned in school depends on its being learned *there*. (Lave, 1997, pp. 18–19, italics in the original)

Fundamental to the apprenticeship perspective is the notion of *practice*: practice as an activity that embodies and builds understandings, as well as one that has the potential to wed an individual to a community which uses and values the particular practices being carried out (Barab et al., 1999). In fact, Lave (1997) argued that understanding *is* practice.

The emphasis in apprenticeship learning environments shifts from the memorization of decontextualized facts and skills described by the teacher or texts toward the appropriation of the socially contextualized practices of the community. Motivations change from obtaining grades on a test to addressing the authentic needs identified by the communities through the carrying out of “tried and true” practices. Therefore, while participating in these contexts, “apprentices learn to think, argue, act, and interact in increasingly knowledgeable ways, with people who do something well, by doing it with them as legitimate, peripheral participants” (Lave, 1997, p. 19).

The Practices of Scientists and How Scientists Come to Know Them

Historically, scientists were considered to make use of rational principles (the orderly process of the scientific method) that allowed them to discover objective “truths” in the world. More specifically, scientists employed the scientific method, which required applying special cognitive skills so that they may define and solve problems that occur in the natural world. However, recent advances in the sociology and philosophy of science have pointed toward a different image of scientists and their practices (Pickering, 1992). In some instances, sociologists have opened up the black box of science, making the transition from examining “ready-made science” to examining “science-in-the-making” (Latour, 1987). When examining science in the making, sociologists have found that the work of scientists is one that is socially constructed and fundamentally situated—not objectively applied (Latour, 1987, 1993; Traweek, 1988). Scientists often develop situationally dependent procedures, with projects taking shape because of contextually available equipment often in relation to unexpected findings (Knorr-Cetina, 1981; Latour & Woolgar, 1979), all of which set the stage for emergent facts that harden as scientists construct arguments so that they may convince their peers. Further, for the scientist, doing science frequently involves functioning as part of a community, having access to community-developed instruments (frequently in scientific laboratories), addressing issues of importance to the scientific community, and convincing colleagues of the legitimacy of findings through conferences and manuscripts (Pickering).

Although the work of convincing peers may occur outside the research site (laboratory or field-based site), for many scientists these places provide the primary source of authority and legitimacy in their production of papers and other “texts” (Latour, 1987; Latour & Woolgar, 1979; Traweeck, 1988). Knorr-Cetina (1992) argued that the laboratory is more than the physical space where experiments are carried out:

... the laboratory is itself an important agent of scientific development. [It is] ... the locus of mechanisms and processes which can be taken to account for the success of science.
(p. 116)

Latour (1987) described the laboratory as “the place where scientists work,” and suggested that it is “powerful enough to define reality” (pp. 64, 93). For many scientists, laboratories and the instruments they contain are as central to science as the “reality” and “truths” that are created and dismantled there. For scientists working in the field, their research sites have the same almost sacred status.

All too frequently, however, it is only the hardened facts (results of the making of science) that K-12 science learners ever see, creating the illusion of science as a collection of pre-established facts to be memorized (Linn & Songer, 1993; Richmond & Kurth, 1998). The K-12 learners never see the collection of assembled allies and tools (scientific instruments, complex inscriptions, trail of texts, trials of strength, social networks) that are fundamental to the making of science, giving them the impression that science is cut and dried, black and white. Further, K-12 learners are not exposed to the rich communities of scientific practice nor the laboratories in which they work. One of the central design challenges of the SAC was how to provide middle school students engaging opportunities to participate in learning/doing science that were authentic to themselves and real-world scientists, and that occurred in those places where scientists do science.

Engaging K-12 Students in Doing Science

For the last decade we have seen commissions, committees, and task forces call for a “new approach” to science education in American K-12 schools. Central to this approach is the importance of authenticity and having students *doing* science (American Association for the Advancement of Science, 1993; Gore, 1992; National Research Council, 1996). Partly in response to these callings, and partly in response to the more general movement of situated cognition and apprenticeship learning (Brown et al., 1989; Collins et al., 1989), we are witnessing a pedagogical shift toward establishing “authentic” science experiences (Krajcik et al., 1998; Means, 1998; Roth, 1998; Roupp et al., 1993). Here, we define authenticity as the quality of having correspondence to the world of scientists, and suggest that this can be achieved through “simulation” or “participation” models for establishing authentic learning environments (Barab, Squire, & Dueber, 2000).

The *simulation* model is predicated on the assumption that the classroom environment (both in terms of the goals, practices, instruments, and peer relationships) should be made as similar to communities of practice outside of school as possible. However, unlike the highly constrained environments (exacting procedural requirements, qualifications, and goals) of doing science outside of schools, in these environments (what Senge, 1994, called “practice fields”), students are able to take ownership and engage in all aspects of the problem-solving process (Barab & Duffy, 2000). It is important to note that the term simulation is not meant to signify that students are simulating doing science, for the students in these environments are frequently doing the

practices of science. Instead, this term refers to pedagogical design intended to support students in reproducing the “doing science” practices of real-world practitioners, but in the context of classroom and as a part of the culture of schools—a simulated “community of scientists.”

Many educators have designed classroom environments so that students engage in the types of thinking and problem solving that real-world practitioners do outside of schools (Barab, Hay, Barnett, & Keating, in press; Barab, Hay, Barnett, & Squire, in press; Kass & MacDonald, 1999; Koschmann, 1996; Krajcik et al., 1998; Lampert, 1990; Savery & Duffy, 1996; Schoenfeld, 1996). Roth (1996, 1998; Roth & Bowen, 1995), for example, has been developing and researching science learning in which the problems were framed by students, based on general goals that they set themselves and around phenomena that they identified as interesting. In one project, elementary students participating in a 13-week-long unit on civil engineering constructed bridges, using toothpicks, that had to have a minimum span of 30 cm (Roth, 1996). More generally, the design was based on teachers’ need to improve their own teaching and on students’ needs for more student-centered, hands-on approaches to doing science, as identified in a school survey. The curriculum was developed to provide students with a practical application of science, in which they engaged in an open-ended engineering problem in a collaborative manner. Central to Roth’s focus is engaging students in the full range of the science process, doing the same types of activities as real scientists, but, and consistent with other “practice fields,” in the context of the classroom with problems they can address.

In contrast to the simulation model in which educators support the development of environments that support students in doing science as part of the classroom activities, the *participation* model (and this research) emphasizes engaging students in doing science “at the elbows” of scientists, in their laboratories and at their field sites. The participation model of authenticity is predicated on the assumption that the authenticity of a learning activity is dependent upon the extent to which learners participate directly in the ongoing practices of a community. Instead of participating in a “practice field” with the expectation that students will later apply what they have learned, the participation model positions students in activities that have direct meaning and are of direct value to a community outside of schools. This is not to imply that there are clear divisions between the two models for establishing “authentic” science learning; however, we have found it useful to reflect on education initiatives designed to promote authentic science experiences in terms of simulation or participation models, while acknowledging that many learning environments have characteristics of both models.

Although there is a long tradition of work study in the industrial arts, participation models are difficult to design in science school contexts because they require that students leave the classroom environment and participate directly with real scientists as part of their communities. For example, Traweek (1988) has suggested that in the physics communities that she studied, apprentices spent years doing the work of expert scientists, having little ownership of the practices or opportunity to engage in authentic scientific discourse. Given the challenges of such a model, and the fact that few students will be willing to take 6–10 years apprenticing in a laboratory before being able to direct their own learning process, educators have been exploring other models in which students have a more active role. One means of establishing participatory authenticity is to foster student–scientist partnerships (SSPs) as part of the educational experience of K-12 science students. Central to the SSP is learning/doing science through hands-on, minds-on activities in which students have an opportunity to participate in a project that is real and important to both students and scientists (Lawless & Rock, 1998; Means, 1998). Several examples of such partnerships include the Global Learning and Observations to Benefit the Environment (GLOBE) project (Finarelli, 1998; Rock & Lawless, 1997), the Global Rivers

Environmental Education Network (GREEN) project (Donahue, Lewis, Prci, & Schmidt, 1998), and Forest Watch (Rock & Lauten, 1996).

The GLOBE program is a hands-on international environmental science and education project designed to be used in K-12 classrooms. Currently, GLOBE involves students in almost 5,000 schools in over 60 countries around the world who take environmental measurements chosen by the scientific community to provide useful data regarding the dynamics of the Earth's environment (Finarelli, 1998). Central to the conception of the GLOBE program is that it is:

... a science and education program (as opposed to a science education program) that would promote the use of student-collected data by members of the scientific research community. The intent was to give equal weight to the goals of science (add to the knowledge and databases of earth science) and those of education (increase students' and teachers' awareness of environmental issues and students' knowledge and skills in science and related mathematics). (Means, 1998, pp. 98–99)

Students engage in collecting real data related to issues such as air temperature, clouds, precipitation, land cover, soil characterization, and tree growth, to name a few. The data are “authentic” in that students upload the data to be analyzed by actual scientists in order to address real-world questions. In addition to scientists using this information, the GLOBE website makes the data available to other schools, in which students can review and comment on other students' data (see Means, 1998, for a snapshot of a GLOBE class in action).

In general, SSPs and simulation models allow students to participate in the practices of scientists, and provide an exciting and innovative means for improving the science education of K-12 students. However, in making the practices and science accessible to the K-12 learner, these environments frequently simplify the science and narrow the scope of the entire scientific enterprise to a select, few practices based on accessibility. For example, both the GREEN and the GLOBE SSP projects have worked with scientists to focus on the practices of data collection and to develop protocols and equipment that are “as simple and straightforward as possible ... [providing] scientific instruments, methodologies, and learning activities suitable to the skill levels of the students ... and [providing] data entry forms that are systematic and easy to understand” (Lawless & Rock, 1998, p. 13). However, we argue that when educators are discussing “situating” science practices for K-12 learners, they are not simply having students do what experts do but in ways students can do them.

Simulation approaches are valuable but eliminate some key elements of what occurs when students *do science where* scientists do science; this includes working in laboratories or at field sites with complex and expensive equipment, as part of a team, and toward goals that advance and are recognized as meaningful by the scientific community. Participation models are valuable but not necessarily practical. SSPs are practical but much of the richness is lost when students participate in simplified science in the classroom or partial, but simplified science through participation with a community of practice. However, connecting students directly with real-world scientists actually working at their field sites, especially laboratories, has exciting educational possibilities for getting kids excited about doing science (Richmond, 1999). In sum, we view both simulation and participation models as having useful characteristics that can inform the design of environments to support students doing/learning science.

Summary: Key Characteristics of Participatory Science Learning

If we as educators are going to design authentic environments that support students in doing science, then we must establish learning contexts that are similar to environments in which

scientists do their work. For example, Richmond and Kurth (1998) had high school students participate in a 7-week apprenticeship with scientists in their laboratories. When students work directly in the scientist's laboratory they have access to diverse tools and to multiple opportunities for feedback about their appropriate use. Additionally, as students moved from the "periphery of the scientific community toward the center, their ideas about what it means to do science grew more complex, more realistic, and richer" (Richmond & Kurth p. 693).

More specifically, the above discussion suggests that apprenticeship learning situations and the notion of learning as participation in authentic contexts have much to offer to formal schooling situations. However, and as discussed above, apprenticeship as a model learning environment also has limitations in terms of providing practical opportunities for engaging students, who do not intend to invest a lifetime of work in the field, in robust science learning practices. Therefore, we have found it useful to expand our thinking and to synthesize the above literature related to apprenticeship learning, the sociology of science, and K-12 science education into a set of design characteristics for developing robust science learning experiences. It is our contention that these elements, to varying degrees, can provide useful guideposts for the design and evaluation of environments intended to support the learning/doing of science.

The key characteristics of participatory science learning that we are advocating are listed in Table 1. The goal of participatory learning environments is to engage learners in authentic science. While it is possible to engage in authentic practices in a rote fashion, the first characteristic is intended to communicate the need to have an active student who is *doing* practices in

Table 1

Key learning characteristics for engaging students in participatory science learning contrasted with characteristics frequently discussed as dominating formal schooling¹ environments

Formal Schooling	Participatory Science Learning
1. Learners <i>listen about</i> the "doings" of others to receive a grade.	1. Learners <i>do</i> domain-related <i>practices</i> to address domain-related dilemmas.
2. Scientific and technological knowledge/practice are <i>presented</i> as hardened facts.	2. Scientific and technological knowledge/practice are <i>situationally constructed</i> and <i>socially negotiated</i> .
3. Learning occurs at the pages of <i>textbooks</i> and the <i>mouths of teachers</i> .	3. Learning is participatory, occurring "at the elbows" of <i>more knowledgeable others</i> , including teachers, scientists, and peers.
4. The <i>textbooks</i> and <i>teachers</i> "own" the problems, which have classroom (not necessarily real-world) application.	4. Practices and outcomes are <i>authentic</i> to and <i>owned</i> by the learner and the community of practice, and are in response to real-world needs.
5. Participants <i>hear about</i> scientific communities of practice, and develop identities as students, jocks, etc.	5. Participants become <i>a part of</i> (developing an <i>identity</i> as a member of) a community of practice.
6. Little emphasis on <i>reflection-in-action</i> and <i>reflection-on-action</i> .	6. Formal opportunity and support for both. <i>reflection-in-action</i> and <i>reflection-on-action</i> .

Note: We have worked with numerous teachers who have created a classroom microculture that endorses more of the Participatory Science Learning characteristics than those listed under Formal Schooling. Therefore, to some degree, we present the extremes as benchmarks for comparison, allowing us to more clearly illuminate the characteristics being highlighted in this paper. However, it is also important to mention that this comparison is not totally unrepresentative of the types of activity frequently characterizing K-12 classrooms that we have observed or that others have described as dominating K-12 classrooms (Resnick, 1987).

response to domain-related dilemmas—not grade or performance dilemmas or mechanistic repetition (Lave, 1997; Schoenfeld, 1996). In other words, the learner’s goals and motivations for doing the practice are consistent with those reasons that motivate real-world practitioners to carry out the practices. The second characteristic of participatory science learning is that students are engaged in the “making-of-science,” and not simply memorizing a set of ready-made knowledge—someone else’s findings (Latour, 1987).

Third, students engaged in participatory science learning work with others who have less similar and more experience and expertise than themselves, supporting the emergence of collaborative group work, not simply individuals working in isolation (Resnick, 1987). Fourth, while working in these environments learners are not simply completing the task for some school reward (e.g., grades) but are working toward addressing a real-world need that they have identified as important to themselves and the world writ large (Savery & Duffy, 1996). Central to characteristic five is the notion that learners working in participatory science learning environments are not simply hearing about the work of authentic communities but are given the opportunity to have overlapping relations, at some level, with real-world practitioners.

Although not directly discussed above, in addition to the first five characteristics we have found that, from an educational standpoint, it is essential that learners also have opportunity for both reflection-in-action and reflection-on-action (Schön, 1987). Whereas the former refers to reflection within the activity, the latter refers to the importance of having an opportunity to reflect following the activity. Schön demonstrated the importance of both types of reflection to the learning process. By incorporating reflection into the learning experiences, teachers are able to fully leverage apprenticeship-like learning experiences by further taking advantage of the school climate, which facilitates reflective practices. In clarifying the six characteristics of participatory science learning that we are advocating, we also compare these with those characteristics frequently observed as typical of more formal schooling situations (Brown et al., 1989; Lave, 1997; Resnick, 1987; Roth, 1998). Although clearly not present in all formal learning environments, they occur frequently enough to serve as an useful and meaningful contrast to the principles being advanced in this discussion.

Now that we have developed a list of key characteristics of participatory science learning, we will use them as evaluative criteria to examine the Science Apprenticeship Camp (SAC). It is important to note that while the second author (KH) was a designer of the SAC, while the first author (SB) was hired to evaluate the camp. The characteristics discussed in this paper, while consistent with the second author’s thinking when the camp was designed, were not explicitly formalized as evaluative criteria until after the camp was developed. Therefore, although the criteria might serve as design guidelines, it is as evaluative criteria that they are being applied in this paper. As evaluative criteria, these characteristics clearly informed discussions among the researchers, the analysis of the data, and the findings in this paper are explicitly organized in terms of each of the six characteristics.

The SAC incorporated aspects of both the simulation (preparing a presentation under the mentorship of classroom teachers) and participation model (doing science under the mentorship of practicing scientists), with an emphasis on the importance of actually working alongside scientists. Unlike the SSPs discussed above, a primary goal of the SAC was to create an opportunity for middle school students to work directly with scientists in their laboratory, using their instruments, and addressing outcomes that were a part of the scientists’ ongoing research program. The challenge was to maintain authenticity for both the scientist and the student without simplifying the laboratory, the equipment, the research questions, the experience, and without requiring each student to participate in the 10-plus-year trajectory of becoming a real

scientist. In accomplishing this, instead of starting with the classroom and making it more like an apprenticeship, the SAC begins with the laboratory and creates apprenticeship opportunities for learners who, otherwise, would not have had access to these types of experiences—they are eighth graders, not graduate students.

Methodology

Data Collection and Interpretation

For this report, naturalistic data are reported to gain a holistic vision of SAC (Guba & Lincoln, 1983; Scriven, 1983; Stake, 1983). An evaluator was present for all 10 days of the camp, and for the final presentation day. In addition to the data directly collected by the evaluator, two other researchers collected field notes, videotaped learners while working in the laboratory, and conducted interviews. The interviews included both semi-structured interviews using questions framed in terms of the Table 1 criteria, and more informal interviews based on the interactions observed in the laboratory on the particular day the interviews were being carried out. We also examined “postings” by the middle school students, teachers, and scientists in the electronic notebook discussed below.

In particular, data collection and this reporting of the research are directly focused on the characteristics presented in Table 1. As such, we acknowledge that our hypotheses were not solely emergent from the data as is the case with much naturalistic research (Glaser & Strauss, 1967; Strauss & Corbin, 1990). Instead, we focused data collection and analysis efforts around the pre-defined characteristics identified as important to the learning of science and summarized in Table 1. However, the interpretations of the data with respect to these issues were emergent and the data analyses were consistent with the constant-comparison method, in which the researcher continually shifts back and forth between the data and their interpretations (Glaser & Strauss).

In daily meetings among the researchers, field notes, learner interviews, and teacher observations were discussed so as to generate assertions used to direct data collection efforts the following day. As data were collected, interpretations were derived and then fed back into future collection efforts, providing “theoretical sensitivity” (Schatzman & Strauss, 1973). In this manner, interpretations were continually being refined during fieldwork, group meetings, and increasingly focused data collection and analyses. To increase trustworthiness and credibility, interpretations were triangulated on data collected through multiple methods, including interviews, fieldnotes, videotape analyses, learner debriefing, and referential materials (Lincoln & Guba, 1985).

Participants

Twenty-four middle school participants attended the SAC and selected one of six partnerships in which they worked collaboratively with three other students, one science teacher, and one practicing mentor scientist. There were 11 girls and 13 boys who came from 13 different schools. Participants were from varying socioeconomic backgrounds and were of varying academic ability. Based on a general letter of solicitation, all participants submitted an essay stating which group they wished to participate in and why. Additionally, six middle school science teachers (3 female and 3 male) who all had been teaching for at least 5 years were selected. These teachers applied either because one of the directors had worked with them before or because they had read the solicitation for student essays and had sent in a resume and letter

expressing their own interest. Based on the response to a letter requesting participation from the associate dean of the College of Arts and Sciences, six scientists (1 female and 5 male) agreed to participate in the camp. The teachers participated in a 2-day workshop before the camp to learn the technology and met on the second day with the scientist they would work with during the camp—collaboratively they worked through learning challenges and discussed the science investigations that participants would pursue during the camp. The scientists also wrote an overview description of their research and posted it in the electronic notebook, which many students read over the Internet before they arrived at the camp.

The Science Apprenticeship Camp

Description of Partnerships

The 2-week camp consisted of six different participatory science contexts organized around particular investigations. In this discussion, however, we will draw our interpretations from data with respect to four groups in which we had the most complete datasets—the other two groups were observed by an undergraduate student who had little research experience. Drawing on the scientists' postings as displayed in the electronic notebook, the following descriptions of each apprenticeship are offered:

- Long-term Consequences of Drug Exposure During Development (Methamphetamine Group)—During this project, participants studied adult rats that were exposed to methamphetamine during the first week of life. In particular, apprentices watched as scientists injected rats with methamphetamine and then observed the behavior of the rats to determine if their previous exposure to methamphetamine during development changed the rat's sensitivity to the drug in adulthood. Learners calculated drug doses, balanced scales, collected data, set up data files on the computer, collected behavior data, and interpreted data.
- Topical studies Using Anti-Juvenile Hormone Agents (Insecticide Group)—During this project, participants analyzed the effects of various insecticides for inhibiting the growth of the Juvenile Hormone in moths. In particular, participants applied topical assays of the treatment insecticide or controls to worm larvae and then observed the differences in growth of the worms. Learners performed dissections, weighed worms, inputted data to a computer, and analyzed and interpreted data.
- "Seeing" Through Bat's Ears (Sonar Group)—During this project, participants 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. Specifically, they used mathematical visualization tools to speculate on how bats use bisonar signals for navigation, communication, and hunting insects. Learners used high-end computer workstations and advanced modeling/visualization software to represent, analyze, and interpret echo signals.
- Building the Gateway to Ultra-high Speed Communications and Computing (Laser Group)—During this project, participants 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-ended questions. They then engaged in a series of experiments using a machine that measured the intensity of laser signals to find the answers to some of these questions.

Apprenticeship Notebook

A common practice of scientists is the maintenance of a research notebook in which they keep track of their field notes, issues for further investigation, data collection techniques, etc. The apprenticeship notebook was developed as a scaffolding mechanism to facilitate this process, and did so in a public manner that allowed participants to more easily collaborate with each other and with the scientists. In this way, the Apprentice's Notebook is a novel approach to the use of technology for supporting apprenticeship learning. Rather than using technology to overcome issues of disparate geographic distances as is done in teleapprenticeship projects like GLOBE (distances were not our problem because apprentices came to the labs) or in Levin, Riel, Miyake, and Cohen (1987), we focused the technology on supporting participants' enculturation processes (recording important data, communicating with scientists, having access to background information, gathering additional information). To accomplish this we used an emerging framework from business and industry called the electronic performance support system (EPSS).

An EPSS is the electronic infrastructure that captures, stores, and distributes individual and corporate knowledge assets throughout an organization, to enable individuals to achieve required levels of performance in the fastest possible time and with a minimum of support from other people. (Raybould, 1995, p. 10)

We modified the EPSS notion to our science learning environment. The electronic notebook we designed stored basic science content related to the particular scientist that participants were working with, captured student experiences, distributed knowledge between and among groups, enabled participants opportunities to interact with scientists in a less threatening asynchronous fashion, and supported the participants as they created their final presentation of their research. Our modified definition of EPSS focuses on multi-faceted support of the concerned (engaged, dilemma-driven) nature of learning that participants faced as they worked with the mentor scientists.

The Apprentice's Notebook is an HTML-based EPSS that has five components: Overview, Schedule, Science Chat, Links, and Notebook (see Hay & Barab, 1998 for a full discussion and analysis of this tool). The *Overview* is where scientists posted background information that participants could read before the camp started, and during the camp when they were not working in the laboratory with the scientist. Teachers and participants also reviewed this section on the first day before they visited the scientist's laboratory, lessening the need for lecturing from the scientist. The *Schedule* was simply an electronic calendar in which all parties involved could view the planned activities for the 2-week camp. The *Science Chat* consists of asynchronous and synchronous communication spaces set up for each group, used by the participants to talk among themselves, to their teachers, and to the scientists. The *Links* is a collection of information resources from the scientist, including lab planning guides and instructional resources. The *Notebook* was an on-line database for the participants to collect their ideas, scientific data, illustrations, digital images, and reflections on their work in the labs.

Camp Organization

After the introduction day, the proceeding 6 days typically began with a brief discussion as groups (consisting of four participants and one classroom teacher) met to talk about their expectations during their time with the scientists. Camp participants and their teacher then spent 2 hrs directly working with the scientist in his/her laboratory. During this time, the participants 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, the learners had lunch as a group.

The second half of the day consisted of the separate groups meeting to discuss data, followed by an approximately 2-hour period in which participants used the electronic notebook designed for this study. The focus during this time was to reflect on their laboratory experiences, to clarify confusions, learn other skills, and to prepare a presentation for the final day. Using the electronic notebook, participants 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 scientists' notes, and worked on their final presentations. A portion of this time was used to teach the participants how to use presentation software, prepare presentations, speak publicly, search the WWW effectively, and pose and respond to scientists' questions electronically.

Days 8 and 9 were designed so that the participants could work on the completion of their presentations. During this period, they organized data recorded in the Apprenticeship Notebook, prepared their presentations, rehearsed delivery, and met with the scientists to verify data interpretations/explanations. 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.

Emergent Group Structures

Three types of group structures were observed at SAC: (1) the "Science Communities," which had already formed around the six scientific communities of practice (biologists, computer scientists, etc.) and had existed previous to the onset of SAC; (2) the "Learner Research Group," which was the group of four students and the middle school teacher; and (3) the "SAC Group," which formed around the overall camp context. It was apparent from interviews, field notes, and videotapes that the participants, although at different times and to varying degrees, were motivated to participate in all three groups. However, although only comprising just over 20% of the scheduled time of SAC, the Science Communities were unmistakably the center of all activities at SAC. It was within the context of the Science Communities that the learners did science; they used lab equipment, and did experiments involving collecting, analyzing, and interpreting data. This is the community in which the participants were apprentices. This community served as the focal point for the rest of the camp, with the other two structures forming around this core (see Figure 1).

The practicing scientists, their laboratories, resources, methods, research questions, and practices represented (stood in for) the entire *Science Community*. They were the conduits through which campers came into contact with the community of practice. The reliance of a one-person representation of the community has some limitations on the participants' understanding of the broader community issues, debates, history, and controversies. However, the community presence was ever apparent. Through the overt connections such as a scientist alluding to this broader community ("I have a presentation at a conference next week where I will be presenting this data"), to more embedded connections such as the Drug Enforcement Agency's logs of the controlled substance (methamphetamine), to the available instruments in the lab, to the scientific rigor with which all activities were carried out, to the data analysis software, or to the scientific articles in the laboratories. All these experiences are influenced, to a large extent derived, and disseminated by the community. In many ways, these connections are just as profound a representation of the community as is the scientist.

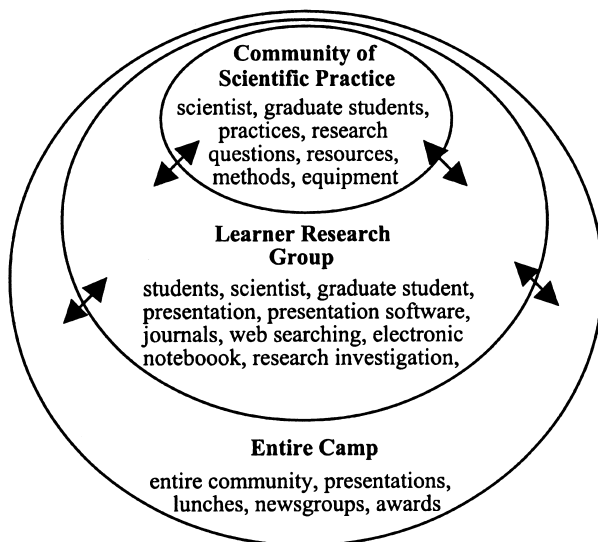


Figure 1. Three different nested learning structures (including associated people, tools, resources, and activities) occurring at SAC.

One of the limitations of SAC was that beyond the collaborating scientist and the indicators mentioned above, the scientific community was not physically a part of SAC. This limitation was especially evident in the creation of students' final presentations. It was at this point where the broader community traditionally impacts the scientist through peer review and conferences. This larger community is fundamental, and in some cases, determines the resources/practices that are being used/applied in each scientist's laboratory. However, in SAC the connection to the community of practice was almost completely ignored by the directors of SAC who took primary responsibility for evaluating the quality of student presentations—turning it into an academic not authentic exercise except when the scientists intervened.

The second group structure was the *Learner Research Group*, which encompassed and was based on the first community. These groups, composed of three to four participants and led by a middle school science teacher, were where the participants spent 75% of the camp time. When they were not apprenticing with the mentor scientist, they were surfing the WWW for information on their project, planning for their final presentation, or examining the data they collected during that day. This structure was dependent upon, but not essential to, the science community.

The other group was the *SAC Group*. This group also encompassed (and formed around) the former two structures. The participants spent approximately 5% of their time exclusively participating in this learning group. This time was spent in three ways. The first was through formal presentations on a number of how-to sessions (WWW, PowerPoint, Making Presentations, etc.). The second included informal discussions that happened during breaks and at lunches. The third was their formal presentation on the last day, where the participants shared their individual projects with all campers.

Findings and Discussion

The results of this study—the findings and data selections supporting them—are presented in six sections organized around each issue discussed above (see Table 1).

Did the Participants Engage in Science Practices to Address Domain-Related Dilemmas?

In general, the participants engaged in *doing* the practices of science. One of the real benefits of SAC was that there was no separation between *doing* science and *learning* science, both occurred simultaneously with practices informing learning and learning informing practices. The participants engaged in practices alongside, and under the guidance, of the more knowledgeable scientists—within the context of practice. There were almost no occurrences of scientists simply lecturing to participants. The discussions that took place between the scientists and learners almost always took place within the context of the laboratory and focused on issues emerging in relation to understanding/doing scientific practices. In this section we highlight the laboratory and presentation practices, primarily with respect to the Methamphetamine and the Insecticide Groups.

As stated previously, the Methamphetamine Group investigated how the stimulant drug (methamphetamine) exposure during development changed the rats' sensitivity to the drug in adulthood. The Insecticide Group investigated the effectiveness of various insecticides at inhibiting the growth of the Juvenile Hormone in moths. There were three types of practices central to both groups' work in the laboratory: Treatment Preparation Practices, Data Collection Practices, and Data Analysis Practices.

The *Treatment Preparation* practices involved the mixing of the methamphetamine dosage for that day's behavioral study or the preparation of the topical assays in the case of the Insecticide Group. In both groups this practice was extremely exacting because of the importance of the dosage to the experiment and, for the Methamphetamine Group, the fact that methamphetamine is a controlled substance. However, even in the context of an exacting practice, the contextualized and negotiated aspects of this practice were present. The scientist highlighted this when she stated, "Now this dose of methamphetamine is based on my prior readings and I have not conducted this experiment before." The practices included using a balance to measure quantities of methamphetamine (less than 1 g) or anti-juvenile hormone agents, logging the amount used for the experiment, calculating how much water to use, measuring the water, mixing the solution with a centrifuge, weighing the rats or the moth larvae, calculating the dosage for each subject, and finally injecting the rats with the methamphetamine¹ or applying the topical assay of the treatment insecticide and controls. Initially, the scientist modeled the practices while the participants observed. However, by the end of the first day, the participants in both groups were being coached through the practices, and by the end of the first week much of the scaffolding had been removed as apprentices engaged in the practices independently.

The *Data Collection* practices involved the participants' collection of both subjective and objective data. After the scientist injected the rats with methamphetamine, apprentices would engage in subjective data collection practices involving the coding of visual surveys of rat behavior for 1 out of every 5 min for an hour. The objective data collection practices were conducted at the same time and involved two lasers crossing the clear plastic cages. A computer recorded when the rats walked in front of the lasers as an indication of relative movement (i.e., a rat that is running from side to side constantly would register high values for this measure). Finally, the participants in the Methamphetamine Group collected and organized the coding

sheets and computer printouts to form a data notebook that contained all their data. Participants in the Insecticide Group were responsible for weighing the moth larvae each morning, recording these weights, and entering them in the computer.

The *Data Analysis* practices were conducted on the final 2 days of the participants' work with the scientists, and involved entering data from the notebook into the data analysis software package to test their hypothesis. The participants looked for a number of relationships and developed a number of graphs that showed their results. Scientists in both groups would push the participants to draw inferences from the data. For example, in the case of the Insecticide Group, they had one moth larvae that, in spite of being in the experimental group, continued to grow as did the control larvae. Rather than offering an explanation, the scientist pushed the students to explain the observation:

Dr. P.: What does this mean? [*Pointing to the graph in which one of the larvae in the experimental condition was as big as the control larvae*]

Mary: That is the one that didn't stop growing.

Chris: She [*the scientist*] knows that. She means what does it mean.

Mary: We already said it could be somehow the solution wasn't applied properly or it was resistant to the stuff.

James: Dr. P., have you had this happen before?

Dr. P.: Yes, we call this an outlier and we don't yet know why it occurred.

Chris: If we know, we might learn a lot about how to make the insecticide better.

James: We would have to cut open all the ones that didn't change and figure out why.

Because of Mary's comment that she thought they had done something wrong, the scientist initiated a rich discussion (not included here for space reasons) about the importance of noticing and researching unexpected findings when doing science. It is significant to note that this is in contrast to typical school experiences in which unexpected findings are usually attributed to student error, with science being portrayed as a predictable world (Richmond & Kurth, 1998).

Later the group analyzed the data using a T-test and found that there were significant differences anyway.

Mary: How come there were still differences with this big one? It wasn't smaller than the other water [*control*] ones.

Chris: That is how statistics work, they take averages.

Dr. P.: It is not that they use averages, they work on probabilities and confidence intervals.

The group then engaged in a discussion about probabilities, which the participants incorporated into their final presentations. With respect to their presentations, the participants debated and then decided to show the graph with the one outlier in it. In their presentation, they explained why this outlier is important, but also why the statistics, "based on probabilities," showed differences anyway (see Figure 2c).

The *Presentation* practices involved all the constructionist practices of planning, organizing content, developing scripts, creating visuals, downloading graphics from the WWW, importing digital images taken in the labs, constructing the presentation, editing the presentation, rehearsing the presentation, and finally giving the presentation. The rehearsal practice was the most interesting practice to report on. First, as mentioned in previous sections, the presentation was seen as the goal from the perspective of one of the camp directors. While all the Presentation practices were heavily influenced by this pressure from the director, none were so obviously influenced as the rehearsal practices. As typical of novice presenters, all of the rehearsals ran

A

PROJECT PURPOSE

The Tobacco Hornworm is one of the most destructive insects to the tobacco plant. The purpose of this project is to analyze potential safe insecticides that will cause the Tobacco Hornworm to go through metamorphosis and die.

b

The Effects of Vinyl Sulfoxide

Control Group

1 2 3 4 5

Vinyl Sulfoxide Group

1 2 3 4 5

c

Comparison Between the Control and the Vinyl Sulfoxide Groups

Control Group **Vinyl Sulfoxide Group**

d

Hypothesis/Conclusion

Hypothesis: If anti-juvenile hormone agents are applied to the larvae it will go through metamorphosis prematurely and die.

Conclusion: When Vinyl Sulfoxide was applied it eventually killed the insect however when Farnesol was applied it did not seem to have an effect until the Farnesol was applied at the correct time.

Figure 2. Screenshots of four slides from the insecticide group's presentation.

longer than their 15-minute time allotment. One director was fairly harsh on both the participants and their teachers for this error because the Presentation Day was his clear focus. Instead of focusing on the director's seemingly arbitrary restriction on the length of their presentation, one scientist who attended the rehearsal suggested that a more authentic constraint is the length of time allocated by the scientific community of practice—practices that regularly restrict scholarly presentations to 15–30 min during a national conference. While this perspective was enforced by the Insecticide group, no mention of more authentic constraints was made in the other groups.

The presentations served as one indicator of whether the participants understood the scientific process occurring in their laboratory. They provided evidence of the participants' understanding of the scientific content, the situated nature of science, and of the practices they had carried out (see Figure 2 for a subset of slides from the Insecticide Group's presentation). For example, in Figure 2 the sophistication of the scientific content and the students' ability to represent it is evident. Briefly, in Slide A, we see a clear statement of purpose that was written by the students. As the presentation continues, we see in Slide B a picture the students took of the worms they treated and of the controls, and also the graph (Slide C) they generated to show the differences in growth of the worms treated with the growth inhibitor with those assigned to

the control group. This presentation included discussion about the one outlier whose growth was not inhibited from the treatment: “We are not sure why it didn’t work. One hypothesis is that the treatment was not put on properly, but another one is that certain worms are resistant.” Last, in Slide D we see their conclusions. What is not evident in these slides is the participants’ enthusiasm and the comments in which they discussed the complexities and their personal experiences of doing science.

In spite of the didactic teaching of how to do presentations, the participants determined the content as well as the order and means of presenting the information, although clearly influenced by feedback and prompting from the teachers, scientists, and camp director. More generally, the responsibility for the presentations for all groups were distributed across group members, with each participant having a particular set of slides and content for which he or she was responsible. However, each of the participants were involved with all aspects of the presentation. This was evident when one of the participants was absent on the day of the presentation, and another learner stood up in front of the audience (including a local television station) and delivered the missing section without the benefit of notes or preparation!

Did the Participants Participate in the Social Construction of Scientific Knowledge?

In the previous section we characterized students as doing science, including the construction of robust scientific presentations. Of the many scientific practices in which students engage, Roth (1998) stated that among the most important are those that are of a linguistic nature—language. When we refer to language, we are not referring to it as a representational medium but as a “tool” to get things done (Dewey, 1938/1963; Garrison, 1995; Quine, 1969; Roth). From this pragmatic perspective, people use language and discourse as a practice for making sense and communicating these understandings to others. It is through these communications that individuals come to make explicit and test various hypothesis about the world. Thus, discourse is a scientific practice in which individuals are required to publicly state and defend varying hypotheses. As such, an important part of *doing* science involves engaging in scientific discourse in an attempt to develop socially negotiated meanings about scientific phenomena (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Roth; Ruopp et al., 1993).

We found the participants to be continually engaged in rich discussions indicative of those discussions that practicing scientists engage in. For example, below we present a transcript of a discussion among members of the Sonar group on whether bats use phase information to determine the size and shapes of objects. Phase information refers to the difference in displacement between two or more waves. In this case it refers to the reflected sound waves that bats receive from their surroundings. In this debate, the participants engaged in hypothesizing about explanations that they believed fit the available evidence and then defended their hypotheses through the use of examples, counter examples, and pointed questioning. Initially, the participants determined the point of contention, developed possible explanations, defended those explanations by providing examples, and then revised their explanations based upon questions and counter examples posed by others. This debate led to the exchange of ideas and thoughts that forced the participants to examine their own assumptions and interpretations. These discussions provided the underpinnings for later hypothesis development during the camp following further study.

In this example, the scientist is talking with the participants about the sound wave data (phase information) that they have looked at on different objects (targets). The scientist is asking them if the data provided make sense. More specifically, the dialogue begins with the scientist asking Tom if they have enough data to determine what type of object they are looking at, and

whether the phase information is even being used by bats to determine the type of object. Tom and Mary's hypothesis (mainly Tom's) is that the phase information *is* important information because it tells the bat what type of object it is looking at. The explanation they develop is a little later (after they think about the data), and it is concerned with why the bat has the phase information in the first place. Larry's hypothesis is that the phase information *is not* needed to determine the shapes and sizes of targets. His explanation is that the phase information does not provide new information regarding the target, so why use it.

Dr. S.: So do we have sufficient data to assume the bat uses phase information to distinguish between the targets?

Tom: Yes, I think the bat can definitely tell with the phase information.

Dr. S.: But you can't tell if the bat is looking at the picture or not.

Tom: Yes, I think that it is. The phase is important information.

Larry: I don't think it would be necessary to know the phase information because, basically if you had sonar vision and looked at something like this you could identify it (*pointing to a piece of paper*). Let's say the bat didn't have the phase information, but had vision like we have then it couldn't identify something like this (*picks up a notebook*), but it could because it grew up knowing about it.

Tom: How could it determine the size of the tree or what kind of tree or what kind of fruit it likes to eat?

Larry: By learning. That is how we figure out what an object is.

Not satisfied with Larry's response to his questions, Tom proposes a problem that he thinks Larry's explanation will be unable to answer or may provide him with deeper insight into his own explanation.

Tom: Lets consider apples and oranges. Both are relatively the same size and shape. How can it distinguish those two without the phase information?

Larry: Same way we distinguish this piece of paper from this piece of paper (lifting up two separate pieces of paper to demonstrate).

Tom: Because we can see the information on the paper but the bat just sees the shape.

Larry: But the bat can see the difference.

In the following exchange, although using faulty scientific reasoning, Tom's claim is basically that we do not know exactly how or if the bat uses phase information but it is there so he must use it and it is our job to discover how he uses the information.

Larry: I don't think the bat needs it.

Tom: It is there for a reason. Why don't we have six fingers instead of five? There is a reason. There is a reason for everything. Why would they have it [the phase information] if they didn't need it?

Below, Larry proposes a problem for Tom's explanation to solve. Larry believes that this problem proves his hypothesis that the bat does not need phase information to see, and asks if Tom's explanation can provide a satisfactory solution. Tom and Larry are engaged in a classic scientific debate when discussing a topic whose solution is not known. This constant give-and-take brings to the forefront those aspects of each explanation that appear to be consistent with the evidence while those aspects that are flawed fall to the wayside and when the remnants of both explanations are combined they might constitute a better explanation than the two individual

explanations separately—another outcome that occurs in science, as in the case of scientific revolution, could be the discarding of one explanation and the triumph of another.

- Larry: Wait a minute. If you say they need the phase information then if you had two similar objects how would the phase information help?
- Tom: What do you mean? Give me an example.
- Larry: Objects of the same shape.
- Tom: Texture and color?
- Casey: Phase information does not tell you the color.
- Tom: In black and white you can tell because the orange would be lighter because it reflects more light than the apple because it is darker.

Larry recognizes what he believes is a flaw in Tom's explanation and seeks to explore where the current thought will lead. Again Larry is asking deep conceptual questions to determine the strengths and weaknesses of the available hypotheses in hopes of determining which explanation is most compelling.

- Larry: It [*the bat*] can't see light. Phase information does not give you light.
- Tom: If it [*the bat*] had really good sonar it could see the ink on the paper.
- Larry: Phase information can't help it determine a green apple from a red apple. They are exactly the same shape. It would be totally clueless if it just used phase information.

Below, the students have discovered a weakness of one explanation; thus one of the explanations is revised.

- Tom: If you use everything else with the phase information.
- Larry: So what good is the phase information? If you grow up and think a pencil looks like a fist. That works out fine. You are just thinking in terms of how we do.

Below, begins a debate to determine if the revised explanation (bat uses phase information plus sonar) is better than the previous one. The cycle of articulate a hypothesis, develop an explanation, defend the hypothesis, and then revise and defend again is being played out.

- Tom: Ok, let's look at a ripe apple compared to a unripe apple. The ripe apple would probably be more dense. The inner part (*Larry interrupts Tom*).

An important point is made below; the fact that the students do not have all the information at hand inherently weakens their explanations, thus, revisions to their explanation will almost be inevitable.

- Larry: Basically their main difference is density.
- Tom: Yes. The bat might be able to see the density, we don't know yet. Just like the question you had asked earlier, "Can bats tell the density of an object?"
- Larry: Yes, but what does this have to do with the phase information?

These questions lie at the heart of the scientist's research and continue throughout the camp as the participants are exposed to new data. These types of discussions, present in all of the groups participating in SAC, suggest that the participants (to some extent) had opportunities to participate in the social negotiation of meaning, a practice that is fundamental to doing science.

Further, these discussions frequently ended up with the participants returning to the data or even collecting new data as they tested and refined their emerging hypothesis.

Did Participants Learn at the “Elbows of Experts” and More Competent Peers?

The scientist’s assigned role was to empower the learner to conduct “science experiments.” The scientists supported the students in becoming knowledgeably skillful by initially modeling the practice and sharing previous research with students. For example, in the Insecticide Group, the participants initially followed the scientist around the laboratory as she proceeded to weigh moth larvae, apply topical insecticide and control solutions, catalog data, and graph previous days’ results. In supporting the participants, she thought out loud, describing what the practices did and why she was doing them. As she was holding the worm and applying the treatment she stated, “I am very careful when I apply the treatment to the worms to make sure that the entire dosage gets on the skin, otherwise the results might not be accurate . . . [saying to herself] I missed a little over here.” She then documented the time and amount in her laboratory journal, stating, “It is important that my procedures be the same each time, so I document everything and that way someone else can reproduce my results.”

In a debriefing session among the students and teacher, one of the participants said, “She is weird. Does she always talk to herself,” and another student stated, “She is just doing that to help us catch on. . . . If you had read what she wrote then you would know what she was saying.” At the next break the first student logged on to the Apprenticeship Notebook and read the research description. Over the course of the week, the scientist switched to playing the role of coach as students did the work; for example, “You need to make sure you get all of it on the skin” or “Good, remember what I said about documenting everything.” And then by the second week we captured multiple occasions in which the scientists would work on different areas in the laboratory as the participants carried out the practices and reflected on the results more independently. At one point we asked the scientist what one participant was doing and she responded, “I don’t know, lets go see . . . [after looking more closely at the work of the student] Ohh, it’s her job to enter the weights into the computer.” This suggests that even during this brief camp students began to have some autonomy in governing their actions in relation to the scientific work. This approach is consistent with Collins et al.’s (1989) notion of cognitive apprenticeship, in which the mentor models, then coaches, then scaffolds, and then gradually fades scaffolding.

Each scientist also enlisted the aid of his/her graduate student(s). These graduate students had, for the most part, been working for at least 2 years with the scientists and were competent in “the work.” Their role was to support the participants, and in at least four of the groups, this meant doing the practices alongside the participants. For example, in the Sonar and the Insecticide groups, the graduate students were carrying out their own research studies, enlisting participants as they felt appropriate. Both groups actually negotiated group responsibilities and supported each other in trading off roles over time. In the Sonar Group, one of the graduate students had the camp participants take measurements and collect and print graphs of various wavelengths for a number of objects. It was the middle school students’ responsibility to mine the data for anomalies. “You have watched me do it [*analyze data*]. It’s your turn, tell me when you find something.”

As stated earlier, the participants had two distinct categories of roles in SAC, and their participation alongside and under the expert guidance of the scientists varied with these roles. The first and primary role was as the scientist’s apprentice and the second was as a presenter of scientific research. These two roles appeared conceptually related both in the minds of the participants and in the directors of the camp; they were markedly distinct in terms of what the

participants did, who facilitated them, the legitimacy of what they did, and the outcomes. In general, the middle school participants did learn about doing science under the expert guidance and mentoring of the scientists. Learning was a seamless part of the environment with learners actively engaged in practices alongside scientists of which learning was a result. There were only two reported incidents across all four groups in which the scientists engaged in didactic lectures outside of the laboratory context. There were, however, numerous occurrences of where the scientist engaged in brief (under 5 min) “just-in-time” lectures in response to student questions.

Another driving force of the camp was project presentations. The participants did not learn about performing quality presentations “at the elbows” of experts, or in a community in which expert performance was being modeled. Rather, the participants were “told” how to develop a presentation (although the content was their choice), and “told” that they were central to the practices of a scientist. Although the scientists offered input and reviewed these presentations, participant learning experiences around the presentations would be better characterized as consistent with the simulation rather than the participation model of science education.

Were the Practices the Participants Engaged in and the Outcomes of these Practices Authentic and Owned by Students, a Community of Practice, and in Response to a Real-World Need?

This implies that the participants perceive their work as legitimate and have the opportunity to move from peripheral to core participants as they become more skilled at the requisite practices. In the scientist-apprentice role, the participants had little control over the primary research question, basic goals, assumptions, parameters, practices, and resources that were used. They entered the ongoing 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 (newcomer) working with a master (old-timer) in a structured community of practice where the practices that they engaged in were well defined. Their roles were to quickly understand the ongoing practices of the scientist and then participate in those practices. The participants had little latitude in changing their technique, instrumentation, site, or subjects. The participants engaged in these practices through a process of watching the master perform the practice and then an appropriation of the individual steps of the practice (Rogoff, 1990).

In spite of the exacting nature of the work, the students frequently perceived their actions as authentic. Closing interviews with the participants indicated that they believed the scientists valued their contributions in the laboratory and that it would be used to inform the scientists’ research—either directly or as pilot data. For example, one of the students stated,

It [the camp] was so exciting because we were doing the real stuff. Analyzing research that she [the scientist] would really use.

Another participant said,

. . . our work was important to Dr. Novell and we had to really follow the procedures she showed us. We helped her determine if she was right, but not totally . . . just more evidence. Our conclusions were that the methamphetamine rats would be more sensitive to it [the drugs], but he will have to continue and get more rats to be sure our work is right.

The fact that the participants wanted to perceive themselves as legitimate participants was evident when one student misinterpreted that the scientist already knew the results of the data, and 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.

The scientist responded,

I apologize for the confusion, I meant [when he stated he found this previously] that I had some preliminary results suggesting the same findings. But science involves reconfirming the data so you are confident before you say the data supports your hypothesis.

Interviews with the scientists further suggested that they did value the participants' work and insights, with one scientist arranging an internship for a participant in the upcoming year. All the scientists indicated that they valued this experience and would again accept participants the following year.

Once the tool-related practices were performed to the scientist's satisfaction, both the scientist and the teacher would often engage the participants in discussion of conceptual issues, "Why do we do it this way?" The goal of these discussions was to move practice from simple mechanistic repetition of actions to deeper conceptual understanding of and appreciation for the importance and meaning of the practices being carried out. In summary, the participants' roles and practices in the laboratory working with the scientist were primarily defined by the scientists; however, this did not seem to deter the participants' valuing of the project. This seems to be contradictory to common assumptions of facilitating student "buy in." What was surprising was that unlike formal education settings where step-wise procedures would most likely undermine personal valuing of the activities ("I'm doing this because Mr. Jones told me to."), here, the contextualized learning environment seemed to foster personal valuing and perceived legitimacy of the work.

In the secondary, but related role, participants engaged in the practice of modern-day scientific presentations. This involved PowerPoint presentation development, WWW searching, public speaking, producing visuals, notebook writing, and delivering a scientific presentation. The participants' roles in these activities 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 led by non-scientists who presented in 1-hour lectures/demonstrations. Thus the participant's role was to take in the information or skill and apply it to their presentation. In their active presentation development roles, the participants had almost complete control over their work. Within the time frame determined by the directors and the requirement that each member of the group have a public role in the presentation, the participants were in control of preparing the presentation. There was some mentoring by the teachers and the scientist, but this was markedly different from the mentoring that was done in the lab. This mentoring took the form of gentle facilitation, not strict adherence to a particular practice. Ownership of the content 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 be detrimental to the scientist's research.

The fact that the participants viewed the development of presentations as inauthentic activity was brought to the teachers' awareness when one participant commented that, "these presentations aren't real . . . they are like school." Following the participant's comment on the presentations, the teachers called a meeting to discuss the problem, and it was decided to enlist the scientist's help in developing the presentations. When the scientist, Dr. Saul, invested in making this aspect important (talking about it in the laboratories, asking the participants questions, calling for a trial presentation in which they would provide feedback), the participants

in Dr. Saul's group viewed the process as more legitimate. For example, evidence of perceived legitimacy was present in the following participant comment with respect to preparing their presentations:

this is our only chance to share our data and prove our experiment was a good one. Dr. S. [the group's scientist] will be there, and she is counting on us.

One of the parents told a researcher:

He has been talking about this presentation for the last three days. He is very proud and excited.

Additionally, the teachers emphasized that doing presentations is an important part of scientific activity and is where scientists share and convince their peers of the importance and validity of their findings. It was clearly emphasized that the presentations should be designed in such a manner that it would accomplish these goals. However, it was not until Dr. Saul said the presentations were important that the students in her group perceived them as legitimate and of personal value. Unfortunately, this was not emphasized as directly in all of the groups by the scientist and some students perceived the presentation as inauthentic.

Did Participants Become a Part of a Scientific Community of Practice?

This condition implies that the learners moved from being peripheral participants toward becoming core participants as they became more skilled at the requisite practices. It is important to note that the goal of this camp was not learner movement to the core of the community. In the context of a community that relies on traditional apprentices that last through undergraduate, graduate, post-doctoral, junior level faculty, to core scientists, the goal of a 2-week camp moving participants to the core is impractical. However, the movement along this trajectory was evident, even though the opportunity was varied across the camp. Overall, the learners felt like they had a legitimate role in the scientist's research program and this role became more central as they mastered the requisite skills. For example, in the Insecticide Group, learner practices consisted of initially simply weighing the already treated worms and progressed to actually applying topical assays on the head of the worms, entering in the data, running the statistical tests, and producing various graphs. In a very real sense, the students experienced working directly with members of the scientific community, contributing to their research (at least peripherally) and using their equipment. Above, we also discussed the students' feelings of authenticity with respect to the work they performed.

In spite of these successes it is important to recognize the limitations of participation that has been gained in only 2 weeks and only in the context of the SAC. This was evident when one student commented, "now, back to school we go." Obviously, even the students did not view themselves as a true member of the scientific community of practice and, as a result, would most likely not develop an identity as a scientist. In addition to the limited time frame, this movement was also constrained due to the fact that the participants' limited background would prevent deep movement along the trajectory from periphery to the core community. But perhaps, the exposure to the professional world of real scientists may impact future career choices or even how the participants do science in their classroom. However, such a claim extends beyond the reach of the collected data.

Did Participants Engage in Reflection-In-Action and Reflection-On-Action?

One exciting attribute of the SAC context was the opportunity for reflection with scaffolding from the teachers. Teachers were able to serve as liaisons between the middle school participants and the scientists. In the laboratory, the teachers served a scaffolding or, more accurately, a bidirectional interpretative role between the scientist and the participants. This role was enacted when the scientists explained concepts or asked questions that the participants 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’s discourse and the participants’ discourse in a way that was both sensitive to the real problem and performed an educative function so that the participants could learn the discourse of the scientist in a manner that did not simplify all the communications, just the confusing ones. Third, it performed an educative function for the scientist so s/he could learn how to better communicate with middle school participants. The paraphrasing also occurred in the opposite direction—when the participant asked questions of the scientist.

The SAC teachers also pushed the participants to reflect on what they had learned during the day and to pose questions to the scientists using the apprenticeship notebook. These discussions frequently led to debates among team members, as is the case in the example discussion on phase information above. During these discussions, the participants reflected on their experiences in the laboratory to develop hypotheses that they believed fit the available evidence. At times, these discussions would continue over into the next day and the scientist could show the camp participants actual data with which to challenge or confirm tentative hypotheses.

In addition to teacher support, the Apprenticeship Notebook section created a powerful support system for one of the driving goals of the camp, the scientific presentation. Drawing on Schön’s (1987) distinction of reflection-on-practice versus reflection-in-practice, the Apprenticeship Notebook facilitated both reflecting back on the previous activities and encouraging the participants to reflect while they were engaged in the activities. Apprentices used the Notebook to organize 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 the participants, thereby, maximizing the participants’ time with the scientist. In terms of maximizing the benefit of the limited time the participants had with the scientists, the results indicate two benefits of the Apprentice Notebook. We will briefly describe these benefits, using illustrative examples from the Sonar and the Laser Group.

First, the Notebook created an alternative avenue of presenting information that educators (and in previous years scientists) frequently teach didactically. The Links section of the Apprentice Notebook was designed to facilitate distribution of basic facts to the campers and the Chat section was a vehicle to ask questions and elaborate on that information. The evidence of the first is derived from references in the Chat.

Jackie: What is a rotation vector and periodic function?

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

Mike: Do all clear solutions absorb the same amount of light?

The scientists also used the Chat room for asking probing questions, often playing off learner questions, to test learner understanding, similar to what a teacher would do in a lecture setting. For example, as a follow-up to Mike’s “clear solution” question (above), Dr. R asks,

What do you think happens to color or transparency of a solution that absorbs light from 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 convenience of the scientist, thus, maximizing the time available for hands-on work where they need to be physically located with the scientist.

Second, the Chat section also created a “reflective zone” that was away from the excitement of the lab where the participants could reflect on the lab experience with each other. For example:

Amie: What are some of the differences between lasers and flashlights?

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

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

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

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

After time to think and formulate questions, this reflective zone gave the participants opportunities and a comfortable social distance to ask the scientist difficult questions. These questions were not simply of a factual nature, but actually went to the heart of scientific practice. For example:

Carrie: How can a cube come out looking like two mountains on a sonar graph?

Terry: 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?

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

It should be noted that Carrie's question goes to the very heart of the bat sonar research. That is, “is the bat sonar a replacement for our vision or a totally different way of perceiving the spatial world?” Her confusion is an attempt to say, “why don't the graphs look like a cube?” The participants took the opportunity that was presented by the Scientist Notebook as a primary vehicle for reflection- on-action. It created a safe space that the students could interact with each other and with the scientist.

SAC Conclusions

It is our belief that teaching science with isolated activities directed toward the building of conceptual representations about ready-made science should be accompanied by, or potentially supplanted with, learning opportunities that support students in doing participatory science—ideally with scientists and in those places where scientists do science. The SAC provided one means for middle school students to participate in learning/doing science in a manner that we describe as participatory science learning. This environment had aspects of both simulation and participation authenticity (Barab, Squire, & Dueber, 2000). With respect to the former, students working as part of their project teams did some of the same types of activities that scientists do, for example, doing domain-related practices in response to domain-related dilemmas and engaging in authentic scientific discourse. However, of prime importance was that the learners were actually doing these practices in an authentic context alongside expert scientists who modeled scientific practices and valued the outcomes.

There are three main differences between the camp and full apprenticeship experiences. First, full “apprentices” participate in the activities with the expectation of becoming a core member. In contrast, SAC participants only spent limited time working with the scientist and their experience might be best described as one where they were able to travel further down the trajectory from the peripheral to the core of the community than other middle school learning

environments, didactic or simulation. The time factor is the second crucial difference. As opposed to years in traditional apprenticeships, students in our camp only worked with scientists for 6 days.

Due to the limited timeframe of SAC apprenticeships, students had limited opportunity to develop a rich and grounded appreciation of the domain in which they were working and, armed with this understanding, establish a set of research questions and resultant studies. Instead, students entered and worked as part of scientific laboratories that had pre-defined structures. Although full apprentices begin in a similar manner (supporting someone else's research agenda), it is with the expectation that at some point they will have opportunities to develop and advance their own research agenda (Coy, 1989; Traweek, 1988). The fact that there was not an opportunity for this to occur, we believe, undermines some of the authenticity of the science practices being carried out, and, potentially, the transformative potential of the camp experience. However, in contrast to GLOBE, SAC participants not only collected data but also used the same types of complex instrumentation and methodologies that scientists use. Additionally, they were analyzing and interpreting the data in the context of a scientific community and presenting it within a simulated scientific community. It is through participation in all these activities that many students did indeed perceive themselves as doing legitimate science and as contributing in meaningful ways to the work of the scientist.

In spite of the fact that it was the scientists who primarily defined the research agenda and methods, many participants were able to gain an appreciation of the situated nature of science. For example, the participants in the Insecticide group had to grapple with the phenomenon of outliers and that science is a complex topic, with one participant speculating whether more interesting information would have been gleaned if the team dissected the larvae that did not react like the others. This type of context is in contrast to the kinds of learning that many students experience in traditional science classes in which it is generally believed that when things go awry it is due to problems with implementation—not an inherent reality of doing authentic science (Richmond & Kurth, 1998). At SAC, these alternative findings were considered an important part of doing science, providing students with a more accurate representation of the practice and culture of doing science in which scientists learn as much (or more) from unexpected results as they do from those findings that confirm their hypothesis. This complexity is a challenging notion to communicate to students who all too often view science as getting the correct answer.

Another important finding was that even though the scientist defined the research agenda and practices, most students viewed their work as legitimate. In fact, one student became frustrated when he believed that his work was not being treated in this manner. In terms of valuing and perceiving learning activities as legitimate, it appears that context matters even in the presentation. An interesting future design experiment will be to have half of the scientists being responsible for introducing the presentations, and then to examine the learners' feelings of legitimacy and the quality of the presentations.

In comparison to traditional apprenticeships, this camp has two important virtues: first, it employs mechanisms (an apprenticeship notebook) to make cost-effective use of a scarce resource, the scientists' time; and second, it uses the middle school's teachers and the structure of activities in the camp to mediate between the scientists and the middle school participants. We have already discussed the benefits of the apprenticeship notebook in that it provided scaffolding to support the participants in discussing problems with the scientist, sharing their work with their peers, and creating a public space for the middle school teachers to guide students and make suggestions about the types of investigations and interpretations in which the students were engaged. In addition to assisting the students with their field notes, the teachers of SAC were

willing to adapt to many diverse roles, including serving as a bridge between the participants and the scientists and linking scientist and participant discourse/practice in a manner that was both sensitive to the real problem and to the abilities of learners.

While teachers could advocate for the work and push the participants to complete tasks, they were not necessarily viewed as experts and there was a tension in which some participants did not view the teachers as credible scientists. Participant perspectives of teachers differed across groups and within groups, with some teachers being viewed as more credible than others. Given the types of questions the teachers asked, it was clear that some of the teachers had taken more responsibility than others in learning the science and, as a result, supporting the participants in understanding the conceptual issues. These teachers were treated with more respect and were able to push the participants' discourse and understandings to deeper levels. In this way, the teachers had an opportunity to both be agents for and detractors from the authenticity of the research experience. Although future research is necessary to develop a grounded interpretation of the important variables, we do believe that it is important that teachers do more than simply connect students with scientists. Teachers need to take an active role in ensuring that the relationship with, and the time both with and away from, the scientist contributes to effective learning.

In terms of limitations, obviously, the resources and personnel necessary in making such a camp useful are extensive. The scientists and teachers at SAC were well chosen and were clearly committed to making the project work. The scientists were extremely willing to work with the participants—sharing their time, equipment, and resources so that the learners would have a meaningful experience. The teachers of SAC were willing to adapt to many diverse roles, and the participants were able to expend 2 full weeks on this learning experience. We have also presented an idealized sense of participatory science learning, and even with the 2 weeks of dedicated activity the scientists had to simplify the research questions so that the students would be able to experience some sense of completion in terms of their investigations. An important part of doing science is experiencing the work that contributes to the creation of a research question, and then engaging in complex, long-term, and open-ended investigations. At SAC, this was clearly limited and is an important limitation when one contrasts the SAC experience to more traditional notions of apprenticeship. In the future, it might prove more effective, although not necessarily practical, if participants are given longer time frames in which to work with the scientists. SAC participation might also be viewed in the context of an extended trajectory of opportunities to support students in doing science, some of which took place in K-12 schools and some of which took place in more participatory contexts.

Implications

Apprenticeships have a rich history as a pedagogical tool for enculturating learners into various communities of practice. In spite of this model's intuitive appeal, the literature on what types of interactions are most useful and how to foster meaningful apprenticeship-like situations is just beginning to accrue. Further, much of this literature is not grounded, that is, not coming from data acquired by examining apprenticeship-type situations as they occur. Rather than collecting actual data and stating this is what it "is" like, this literature tends to be more theoretical, referring to what it "should be" like. In addition, much of the quality research has been carried out in anthropological circles, in which the apprenticeship experiences occur over extended time frames, which are not easily adaptable to the constraints of schools.

In this article, we examined a learning environment that has many of the key characteristics of apprenticeships as well as some additional learning characteristics, and we have conducted

research on its educational potential. By doing so we have made some significant epistemological commitments in the way we view learning and how to achieve authenticity. Many science education initiatives simulate real science in the context of the classroom, with the expectation that the learner will view the activities as authentic because they are doing the types of things scientists do. In contrast to the simulation model of doing science education, our goal was to support students in doing science where scientists do science, and with the equipment they use. Instead of making the formal education of the classroom more apprenticeship-like, this project was designed to support students in doing authentic science “at the elbows” of real scientists. This included the mentoring and scaffolding of learners to think and act more like experts, connecting them with authentic problems and resources, or helping them see the larger context of the community of practice.

More generally, we described six characteristics of participatory science learning that were primarily derived from the literature on apprenticeship learning, the sociology of science, and K-12 science education (see Table 1). We then used these as evaluative criteria to examine the trajectory of experience of middle school learners as they participated in a 2-week long camp. Overall, data suggested that during this brief camp where students only worked with scientists for 2 hrs a day, students were able to engage in many of the key principles of doing authentic science, including doing domain-related practices in response to domain-related dilemmas, negotiating scientific and technical meanings, and learning “at the elbows” of more knowledgeable others. Although we do not contend that this experience represented a full apprenticeship experience, we do suggest that the experience embodied some of the key characteristics of learning in apprenticeship situations, and allowed students to participate in authentic science practice.

We believe that, more important than the SAC context in particular, is the value of the characteristics introduced in this paper for the design and evaluation of participatory science learning environments in general. These types of environments will come in many shapes and sizes and will emphasize simulation and participation authenticity to different degrees. For example, while problem-based learning environments may emphasize simulation activities, apprenticeship and internship connections may more heavily emphasize participatory authenticity. Whereas the latter activities build on relations and connections to real-world practitioners, simulation activities involve the building of connections to real-world issues and the importance of supporting learners in becoming their own community of practice (Barab & Duffy, 2000; Brown & Campione, 1990, Lampert, 1990, Roth, 1998, Scardamalia & Berieter, 1993).

Communication tools such as the apprenticeship notebook used during SAC can make apprenticeships more accessible to classroom learners, can promote interaction and dialogue between learners and the scientist, can promote reflection on practice, and can serve as a public medium for storing data, pictures, and field notes to be used in learner presentations. The Apprentice Notebook, although designed for SAC, is a tool that can be incorporated within the context of schools, where it could be used for introducing future apprentices to the work of scientists and for maintaining contact with previous apprentices. Other learners not participating in the camp could also view learner–scientist discourse and gain insights into this community. In this manner, the internet may serve as a tool (or resource) allowing “outsiders” to gain an “insider’s” perspective. It could also be used to support authentic assessment, producing a window into the *process* of learning. As cognitive apprenticeship models of learning become more pedagogically desirable and with tele-apprenticeship more geographically possible, electronic support systems can maximize the learning impact of the precious contact time with mentors and their facilities.

As scientists, educators, and researchers continue to research participatory science learning, 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. It is our expectation that the principles derived from these investigations will be applicable to multiple learning contexts, whether they are informal or the more formal classroom environments that have taken on the primary responsibility of enculturating our youth. It is not our intention to replace either medium, but to advance a set of characteristics that may serve as useful evaluative and design criteria for understanding and designing participatory science learning environments that strive toward supporting both simulation and participation authenticity. We look forward to the continued discussion of the value of the characteristics advanced in this article for designing and evaluating participatory science learning environments.

Research reported in this paper was supported in part by a PROFFITT grant from the School of Education at Indiana University. We would also like to thank Michael Barnett and Carrie Olah for their contributions, and the project directors Gordon Fricke and Steve Math for their collaboration in both the design and evaluation of the Science Apprenticeship Camp.

Note

¹Because the camp context did not allow for proper training in animal handling, the scientist conducted this practice.

References

- American Association for the Advancement of Science. (1993). *Benchmarks for Science Literacy*. New York: Oxford University Press.
- Anderson, J.R., Reder, L.M., & Simon, H.A. (1996). Situated learning and education. *Educational Researcher*, 25, 5–11.
- Barab, S.A. (1999). Ecologizing instruction through integrated units. *Middle School Journal*, 30, 21–28.
- Barab, S.A., Cherkes-Julkowski, M., Swenson, R., Garrett, S., Shaw, R.E., & Young, M. (1999). Principles of self-organization: Ecologizing the learner–facilitator system. *The Journal of The Learning Sciences*, 8(3–4), 349–390.
- Barab, S.A., & Duffy, T. (2000). From practice fields to communities of practice. In D. Jonassen & S.M. Land. (Eds.). *Theoretical foundations of learning environments* (pp. 25–56). Mahwah, NJ: Lawrence Erlbaum.
- Barab, S.A., Hay, K.E., Barnett, M.G., & Keating, T. (2000). Virtual solar system project: Building understanding through model building. *Journal of Research in Science Teaching*, 37, 719–756.
- Barab, S.A., Hay, K.E., Barnett, M.G., & Squire, K. (in press). Constructing virtual worlds: Tracing the historical development of learner practices/understandings. To appear in *Cognition and Instruction*.
- Barab, S.A., Squire, K., & Dueber, B. (2000). Supporting authenticity through participatory learning. *Educational Technology Research and Development*, 48, 37–62.
- Brown, A.L., & Campione, J.C. (1990). Communities of learning and thinking, or a context by any other name. *Contributions to Human Development*, 21, 108–126.
- 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.
- Coy, M.W. (1989). *Apprenticeship: From theory to method and back again*. Albany, NY: State University of New York Press.
- Dewey, J. (1963). *Experience & education*. New York: Collier MacMillan. (Original work published in 1938)
- Donahue, T.P., Lewis, L.B., Price, L.F., & Schmidt, D.C. (1998). Bringing science to life through community-based watershed education. *Journal of Science Education and Technology*, 7(1), 15–23.
- Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher*, 23, 5–12.
- Finarelli, M.G. (1998). GLOBE: A worldwide environmental science and education partnership. *Journal of Science Education and Technology*, 7(1), 77–84.
- Garrison, J. (1995). Deweyan pragmatism and the epistemology of contemporary social constructivism. *American Educational Research Journal*, 32, 716–740.
- Glaser, B.G., & Strauss, A.L. (1967). *The discovery of grounded theory*. Hawthorne, NY: Aldine.
- Goody, E. (1989). Learning and the division of labor. In M. Coy (Ed.) *Anthropological perspectives on apprenticeship*. New York: SUNY Press.
- Gore, A. (1992). *Earth in balance: Ecology and the human spirit*. New York: Houghton Mifflin.
- Guba, E.G., & Lincoln, Y.S. (1983). Epistemological and methodological bases of naturalistic inquiry. In G.F. Madaus, M.S. Scriven, & D.L. Stufflebeam (Eds.) *Evaluation models: Viewpoints on educational and human services evaluation* (pp. 311–334). Boston, MA: Kluwer-Nijhoff.
- Hay, K.E., & Barab, S.A. (1998, May). Electronic performance support system: Supporting science apprenticeships. Presented at the annual meeting of the American Educational Research Association, San Diego, CA.
- Kass, H., & Macdonald, A.L. (1999). The learning contribution of student self-directed building activity in science. *Science Education*, 83(4), 449–471.
- Knorr-Cetina, K.D. (1981). *The manufacture of knowledge: An essay on the constructivist and contextual nature of science*. Oxford, UK: 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.
- Koschmann, T. (Ed.). (1996). *CSCL: Theory and practice of an emerging paradigm*. Mahwah, NJ: Erlbaum.
- Krajcik, J.S., Blumenfeld, P., Marx, R.W., Bass, K.M., Fredricks, J., & Solloway, E. (1998). Middle school students' initial attempts at inquiry in project-based science classrooms. *Journal of The Learning Sciences*, 7(3), 313–350.
- Lampert, M. (1990). When the problem is not the question and the solution is not the answer: Mathematical knowing and teaching. *American Educational Research Journal*, 17, 29–64.
- Latour, B. (1987). *Science in action: How to follow scientists and engineers through society*. Milton Keynes, UK: Open University Press.
- Latour, B. (1993). *We have never been modern*. Cambridge, MA: Harvard University Press.
- Latour, B., & Woolgar, S. (1979). *Laboratory life: The social construction of scientific facts*. Beverly Hills, CA: Sage.

Lave, J. (1988). *Cognition in practice: Mind, mathematics, and culture in everyday life*. Cambridge: Cambridge University Press.

Lave, J. (1993). Situating learning in communities of practice. In L.B. Resnick, J.M. Levine, & S.D. Teasley (Eds.) *Perspectives on socially shared cognition* (pp. 17–36). Washington, DC: American Psychological Association.

Lave, J. (1997). The culture of acquisition and the practice of understanding. In D. Kirshner & J.A. Whitson (Eds.) *Situated cognition: Social, semiotic, and psychological*.

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

Lawless, J.G., & Rock, B.N. (1998). Student scientist partnerships and data quality. *Journal of Science Education and Technology*, 7(1), 5–13.

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.

Lincoln, Y.S., & Guba, E.G. (1985). *Naturalistic inquiry*. Newbury Park, CA: Sage.

Linn, M.C., & Songer, N.B. (1993). How do students make sense of science? *Merrill-Palmer-Quarterly*, 39, 47–73.

Means, B. (1998). Melding authentic science, technology, and inquiry-based teaching: Experiences of the GLOBE program. *Journal of Science Education and Technology*, 7(1), 97–105.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy 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.

Pickering, A. (1992). *Science as practice and culture*. Chicago, IL: University of Chicago Press.

Quine, W.V. (1969). *Ontological relativity*. In W.V. Quine, *Ontological relativity and other essays*. New York: Columbia University Press.

Raybould, B. (1995). Performance support engineering: An emerging development methodology for enabling organizational learning. *Performance Improvement Quarterly*, 8(1), 7–22.

Resnick, L.B. (1987). Learning in school and out. *Educational Researcher*, 16, 13–20.

Richmond, G. (1999). Scientific apprenticeship and the role of public schools: General education of a better kind. *Journal of Research in Science Teaching*, 35(6), 583–587.

Richmond, G., & Kurth, L.A. (1998). Moving from outside to inside: High school students' use of apprenticeships as vehicles for entering the culture of science. *Journal of Research in Science Teaching*, 36(6), 677–697.

Rock, B.N., & Lauten, G.N. (1996). K-12 Grade students as active contributors to research investigations. *Journal of Science and Technology*, 5(4), 255–266.

Rock, B.N., & Lawless, J.G. (1997). The GLOBE Program: A source of datasets for use in global change studies. *IGBP Newsletter*, 29, 15–17.

Rogoff, B. (1990). *Apprenticeship in thinking: Cognitive development in social context*. New York: Oxford University Press.

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. (1998). *Designing communities*. Dordrecht: Kluwer.

Roth, W.-M., & Bowen, G.M. (1995). 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.

Ruopp, R. Gal, S. Drayton, B. Pfister, M. (1993). *LabNet: Toward a community of practice*. Hillsdale, NJ: Lawrence Erlbaum.

Savery, J., & Duffy, T. (1996). Problem based learning. An instructional model and its constructionist framework. In B. Wilson (Ed.) *Constructivist learning environments: Case studies in instructional design* (pp. 135–148). Englewood Cliffs, NJ: Educational Technology Publications.

Scardamalia, M., & Bereiter, C. (1993). Computer support for knowledge-building communities. *The Journal of the Learning Sciences*, 3, 265–283.

Schatzman, L., & Straus, A. (1973). *Field research: Strategies for a natural sociology*. Englewood Cliffs, NJ: Prentice-Hall.

Schoenfeld, A. (1996). In fostering communities of inquiry, must it matter that the teacher knows the “answer”? *For the Learning of Mathematics*, 16(3), 11–16.

Schön, D.A. (1987). *Educating the reflective practitioner*. San Francisco, CA: Jossey-Bass.

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

Senge, P. (1994). *The Fifth Discipline fieldbook: Strategies and tools for building a learning organization*. New York: Doubleday.

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.

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

Strauss, A.L., & Corbin, J.M. (1990). *Basics of qualitative research: Grounded theory procedures and techniques*. Newbury Park, CA: Sage.

Traweek, S. (1988). *Beamtimes and lifetimes: The world of high energy physicists*. Cambridge, MA: Harvard University Press.