

## The Value of an Emergent Notion of Authenticity: Examples from Two Student/Teacher–Scientist Partnership Programs

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**Abstract:** We make the case for an emergent notion of authenticity of science based on systems theory and neo-Piagetian thought. We propose that authentic science is an emergent property of a dynamic system of learning precipitated by the interactions among students, teachers, and scientists that occur within the contexts defined by the internal and external constraints of the cultures of the schools and communities within which they operate. Authenticity as an emergent property of the learning process challenges the basis for many science curricula and current pedagogical practices that take scientists' science as their norm and that assume a priori that such is authentic, i.e., it practices preauthentication. We argue that what constitutes authentic science can be taught neither in the traditional didactic modes nor through simulations of scientists' science in the classroom. Instead, authenticity needs to be seen as emergent and as diverse in meaning. To illustrate this point, we draw from two different face-to-face, teacher/student–scientist partnership programs. Both studies support a notion of authenticity that emerges as teachers, students, and scientists come to interact, make meaning of, and come to own the activities they engage in collaboratively. We conclude by considering the implications of such an analysis for science education.

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Authentic science has become a popular term in the current science education reform movement, but what authenticity implies is often unclear. For many, authentic science has become

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a synonym for science activities that resemble scientists' everyday practice (Martin, Kass, & Brouwer, 1990; McGinn & Roth, 1999; Roth, 1995, 1997). This notion of authenticity has led science educators to develop practice fields for doing science in the classroom where students talk and think science, and help decide what is to be learned through inquiry and discovery under teacher guidance (Cunningham & Helms, 1998; Driver, Asoko, Leach, Mortimer, & Scott, 1994; Krajcik et al., 1998; Lemke, 1990; Martin et al., 1990; Radinsky, Bouillion, Hanson, Gomez, Vemeer, & Fisherman, 1998; McGinn & Roth, 1999; Nicaise, Gibney, & Crane, 2000; Roth, 1995). For others, authentic science embodies participatory models of science education that allow students to work at the elbows of scientists and become members of a research team through work on a real problem that may advance science (Barab & Duffy, 2000; Barab & Hay, 2001; Bouillion & Gomez, 2001; McGinn & Roth, 1999; Radinsky, Bouillion, Lento, & Gomez, 2001; Richmond & Kurth, 1999; Richtie & Rigano, 1996).

We argue that the focus on designing and establishing authentic science learning environments and tasks has neglected to ask what authenticity means, to whom, and according to whom. School communities consist of teachers rather than professional scientists, with training in science content only, and hence often a rudimentary understanding of what real scientists actually do (Barab & Duffy, 2000; Bencze & Hodson, 1999; Cunningham & Helms, 1998; Hodson, 1998). If the science of scientists or the participatory models were used, the questions about whose science practice and which components of it are simulated become pertinent (Buxton, 2001; Eisenhart & Finkel, 1998). Finally, what is considered authentic by a teacher may not be considered authentic by the scientist or the student (Barton, 1998a, 1998b, 2001a, 2001b). Yet, the current widespread practice of designing learning environments and tasks that are considered authentic *a priori* embodies a passive view of the learner and the teacher, treats authenticity as static rather than dynamic and as fixed rather than emergent, and ignores the potential of transformations of learning environments by its participants.

The central aim of this article is to develop an emergent notion of authenticity as seen through the lens of systems theory as widely used in the biological sciences (Salthe, 1985; Bateson, 1973, 1979). Accordingly, authenticity is no longer taken as being located in the scientists' science, the learner, the task, or the environment, but instead perceived as an emergent property of these components as they interact in a complex manner (Simon, 1962). In short, authenticity is taken to be emergent and diverse in meaning by nature (Barton, 1998a, 1998b, 2001a, 2001b; Fusco, 2001; Hodson, 1998; Wellington, 1998).

Authenticity as an emergent property grounded in ecological and self-organization models has been previously proposed by Petraglia (1998) and applied by Barab, Squire, and Dueber (2000) in their evaluation of a professional development model focusing on the authentic use of technology in classroom teaching. While acknowledging such work, the goal of this article is to describe what an emergent notion of authenticity from a systems theory approach means for science education. We begin by clarifying the meaning of an emergent notion of authenticity through an analysis of a university outreach project that shows how negotiations among components of such a partnership come to define multiple meanings of authenticity over time. We then discuss two defining characteristics of an emergent notion of authenticity: (a) the need for sustained involvement and experiences over time, and (b) the need for ownership of such experiences by the participants (teachers, students, and scientists). To illustrate what these two characteristics imply, we draw from a project in fire ecology that is part of a federally funded Math and Science Upward Bound Program. In conclusion, we address the consequences of an emergent notion of authenticity for science education and science literacy development. To guide our readers, we begin by first offering a brief, albeit selective description of authenticity as it has been used and become redefined over time.

## Conceptual Framework

### *Static Notion of Authenticity*

Authenticity is a popular term that became part of the lexicon of constructivism and the movement toward the design of effective learning environments (Brown, Collins, & Duguid, 1989; Petraglia, 1998). Authenticity also emerged as an important concept within the debate between everyday cognition and schooling (Resnick, 1987) and the recognition of the situated nature of ways of knowing (Lave, 1988). It led to the adoption of the apprenticeship metaphor to learning, whereby students can become engaged in real-world activities in the classroom (Brown et al., 1989).

Influenced by such general movements in education and theories of learning, science educators were charged to present science as it really is and move beyond textbook science (American Association for the Advancement of Science, 1989; Martin et al., 1990; National Research Council, 1996). The scientists' science became the model for the development of authentic educational experiences. Science was recognized as a fundamentally social activity in which members of a community share resources to achieve a common goal (Driver et al., 1994; Roth, 1995, 1997). Students were offered opportunities to find solutions to real problems by asking questions they deemed important, by designing and conducting investigations, and by analyzing and reporting data (Krajcik et al., 1998).

Despite such reform efforts, the general approach of mapping the practice of scientists to the classroom has been questioned (Barton, 1998b; Martin et al., 1990). Furthermore, school apprenticeships are not to be equated with job apprenticeships in which authentic learning entails taking part in the real activities of practitioners over a sustained period (Lave & Wenger, 1991). In fact, and in line with practice theory, school science is best perceived as a form of science practice that by its nature will always be different from what real scientists do.

In recognition of the limitations, if not impossibilities, of creating scientists' science apprenticeships in the classroom or its close vicinity, face-to-face and virtual teacher–scientist and student–scientist partnership programs<sup>1</sup> have become a popular pedagogical tool because in most cases they offer opportunities for engagement in authentic practices as part of a real community (Barab et al., 2000; Cohen, 1997; Lawless & Rock, 1998; Radinsky et al., 2001; Richmond & Kurth, 1999). By working at the elbows of scientists, students and teachers learn about the content and process of science while they come to participate in a wide range of studies of scientific phenomena (Barab & Hay, 2001; Tinker, 1997). Most important, participation is embedded “in ongoing activity within the ecological niche in which the real-world practitioner functions” (Barab et al., 2000, p. 40) which will naturally result in an authenticity that is in synchrony with the science of the scientists.

Note, however, how the simulation model of scientists' science in the classroom and the participatory model of science education made possible through partnerships between scientists' science and school science both adhere to a static notion of authenticity. Both models tend to assume that by bringing the practice of scientists and the practice of school science together in some manner (whether in the school context or the ecologically valid niche of science practitioners), authentic science will be present by default or emerge given the learners' perceived meaningfulness and use value of such experiences (Barab et al., 2000). Both models preauthenticate the learning environment in some manner in that they place authenticity in the scientists' science. Through detailed analysis of learning in such participatory learning environments, it has become clear, however, that authenticity does not always flow out of the self-organizing dynamics as an individual becomes a participant of such communities of practice (Barab et al., 2000). Furthermore, whether the scientists' science (real or simulated) is a good and possible model

for authentic school science remains an issue that needs to be addressed and that we and others (e.g., Eisenhart & Finkel, 1998; Roth & Lee, 2002) question and to which we will return in the conclusion.

### *An Emergent Notion of Authenticity*

The emergent notion of authenticity is rooted within systems theory (Koestler, 1967; Simon, 1962), practice theory (Lave & Wenger, 1991), and the ecological-psychology perspective (Young, Barab, & Garrett, 2000). These approaches all oppose the practice of preauthentication and the practice of locating authenticity within a component of the system, or a simple combination of components. Essential to systems theory is also the phenomenon of emergence in that qualitatively new collective phenomena can arise through the coherent behavior of its parts, processes and agents (Lemke, 1995, 2002). What emerges depends on the interactions of the components of the system, and the boundary conditions or context under which the system is operating. For this reason, what authentic science looks like depends on each particular case and emerges as components of the case (teachers, students, contexts, activities, etc.) come to interact with one another in a complex manner.

Some science educators have proposed the development of an emergent notion of science that locates it in the world of its users and their interactions (Dewey, 1938; Petraglia, 1998). For instance, inquiry and project-based pedagogy offer opportunities to teachers and students to investigate, talk, read, and write about questions of interest to them (Krajcik et al., 1998). What makes such an approach authentic is that teachers and students get to pose questions that are anchored in authentic or real-world problems they are familiar with. Note, however, that such an approach is still grounded in the scientists' science as experienced by these students and teachers and not their lived experiences per se, which can pose some limits for participation for students who are not as fluent in the discourse of science as others (Moje, Collazo, Carrillo, & Marx, 2001).

In recognition of such a problem, other researchers begin with a science that is truly grounded in the students' daily experiences rather than the scientists' science. For instance, Barton's work (1998a) in an after-school science program demonstrates how activities that may have little to do with science initially become authentic to their participants once they claim ownership of them and are given the opportunity to participate in and reflect on their actions together. In this case, talk about feelings related to living in a shelter turned into a discussion about the ugly and dirty, rundown, and polluted neighborhood, and their dislike of abandoned lots and smelly gas stations they encounter on their walks home from school, which led to the study of pollution in their community. Similarly, Edwards and Eisenhart (2001) began with student interests in popular music and channeled these interests toward neighborhood autobiographies, to studies about dogs, and finally to the study of light waves. In these examples, authentic science comes to stand for science that becomes meaningful if seen within the context of the students' lives. But is this the science of scientists? It clearly moves us away from a model of authentic science education that is grounded in the science of scientists to a science that is continuously negotiated among scientists, instructors, and children. It is a science that is ecologically grounded in and becomes defined through collaborations and ongoing negotiations among the participants in such partnerships, and hence an authenticity that is also emergent.

Whereas the above examples underline the value of an emergent notion of authenticity, systems theory offers a theoretical means to further conceptualize such a construct. For instance, systems theory can be used as a metaphor to underline the fact that "the whole behaves as more than the sum of its separated parts" (Lemke, 2002, p. 1). That is, an activity is not authentic

because it consists of certain components that can be identified or prescribed a priori, but because of the dynamic manner in which these components come to interact and define the overall system over time. In essence, systems theory moves us beyond linear intuitions about cause–effect relationships and for this reason makes it a valuable heuristic for rethinking the meaning of authenticity in science education.

To underline the value of systems theory in thinking about the nonlinearity and complexity inherent in authentic science education, we examine two different situations in science education in this article. Systems theory has already become an invaluable heuristic for understanding human development (Smith & Thelen, 1993; Thelen & Smith, 1994) and educational change (Lemke, 1995, 2002; Bateson, 1973, 1979), whereas it has a somewhat longer history of use in physics, chemistry, ecology, and evolutionary biology (Kitano, 2002; Salthe, 1985; Simon, 1962).

### Methodology

We present two case studies (Donmoyer, 1990) to situate our argument for an emergent notion of authenticity, with each emphasizing different features of the dynamic that came to define authenticity. The first case exemplifies the meaning of it in the context of a system with an emphasis on interactions and interdependences among teachers, scientists, and their educational environments; the second case gives more focus to students' interactions with scientists.

The two cases were selected given their illustrative power of the theoretical construct at issue here. The fact that both cases are instances of informal science education programs should not be taken as a suggestion that authentic science only happens in informal educational contexts. Instead, the aim is simply to illustrate what an emergent notion of authenticity can look like in situ. Both cases were part of larger ethnographic studies examining the kinds of learning opportunities in science and understandings of science the two programs offer to youth (Miller, Andrews, & Moore, 1999; Rahm, Naughton, & Moore, 2002). How the cases themselves were constructed is addressed as they are introduced.

#### *Example 1: Schoolyard Plot Project*

The schoolyard plot project is an outreach project of the Long-Term Ecological Research (LTER) Program funded by the U.S. National Science Foundation. All 24 LTER sites in the United States and Antarctica support Schoolyard LTER programs. A qualitative case study (Spradley, 1980) was undertaken of the collaboration between the scientists and the teachers during the development phase of this project. Field notes were collected of two scientist–teacher workshops in addition to journal notes of site visits and teacher and student interviews during the school year (Miller et al., 1999). Through numerous rereadings of field notes and discussion among the authors, a solid understanding of how each teacher perceived his or her participation in the program was developed. These data were supplemented with demographic information about each teacher's setting, and the concerns and research interests teachers had raised during meetings and informal conversations, on which basis the final case could then be constructed (VanMaanen, 1988).

#### *Emergence of Authenticity through Negotiation*

The scientists began the collaboration with three different scenarios in mind for their partnership. One scenario was to have participating schools replicate experiments currently under

way in demonstration plots at the university. A second scenario was to have schools contribute to already ongoing projects at the LTER site. A third scenario was to have schools develop a unique experiment for the schoolyard that is patterned after the LTER model. Hence, scientists came into the collaboration with ideas for research programs and protocols suggestive of the scientist-led model of a partnership (Tinker, 1997). At the same time, based on prior research, they knew that the third scenario was most likely to be adopted, given the unique features of each site and the different needs of the students at each site (Miller et al., 1999). Hence, the scientists were open to suggestions by teachers and students.

To open the floor for negotiation, teachers were presented with an example of a research project carried out by a group of students from a local summer program at the university demonstration plots. The study consisted of four manipulations arranged in a randomized block fashion to determine the roles of microbes in controlling secondary successions as a result of nitrogen supplied. The plots were manipulated as follows: 4 plots served as controls, 4 were treated with nitrogen fertilizer, 4 were treated with sucrose (table sugar), and the remaining 4 were treated with a combination of nitrogen fertilizer and sucrose. The plots were seeded with a standard mix of native seeds. With guidance by scientists, students then recorded frequency and relative frequency of different plant species, plant litter and bare ground, and sampled the soil for bacteria, fungi, protozoa, and arthropods.

Although teachers valued that presentation, they opted, as anticipated, for projects that met the unique features of their sites and the interests of their students (Table 1). Each teacher joined the partnership with different motives and goals. The face-to-face interactions with the scientists at the workshops and through informal conversations at school visits forced a negotiation of the partnership over time that challenged the leadership and prescriptive approach that the scientists initially envisioned. In fact, the scientists came to realize quickly that what counted most was a state of mind for collaboration, rather than the science per se, i.e., the physical establishment of schoolyard plots or the duplication or extensions of projects already ongoing.

It shows that by bringing scientists and teachers together, authentic science does not simply happen in a prescribed or static manner. Instead, authentic science emerges, is negotiated, and depends on how the components of the system (in this particular case the partnership) come to interact with one another over time. For instance, Sue came from a rural-agricultural community, serving only 46 high school students. She was interested in pursuing issues related to farming, such as how to maintain a healthy soil, the role of conventional and conservation tillage, pesticides, and other issues pertinent to sustainable agricultural programs. At the same time, some of her students were committed to other aspects of ecology, changing their projects from one year to the next. Accordingly, the science emerged as teachers, students, and scientists came to interact, and could not have been predicted based on one of these components, but rather came to be defined through an interaction of them.

Ancillary issues also came to define the kind of science that emerged. For instance, Sue was enthusiastic and was able to put much time into the partnership. It made it possible for her to drive her students to the university laboratories on numerous occasions where equipment and expertise were available. The parents of her students also supported their scientific work and helped out when needed. Furthermore, this group was the only one that approached ecology as a science rather than as environmentalism, a popular misconception found at the other participating schools, facilitating collaborations with scientists who also shared a similar research approach.

The approach that worked for Sue, however, would have been meaningless to other groups of students and teachers participating in the partnership, underlining the diversity of authenticity. For instance, Erin came from an alternative charter school in a midsize suburban town with

Table 1  
*Participating schools and their research interests*

Teacher	Setting	Current Concerns and Research Interests
Sue	Small rural village Small high school (46 high school students only)	No need for an actual plot but ideas and support to conduct studies that also lend themselves to science fair projects was requested. Research interests: <ul style="list-style-type: none"> <li>• How to maintain a healthy soil.</li> <li>• Role of conventional tilling.</li> <li>• Pesticide and its relation to soil.</li> <li>• Forensic entomology and blood splatter analysis</li> </ul>
Lewis	Semirural village Midsize high school	Started own plot years ago; likes to protect it from intruders through the establishment of a fence Research interests: <ul style="list-style-type: none"> <li>• Warming studies (fiberglass domes to measure transpiration)</li> <li>• Effects of rain on plant growth</li> <li>• Rain shelters to study precipitation patterns</li> <li>• Effects of grazing on short-grass</li> </ul>
Tim	Suburban town Midsize high school	Struggles in development of plots given lack of space and lack of approval for fence. Research interests: <ul style="list-style-type: none"> <li>• Greenhouse—potting experiments with different cultures (protoactivity trials)*</li> <li>• Weather station*</li> <li>• Soil probes</li> <li>• Research-driven projects that draw students into science</li> </ul>
Erin	Midsize suburban town Alternative charter school Small student–teacher ratio	Area for plots was identified. Could also do with wheel barrels as plots Research interests: <ul style="list-style-type: none"> <li>• Develop and sustain healthy environment</li> <li>• Decomposition of trash</li> <li>• Comparison of environments of other semirural city schools: find ways to improve it</li> </ul>

*Note.* Pseudonyms are used for all teachers.

\*Activities in which all groups were interested.

agricultural influences, serving students who dropped out of public high schools due to family issues, pregnancy, drug use, or encounters with the law, and who were trying to reenter the education system and finish high school. Erin noted that her students would show little interest in replicating a study real scientists had done. Instead, she focused her effort on how a healthy environment in an inner city can be restored and maintained. At the same time, Erin was also much consumed by day-to-day tasks involved with teaching at-risk students and had less time than Sue to put into the science projects. Structural constraints at her school further undermined students' engagement in science activities over extended periods. Accordingly, the kind of authentic science that emerged for Erin was different from the one that came to define Sue's participation (Table 1). Authentic science cannot simply be prescribed through an innovation but emerges through interaction of multiple components of an educational system over time.

The manner whereby the partnership became authentic for Tim and his students shows yet another dimension. Tim taught at a high school serving middle- to upper-income level students in a

midsize suburban town. He was most interested in initiating research that would then draw the students in, rather than having the students themselves decide where to start. One of the classes is studying the aspects of ecology at a community nature area by looking at vegetation characteristics on and off prairie towns, arthropod pitfall trapping, and the idea of roads as corridors for the invasion of exotic plant species. Tim's thinking is that this project will have something for every student to do, gets the students out of the classroom into the field, and may provide the community with information for natural resource management because prairie dogs and invasive species are a hot topic for land management in the west. Hence, Tim's own interests and context came to define the science activities. Although he took charge of defining the kinds of projects to pursue, there was still enough room for the emergence and negotiation of meaningful activities. By beginning with topics already under study at the school (i.e., ecology at a community nature area), what authenticity came to mean here differed. Student choice and teacher-student negotiation were less prominent than in the other two examples, yet still came to define, among other components, the kind of science that emerged. Accordingly, the components of the system that gave rise to an authentic science were like the ones previously described, but they came to interact in a different manner, leading to an emergence of authenticity specific to this case.

Partnership models, as the one we described, too often embrace a static notion of authenticity, in that they assume that authentic science gets done once teachers and scientists are brought into contact. Yet, our study, among others (Barab & Hay, 2001; Barab et al., 2000), speaks to the dynamic and emergent nature of authenticity. The form taken by the schoolyard plots and associated projects could not be prescribed by the researchers, but instead became a process of negotiation among the groups of people involved and the contexts within which they had to work. Hence, such collaborations can take a variety of forms and need to be thought of as constituted by the collaborative context that exists between a scientist and a classroom teacher. What authentic science means needs to be actively and continuously renegotiated through interactions among scientists and teachers, and even further through involvement of the students.

The structures and organizations of schools are also components of the system that need to be considered in examinations of the emergence of authenticity. For instance, Lewis, who had taken initiative to develop a schoolyard plot on his own with support from a teacher development grant years before, participated in the partnership with the motive to legitimize the use of plots for science teaching (Table 1). Because of growth at the school resulting in the need for more parking space, the existence of his plots were threatened. Given his motive, he was most interested in finding a way to protect this area, while he was also eager to gather new project ideas. Accordingly, what authentic science came to mean in this case was determined by the negotiation among the scientist, the teacher, and the students within the constraints imposed by school officials and district administrators. The examples presented in our first case study illustrate how different components of a system come to define the kind of authenticity that emerges, and the value of moving beyond a practice of preauthentication. Whereas this case already makes evident the value of sustained experiences and involvement in a science activity (or in this case partnership) and eventual ownership of such an activity by schools, teachers and/or students, what these two characteristics imply is further illustrated through our second example.

### *Example 2: Fire Ecology in a Math and Science Upward Bound Program*

COSMOS is a Math and Science Upward Bound Program funded by the Department of Education. It is a voluntary longitudinal program that includes a 6-week residential summer

program centering on hands-on research group projects that teach students much about the process of science and the use of mathematics and technology as tools in that process, with opportunities for students to participate in a summer research internship. Monthly school visits, academic assignments, college application guidance, and field trips give a continuity to the program during the school year. The program accepts students who are in 9th or 10th grade and who are either first-generation college-bound and/or low-income (annual salary at <150% poverty level). The student body is gender balanced and ethnically diverse (42% European Americans, 40% Hispanic, 18% Hmong and Vietnamese, and <1% African American and Native American). Most students participate in the program for three consecutive summers. Despite its academic focus, the structure and activities of COSMOS make for a unique learning environment typical of informal science programs (Crane, 1994).

A qualitative case study of the program was initiated in the summer of 2000 and continued in 2001, examining the kinds of learning opportunities in science COSMOS offers to students over time (Rahm et al., 2002). Through the collection of field notes and video recordings, students' forms of participation in science activities could be examined. Such data was supplemented with yearly interviews of students and instructors examining their perceptions of such science activities and of science in general (Spradley, 1980). In this article, we focus on video data and field notes from a program activity in fire ecology that has been part of the program since its inception in 1996. As part of the program, a weekend is spent in a camp in the mountains. The camp was partially destroyed by a fire in 1994, lending itself well to a study of vegetation and regrowth in a variety of plant communities over time. The fire ecology project is used to teach students data collection skills, analytical techniques, and presentation skills. Students are first engaged in an analysis and presentation of fire ecology data from previous years, and only later collect new data—a sequence that may appear somewhat odd, yet is meaningful within the context of the whole program. For ease of readability, however, we begin with a description of data collection and analysis and illustrate the ways that these activities made possible sustained involvement in a scientific activity. That part of the case was constructed through an analysis of field notes and interview protocols pertaining to the fire ecology activity. We then turn to a dialogue following participants' data presentation to illustrate how project ownership came to mark the project as authentic. The particular dialogue was chosen because it illustrates how two students' ownership of the activity (i.e., Monica and Jay) came to define authenticity here. It was transcribed verbatim and examined for illustrations of scientist–student negotiations.

*Role and Value of Sustained Involvement in a Scientific Activity and Community.* Groups of about 5 students (2 in their first year, 2 in their second year, and 1 in the third year) collect data in one of the five sites through the transect sampling technique. Doing transects entails many steps. First, a long tape marked at set intervals is laid across the area to be studied. Data collection points are established every 10 m. Beginning at the origin, the quadrat (a rectangle frame also referred to as Daubenmire square, named for its inventor) is used at each of those points to determine groundcover. Within each frame, students recorded the presence and absence, and the percentage of the area covered within the frame of the following: (a) grass—any grass or grass-type plant; (b) forb—a nonwoody, leafy plant; (c) shrub—a plant that is woody but not a tree; (d) saplings; (e) dead trees; (f) bare ground; and (g) rocks. Using these measures, the students calculated the frequency of each category, and relative frequency (how many times it is found in relation to other types of cover). Trees were also identified and their sizes recorded using the point-quarter method (a specific procedure to determine trees within a 5-m radius of a data collection point). Groups were also asked to describe their sites and identify some flowering plants.

Students followed scientists’ data collection protocols and were fully engaged in all aspects of data collection. For instance, groups practiced doing transects under the guidance of scientists and third-year students before collecting the actual data for the study. Guidance took many forms from advice on how to position the quadrat, to making sure everybody was involved and on task, to answering questions about the data to be collected. An example is Monica’s level of scaffolding as her group begins assessing plant growth in a quadrat:

Speaker	Dialogue	Comments
Monica:	Okay, Is that a grass or a forb?	Points to plant.
Somebody:	A grass!	
Monica:	I was just making sure you were on the same page.	Justifies question to group. Mumbling
Monica:	So now, does everyone agree?	
Daniel:	Forbs.	Notes new category.
Pete:	So what am I supposed to do for the description?	Asks for guidance.
Monica:	We just do it at the end. Just pay attention to all the fallen things here. Do you see all the dead trees?	Helps the group focus on quadrat.
Daniel:	There is about 5% of forbs.	Estimates forbs.
Monica:	You know what’s easiest, you start with the biggest thing, whatever you see the most of in there	Offers a strategy.
Susan:	Yeah, bare ground.	Responds to advice.
Monica:	And then take that and then whatever.	

Monica, a third-year student who took on the role of a mentor, directs her participants’ attention to the kinds of plants they are attempting to differentiate within the quadrat. Later, Monica again makes sure her group is on task. She postpones advice for the two team members who are in charge of the site description and instead gets everybody to focus on the burned wood pieces scattered in their area, a unique marker and feature of their site. The group then struggles to identify the vegetation and determine groundcover. Monica offers some practical advice: “Start with the biggest thing,” which first-year students immediately followed. This example illustrates the traditional apprenticeship model in which old-timers (here third-year students) help newcomers (first-year students) become masters of a new practice through guidance and modeling (Brown et al., 1989). As one mentor summarizes:

Our role is to help other students to kind of go through running a transect and then setting it and doing the percent cover and so our role is just to be the leader and teach them, not necessarily do all the work, but start it off and they just slowly get used to doing it.

Note also the sustained nature of involvement this project made possible. First-year students, the novices, were apprenticed by their peers who had become old-timers of this practice through involvement over time. At the same time, third-year students had become full members of this community of practice and were the masters who mediated the different data collection phases. For instance, here, newcomers were involved in the process of achieving consensus for ground-cover categories, and literally learned by doing with some guidance, as the following excerpt illustrates:

Speaker	Dialogue	Comment
Rose:	Litter is like 20. Twenty percent litter.	The recorder, notes one category amount.
Nan:	So then 15 bare ground?	
Heather:	I don't think there is that much bare ground.	
Rose:	But look at all that, oh yeah, it's true.	Challenges others.
Kim:	So more litter than bare ground?	Third-year student.
Nan:	I would say like 10% bare ground.	
Rose:	I would say there is more forbs. Right here, there is sage, like down here. Can you see that. It's like	Points to different plants.
Chris:	The bare ground is like all along here, though also, it's like under the dead stuff.	Points with foot to another area.
Heather:	But that wouldn't count as bare ground?	Suggesting area underneath plants.
Chris:	Yes it does.	
Heather:	No.	
Kim:	So what about the bare ground, what percent?	Guidance—try to get an agreement.
Rose:	Bare ground is not that much. Really, 10% at the most.	
Nan:	Yeah, that's what I say bare ground 10% too.	Agreement between two estimators.

Estimation was often done through comparison of at least two different categories. For instance, litter and bare ground were compared here in attempts to get to an agreeable estimate. This led to a disagreement about the amount of bare ground. While Chris pointed to bare ground underneath plants, Heather questioned whether such should be counted. Note how Kim, the third-year student, offers little advice here. Instead, he tries to get the others to agree on an amount of bare ground. Mentors tried hard to step back and help others learn by doing data collection and analysis. Bare ground was now taken to represent 10% by 2 of the 3 estimators, a small change from the initial estimate by Nan (15%). Negotiation of this kind is important and reflective of the kinds of processes scientists engage in as they collect similar data in the field (Bowen & Roth, 2000a, 2000b). It suggests that students took this task seriously and enacted the role of real scientists engaged in data collection.

Clearly, the fire ecology project offers participants sustained involvement in experiential-based science at the elbows of scientists and expert students. In essence, it illustrates an apprenticeship-like situation. Through involvement in the fire ecology project for 3 consecutive years, participants were able to develop a deeper understanding and appreciation of the science embedded in that task and could come to see it as meaningful and valuable:

Like, you see a lot of grasses have grown back. A lot of baby trees that you never think would grow back this quickly... just being able to be around all the younger students and seeing them be amazed that there's [been] a fire. In some places, it doesn't even look like it and then you can tell in other places that there was... Yeah, over the 3 years I saw a big change and I'm sure they will, too. I mean, the first-year students were probably, like, wow, there's not, this is boring. But as it goes on, that's how I was my first year, but as it goes on you see the changes, and you're, like, wow, things just grow.

Seeing how (almost) randomly a fire can destroy the vegetation while also noticing the speed at which life comes back after a fire was novel to these students. It was also something that became evident to them only after numerous visits to the same site and through close examination of regrowth over time. It speaks to the power of sustained involvement in a project over time, something many partnership programs lack (see, for instance, Barab & Hay, 2001; Richmond & Kurth, 1999).

Sustained involvement not only makes possible a deeper understanding of and actual membership in the science practice, it is also essential for authenticity to emerge. In our site, students were initially unclear about the meaning behind data collection and only through involvement in all components of the project (collection, analysis, and presentation), by seeing vegetation growth changes over time, and by taking on different roles over time did the fire ecology project become meaningful and valuable to most:

I am really interested in nature and the way things work and going out there and doing a hands on activity is really good to see. Like, earlier this year we were presented with information about the fire. I did that last year so our information was in there and then every year we do that fire project and I think it has been 5 years that they have done it now. So going out there after you do the presentation is, like, okay this is why we do this and stuff like that. It gives you like the real scientist feel, like when scientists go out and do field work that is what they do.

A static view of authenticity would argue that having students work with scientists will increase their understanding and appreciation of science. This analysis emphasizes that simply having students do what scientists do or by having students work at the elbows of scientists does not guarantee that science is authentic to youth. Only once the students understood the meaning and value of their work did the project become authentic to them. It illustrates well the value of an emergent notion of authenticity in that authenticity did result from a complex interaction and relationship among students, their forms of participation over time, student–scientist interactions, and the students’ interactions with the tools and objects of science in a real-world context. Note also that not all students came to value this activity. For some, it remained an activity they participated in yet would not have sought out on their own. That is, not all students came to own the project. Hence, project ownership is an important yet not defining feature that mediates the emergence of authenticity.

*Role of Ownership of the Fire Ecology Project.* One of the primary objectives of the presentation of the fire ecology data is for students to enhance their presentation skills. Students were given data sheets that summarized the previous years’ data and put in charge of one of the sites. They were asked to develop two hypotheses based on the data, find background information about fire ecology, test their hypotheses, develop tables, figures, or graphics to present their results, and make inferences about potential future studies. For some, it was their first encounter with the fire ecology data, with developing presentations, and with the presentation software, while second- and third-year students now had an opportunity to present data they themselves collected the previous year. Interestingly, project ownership made it possible for second- and third-year students to also question certain components of the scientists’ practice and to challenge scientists as they commented on their presentations:

Speaker	Dialogue	Comment
Scientist:	You guys are not the only ones who said this, I heard this from a number of the talks that there seems to be a problem, you are having a problem with the fact that the transects may have been laid down in slightly different areas. How many, how many quadrats within each transect were taken?	Scientist questions the whole group about their interpretation of sampling error while sitting in the audience.
Jay:	Ten.	
Scientist:	Ten quadrats? Okay. So essentially you are in an area and you have taken 10 samples. And you are getting an average.	Scientist gets students to think about sampling.
Jay:	Right.	
Scientist:	Of those 10 samples. Why, why would it be a problem. Why is it a problem if you are then going to put the transect down and even if it is over a little bit and you are then going to take 10 more samples the next year and then going to average?	Scientist engages students further to have them understand the issue under contention in new way.
Monica:	Because even if it's, ugh, just like a couple of feet over, it's messing with the data because you're seeing how things grow over a period of time. And if you aren't looking at the same things year after year, then your data is going to get messed up because you aren't collecting the same things.	Second-year student challenges scientist.

One of the ecologists in the audience noted that all groups appeared to have a problem with the manner in which the data was collected. Instead of leaving it to the students to defend their positions, however, he then asked about some of the specifics of data collection. He attempted to reemphasize that they were assessing regrowth in an area in which samples were taken, samples that might not have been absolutely identical but that were statistically representative and within the target area, and of which they took an average. In doing so, he subsumed an understanding of the difference in meaning between sampling in an area as opposed to a specific site. By using an average of measures rather than measures per se, he further attempted to clarify a method that diminishes threat of sampling error. Although the meaning of sampling in an area appeared a transparent concept to the scientist, the students did not understand it as such. In fact, Monica kept insisting that they were not “looking at the same things year after year” which put data validity into question for her.

Monica's and Jay's prior understandings of the scientific methods came to color their interpretation of the data collection procedures they engaged in at the elbows of scientists. Their notions are illustrative of the inductively logical process of scientific investigation typically portrayed to students through the standard scientific methods (Duschl, 1994) and the “cookbook exercises” that make up most classroom projects (Hodson, 1998). In essence, the students raised concerns about the rationality of science. They did not understand that hypothesis testing is a “messy” multistep decision-making process carried out in a community of practice (Hodson, 1998). It shows that their own notions of the scientific method were more powerful than the experiences they had in the field or the current dialogue with a scientist. Richmond and Kurth (1999), who reported on a similar partnership program, also noted their students' struggle with notions of uncertainty and lack of control in scientific investigations.

Even more important for our discussion, however, is the students’ active engagement in the ensuing dialogue which makes apparent their ownership of the project. In fact, the back and forth exchanges make evident the manner in which science knowledge was co-constructed and co-managed by the scientists and the students. The students were clearly comfortable to challenge the scientist’s take on the sampling method, and hence his authority, as the subsequent exchange illustrates:

Speaker	Dialogue	Comment
Scientist:	What are the things you are measuring? I guess that’s what really, that’s really what it comes down to. You stated that really nicely. What, what is it that you’re trying to get a handle on? Is it specific shrubs or is it an area that was affected by the fire?	Scientist attempts to have students reflect further about unit of measurement.
Monica:	It’s the area.	
Scientist:	Okay. So if that’s the case then I would argue that it, it really wouldn’t matter if it [the transect line] was over a little bit. That when you lay that transect down across the same area, if you are getting 10 samples within that area so then you’re going to get an average of what’s happening in that area.	Scientist reinstates notions of area and average.
Monica:	But it’s 10 different samples from a completely different resource, so	Monica challenges further.
Scientist:	But it’s in the same area though.	
Jay:	But what you’re trying to compare is that same exact area. It’s like when you run an experiment you wanna change like one variable at a time.	Makes evident the inductively logical process of a scientific investigation.
Scientist:	Right.	
Jay:	And when you’re doing this, you’re changing, like, you know three different variables at once.	
Scientist:	Okay.	

Note how the scientist restates his argument in a further attempt to clarify the meaning of sampling error. Yet, Monica insists that they are getting “different samples from a completely different resource.” Jay further substantiates Monica’s point by emphasizing that they did not look at “that same exact area,” and hence changed too many variables leading to sampling error. Jay’s addition gives further credence to “their” interpretation of sampling error.

Clearly, students took an active part in the dispute and were able to use each other as resources to articulate their position. The fact that they were ready to defend their interpretation of sampling error suggests that they had gained ownership over the project. By challenging the scientist’s interpretation, they could make explicit their understanding of research and use it as a resource in this exchange to gain the floor and be listened to. Having collected the data themselves positioned the students as knowledgeable peers next to the scientist and as legitimate participants in a scientific dispute. Accordingly, what made this partnership program and project authentic was not the fact that youth got to do science at the elbows of real scientists, but that they had multiple opportunities over time to do real science and thereby become full respected members of this community of practice.

Seen through the lens of systems theory, the following components came to define the system: opportunities to pursue data collection at the elbows of scientists, opportunities to engage in real data analysis and presentation of data, opportunities to co-construct and challenge the authority of scientists, and opportunities to become a member of a research community through sustained involvement. Other components certainly were also important, such as student interest in the activity, the form the partnership took among scientists and students, and opportunities for continuous negotiations among the members of the system. Yet, most important for the argument of this article is the dynamic relation among such components that came to define the kind of science that emerged and that came to be taken as authentic among the members of this particular partnership. Whereas possibilities for sustained involvement over time and project ownership are two defining characteristics of authenticity, these two characteristics alone do not ensure the emergence of authenticity. If we were to advocate such a perspective, we would again be preauthenticating student activities. Instead, we argue that these two characteristics are important, yet not defining components of a system. They are components of a system that mediate the emergence of authenticity.

### Discussion

We began the article with questions about authenticity: what it means and according to whom. We proposed the value of an emergent notion of authenticity that situates it no longer in individuals, tasks, or communities, but instead in the dynamic interactions among these components (Barab et al., 2000; Barab & Hay, 2001). Authenticity was presented as an emergent property of a system (e.g., the two partnership programs) based on the interactions and relations actors (i.e., students, teachers, scientists) have with the many components, levels, and layers (i.e., school setting, administration, fiscal constraints, time) of such a system (Simon, 1962). We advocated a nonreductionistic and nondeterministic perspective toward authenticity that has its roots in structural approaches to learning and development as advocated by Piaget (Petraglia, 1998) and systems theory as widely used in biology (Bateson, 1973, 1979; Koestler, 1967; Salthe, 1985; Simon, 1962). The two cases presented exemplify the ways in which authentic science is best understood as grounded in the relations and negotiations among the worlds of teachers, students, and scientists as they collaborate in ecologically valid contexts. The first case underlined such a negotiation, whereas the second stressed the role of sustained involvement and the value of project ownership. What it means to do authentic science is negotiated and emergent from the components within a complex system that also includes the social, historical, political, and physical contexts of the lives of teachers, students, and scientists (Barton, 1998b).

Most important, the science that emerges is grounded in the relations between the world of scientists, teachers, and students and for that reason no longer represents the scientists' science per se as advocated by current science education documents (American Association for the Advancement of Science, 1989; National Research Council, 1996; Rutherford & Ahlgren, 1990). Hence, the emergent notion of authenticity discussed in this article does not suggest an idea for science education reform. Instead, our article questions the premise on which current innovative science practices are based: namely, the practice of preauthentication. In fact, we suggest that current science reform movements who advocate scientists' science (Roth, 1995), inquiry science (Krajcik et al., 1998) or community science (Richmond & Kurth, 1999; Roth, 1998) may not be more or less valid than traditional practices of science education because they are all based on a premise we question: the static view of a science that fits all and the practice of preauthentication. As shown here, when we look more closely at what happens in and outside of classrooms, it becomes evident that the kind of science that gets done evolves and takes on many forms and is

negotiable and dynamic rather than static. For these reasons, we agree with Barton (1998b), who suggested that “a science for all can truly be for ‘all’ only if it is removed from the center and allowed to be a positional and dynamic construction of multiple realities” (p. 539). In fact, our first example illustrates well how the science that got done reflected the ecological niche within which it emerged, which included the classroom but also the context surrounding it, and hence illustrates well how misleading and superfluous such distinctions can be. Accordingly, authenticity is not taken to be located anywhere but is understood as emergent through the interactions of components of a system. Nevertheless, we have shown that the presence of certain components is more conducive to the emergence of authenticity. For instance, involvement over sustained periods of time as well as possibilities for project ownership were seen as important yet not defining variables.

Similarly, research in science education has shown that inquiry- and project-based science, for example, in which the study of science begins with students’ questions, is conducive to authentic science (Krajcik et al., 1998; Moje et al., 2001). We would certainly agree with this. Yet, we challenge the causal relation between curriculum design and authenticity and instead suggest that student questioning is most likely an important component of a system within which authenticity can emerge. Other components, however, also need to be considered to understand fully what makes inquiry science valuable and authentic to some students, teachers, and researchers. At the same time, through a focus on the emergence of authenticity, we may also better understand why so many children still fail in science and why some also struggle in inquiry science classrooms, for instance (Moje et al., 2001). By examining how components of a system interact, problems and tensions in the system can also be identified, and, based on such an analysis, steps may be taken to improve on components and their relations in a manner to ensure learning and authenticity for its participants.

### Conclusion

In conclusion, we contend that authenticity remains an important concept that can help us think of science education in new ways if understood as emergent. It leads to an emphasis on understanding the processes rather than products of learning. The question is then reformulated to how we, as educators, scientists and researchers, can find ways to support the emergence of authenticity and lead students toward an understanding of science that has something to do with the real world of theirs and is meaningful to them. In addition, we have to keep thinking about ways to offer all students learning opportunities that do matter to them and that they deem valuable. Finally, we have to remember that students’ and teachers’ worlds (e.g., preconceptions about science, contextual features teachers and students have to accommodate) can pose serious obstacles to learning and involvement in activities at a level that can make the science meaningful and valuable to them. In essence, we have to become more aware and take seriously issues with which our children and teachers struggle. To begin with their needs and interests rather than science per se may be particularly promising (Barton, 1998a, 1998b, 2001a, 2001b). In so doing, we have to keep in mind the social production of scientific knowledge and the social production of school science (Gaskell, 1992). Martin et al. (1990) reminded us of that point:

It may seem banal to state it, but education involves being with, working with, teaching and learning from children. This means that our notion of authenticity must be mediated by the realization that what is authentic for the adult may not be authentic for the child and vice versa. Any attempt to develop an authentic view must first be grounded in the individual. (p. 550)

Currently, too many students lack access to the real world of science and are disenfranchised from science by cookbook or textbook science activities. This, we are told, is a state of affairs we can no longer afford to ignore. Authenticity as grounded in the relations among actors within a system, as emergent, and as diverse in meaning is a promising notion that can help us move beyond the mythic notion of authenticity based solely on scientists' science that has come to dominate current school science practices. An emergent notion of authenticity also reminds us that the goal of education is not to make scientists of students, but to provide them with access to experience-based science activities that provide them with new perspectives and insights into the complex world of science that is part of everything we do. Our two examples illustrate how teachers and students could gain access to a small component of the world of science through two different partnership programs. Although only a fragment of the complex world of science, such an experience appears to have helped them see science in a new and more positive way, and as something worth investigating, knowing about, and participating in. All students need to be offered experiences of this nature; whether they happen in classrooms or outside is irrelevant. What matters is the approach we take to support the emergence of authentic science—and that we move beyond the practice of preauthentication.

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#### Notes

<sup>1</sup>The following are recent examples of such collaborations: the National Geographic Kids Network (Bradsher & Hogan, 1995), the Global Learning and Observations to Benefit the Environment project (Means, 1998; Rock & Lawless, 1997), the Global Rivers Environmental Education Network project (Donahue, Lewis, Price, & Schmidt, 1998), and Forest Watch (Rock & Lauten, 1996), among many others (Cohen, 1997).

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