Learning Science in the Community[1]

Stuart Lee (shlee@uvic.ca) & Wolff-Michael Roth (mroth@uvic.ca)
University of Victoria

We live in a time when tremendous technological extension of human abilities and lifeworlds[2] is having a profound effect on our culture, neighborhoods and environment. Even with all this power available to them, many people remain on the outside of the technological riptide surging through society. Some science educators claim that this is evidence of a severe problem of technological and scientific illiteracy (Hazen & Trefil, 1991). Unless our students become scientifically literate, these educators say, they will have great obstacles to becoming empowered participatory citizens integrated meaningfully into society.

Although we may agree that there is a societal problem of scientific and technological illiteracy, we take a different view of both the problem and potential solutions. For us, common examples used to "demonstrate" illiteracy fail to be convincing. For example, the film "A Private Universe" showed Harvard Ph.D. graduates who explained summer heat and winter cold in terms of the sun-earth distance rather than the inclination of the sun's rays. In response to claims that this shows illiteracy, we reply that the inference is quite reasonable (it is valid for asteroids), and the fact that this interpretation is wrong in the context of the earth has little relevance to the graduates' lives. Another standard example is the difficulty many people experience in appropriately programming a VCR. In this case the problem could be considered one of poor design or technical writing (e.g., Winograd, 1996).

We are more interested in how people do "science" than whether they can recite fragments of scientific discourse or interpret engineers' technical inscriptions. When planning a meal, building a compost pile, taking a child for a nature walk, how does a person make sense of and act appropriately toward their physical surroundings?

We offer the thoughts of the Belgian philosopher, Gerard Fourez, as a different approach to science literacy. In an article on scientific and technological literacy (Fourez, 1997.), Fourez outlines some of the major practices one may engage in through the everyday use of science, whether as an environmental activist or an engineer. These frame his notion of scientific literacy, and include the skillful use of "experts; black boxes; simple interdisciplinary models (rationality islands); metaphors, comparisons and images; translations; standardized and disciplinary knowledge; and rationality in the process of making decisions." Using these criteria for assessing literacy, we suggest that science is very different and much more than what is currently taught in schools.

---

[1] Paper presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, LA, April 28-31, 2000. The preparation of this paper was made possible by grants 410-96-0681 and 410-99-0021 from the Social Sciences and Humanities Research Council of Canada (SSHRC) and by an internal SSHRC grant from the University of Victoria. We are grateful to Sylvie Boutonné and G. Michael Bowen for their help during the data collection.

[2] The term "lifeworlds" refers to the entirety of lived experience, as a being in the world, and draws its conceptual basis from Heidegger's phenomenology (Heidegger, 1977). For example, television news extends our lifeworld far beyond our everyday experience.

This chapter explores the questions: What does "scientific literacy" look like? How does the experience of participating in an authentic science-related activity differ from that of learning science in school? and What is science? We scaffold our analysis of a case study on Fourez's notion scientific literacy (Fourez, 1997), and Bourdieu's "logic of practice" (Bourdieu, 1990).

In the rest of this introduction, we critique current educational practices, focussing on two problematic aspects of science education. To suggest what we think scientific literacy looks like, we sketch anthropologists' findings of what technoscientific professionals do at work, and touch on some of the common features of science in everyday life outside the work world.

School, Professional and Everyday Science

Is School Science Scientifically Literate?

Over the past decade, science education as enacted in schools has come under criticism because of the constraints to meaningful learning it constructs (Tobin, 1990; Tobin & Gallagher, 1987). We do not want to pursue this line of argument, although it is clear that little has changed since Tobin and his associates' first qualitative research projects (Roth, Boutonné, McRobbie, & Lucas, 1999). Here, we want to briefly address two issues seldom discussed, but significant in the context of our recent work. First, science and other subjects in schools are clearly demarcated into different domains spatially, in separate rooms, temporally, in time slots and cognitively into distinct subjects. Second, science encourages the production of a submissive populace, striving to please an authoritarian figure and discourages engaging in and challenging the current social political issues of the time.

Demarcations. In schools, the main narratives of science are divided into units of subject area and within subjects, into groups of decontextualized "facts." In everyday scientific endeavors these divisions are not so clear. Relations become more important as people gather together the appropriate tools (advice from an expert in another field or a new detection method) irrespective of discipline, to solve a problem. Facts become less important than the contexts, which argue for or against the acceptance of knowledge claims. What controls were run? What was the sample size? How was the variable measured? Who did the work? These are the issues practitioners consider when working with "facts."

Schools also create boundaries between science and other aspects of society, such as economics, politics and history. Science is taught as a sterile, disinterested pursuit of "perfect" knowledge. It is not uncommon to hear science teachers tell their students "That's not science, that's politics. Let's keep out of politics." This is not consistent with sociological studies of science and technology, which have repeatedly shown science to be interwoven in a constitutive way with other aspects of life (Latour, 1993a, 1993b).

The dissociation of school science from other school subjects is also embodied in the physical structures of school life. Beginning with middle school, students often move into specialized rooms (“laboratories”) where they enact particular practices said to develop their scientific skills. This physical separation demarcates science and associated practices. Laboratories become special places (“cathedrals” [Knorr-Cetina, 1992]), with their special almost religious routines, their own forms of discourse, forms of adulation, etc. (Fuller, 1997). Although some everyday professional science is performed in laboratories, much everyday science is practiced outside their bounds—in offices, kitchens and backyards.

The temporal sequencing of the school day which jerks children out of an activity before they can develop a coherent sense of it or a conceptual context before they understand it both contribute to an experience of alienation from the subject.[3] These short time slots are also experiences of time that are not consistent with those experienced while practicing science. Science tends to progress slowly. It is prolonged (it commonly takes researchers days or weeks to answer a simple “yes or no” type of question and up to years to address more complex issues) and cyclical. The same procedures are enacted over and over again, the same sites visited, or the same samples analyzed.

With so many boundaries separating science as taught from both other subjects and the practice of science (formally and informally) in the everyday world, it is little surprise that science is often not experienced as a subject relevant to students’ lives.

Creating a Compliant Populace Many aspects of school science devalue the lifeworlds the students bring to it. School science is taught as if it trained future working scientists (Roth & McGinn, 1997). This focus is reflected in the systematic presentation of the detailed mechanics of theoretical constructs (“concepts,” “scientific process”). These are comprehensible and of interest to only a small number of students (as Lemke [1990] showed, mostly white middle class) and the “dress rehearsals” of routines of the lab where one is led through a standardized set of procedures. Little heed is paid to the fact that the very discursive forms and activity structures themselves are biased along the lines of traditional markers of difference such as gender, race and socio-economic status (Haraway, 1995; Roth & McGinn, 1998). This focus on scientists’ science unrelated to the children’s world effectively silences the students and encourages them to become passive and memorize meaningless (i.e., disconnected from what they know) bits of text.

Given that success and attendant rewards (marks, self confidence, career options) depend on the selection (grading) mechanism, it is not surprising that the motivation driving students’ learning of scientific minutiae is often to “get things right,” to please the teacher. In science classes, people are judged more certainly to be right or wrong than in other subjects, such as English or Philosophy where critical reasoning and original thought are given credit. This authoritarian emphasis on “getting it right” typically results in the average student agonizing over whether or not they can guess the expectations of the instructor on exams and assignments, rather than being driven to explore an issue more deeply because of their passionate interest in it.

---

[3] In several innovative curricula, we could show how children build deep understandings in a variety of domains. These include simple machines (Roth, McGinn, Woszczyna, & Boutonné, 1999), ecology (Roth & Bowen, 1995), or structural engineering (e.g., Roth, 1998). When students are empowered to explore phenomena over long periods of time, driven by their own interests and intents, students tend to show tremendous intellectual competency.

Even the practice of science through student labs becomes more of an effort by the student to “see” what they are expected to see and to do things the way they are supposed to be done (Roth, McRobbie, Lucas, & Boutonné, 1997) than an activity driven by their needs and curiosity. It becomes a ritual dress rehearsal rather than authentic practice (Bourdieu, 1990).

Finally, the system of rewards (marks) leads to a stratification, some say a rite of passage (Brookhart, 1993) to select appropriate individuals, which ultimately benefits only the “successful” (compliant) students and those institutions which train and employ scientists: industry, government and universities. This symbolic violence excludes many students with interest and aptitude not measured by the regimented assessment system. It seems that both the subject matter and the method of instruction are not geared toward generating a scientifically literate populace, but rather function like a Fordian production line in a Foucauldian (disciplining) institution that forms employees of a certain class for a limited number of powerful institutions.

Laboratory Science, Science at Work

Over more than two decades, increasing numbers of ethnographic studies in scientific laboratories (and other similar environments) have shown science in a heretofore unknown perspective. Science as practiced is very different from the way it is presented in schools and through the traditional, objectivist history of science (e.g., Fuller, 1997; Knorr-Cetina, 1981; Latour & Woolgar, 1986; Law, 1994; Pickering, 1995). Accordingly, science as practice is very context dependent in both a local sense (tools, people, discourses, local practices) and in a global sense (politics, economics, funding cycles, societal problems). Many “facts,” to scientists, are understood to be dependent on many variables and reproducible under only the most controlled conditions. Rather than being self-evident, facts are often woven of strands selected carefully from complex webs of information.

The practice and experience of research is an activity well characterized by sociologists of science (e.g., Latour & Woolgar, 1986; Pickering, 1995). It is an active pursuit, typified by pursuing a question(s) of importance to the researcher. This practice involves framing questions, engaging with technology in a purposeful way to answer (or engage) these questions, creating and circulating artifacts, engaging in discourse to solidify the interpretation of the artifacts, creating inscriptions around the artifacts, presenting the intellectual nexus at conferences, and convincing others of both the importance and validity of knowledge claims. The construction of facts is seen as a complex phenomenon, where whom you convince with your data is just as important as producing “conclusive evidence.” In daily research practice, there is a high tolerance for and indeed an expectation that practitioners will make errors in the course of their work. Improvisation, both due to technical constraints and shifts in understanding the problem, is the norm. Scientists are professionals, who need to be able to argue persuasively against opposition, act and think autonomously and take risks in their daily practice.

Science is also practiced at countless sites outside of laboratories. The fields of medicine, engineering, surveying, urban planning, law and marketing (among others) demand practices, which use scientific techniques to examine the world at large and to justify appropriate actions. The boundaries between not only scientific disciplines but science and non-science blur at these sites (Fourez, 1997). Science becomes one of a range of (discursive, material) resources available to practitioners in order to solve a problem.

Science in Everyday Life

In our culture, science is given primacy to define the "essential world" (Haraway, 1995). Unlike culture and politics, which are acknowledged to be the result of negotiation and to be constantly in flux, science promises us knowledge of a "real" world that stands beyond time and context. This timeless utility gives science a high position in our culture; it is called upon to provide instructions of how to do things and guidance on whether to do things. Even its linguistic register has become a powerful legitimizing rhetorical resource. Because of this, a great deal of political activity swirls around science—in many public debates the conflicting parties jostle for the right to claim science as their ally (e.g., Gieryn, 1996).

But the use of science in everyday life goes beyond the public debates. We all interact with science every time we wonder about the tests our doctor orders for us, or whether or not we should buy a water filter, or whether we take our babies out in the sunshine and for how long. It is a tool we use to make sense of and guide us in our decisions about the world.

But the flow of information is not just in one direction, from science to the masses. Science is also formed and informed by "real world" factors. Its metaphors are those of the culture in which it is embedded (the computational metaphor of neuropsychology, the "blueprint" metaphor of the genetic code). The problems it tackles are determined largely by societal expectations (the Manhattan Project, AIDS research) or those of business ("terminator" seeds, CFC's). And the kind of and pace of information it produces is determined in part by public or private funding agencies whose largesse gives scientists access to the equipment they use (Epstein, 1995, 1997).

Activists straddle a unique place in the science world. They enact science, they depend on it to define their goals and justify their claims, they influence its direction through politics and the media (Eisenhart, 1998), and they work to involve citizens in its process and debates. The practice of activism can be thought of as the confluence of many of the different streams of science-related activity

In the remainder of this chapter, we provide a case study from our ethnographic research which tracks a suburban middle class environmental activist group as they work toward improving the health of a local stream and the watershed that feeds it. We present the work in the group as an authentic everyday science-based activity. By examining the learning that goes on within the group, we can tease out many aspects of learning that prove true to both the descriptions of scientists' scientific practice and science as it is enacted in everyday life. Here we confront people grappling with the issue of enacted scientific literacy as they use it rhetorically, to guide their physical actions, and to frame their understanding of the place in which they live.

Case Study: The Riffle in Graham Creek

Our case study involves activities surrounding a watershed in the community where one of us (Michael) lives and in an on-going manner teaches in a local middle school (see Roth & Lee, this book), and where the other (Stuart) is a member in an environmental activist group. Our research is therefore enmeshed with community life. In this community, we have therefore been enacting participant-observer and observer-participant research and in particular with the community-based activist group, the Henderson Creek Watershed Restoration Project ("the Project"). As part of living and doing research in this community, we have come to realize that not only are our lives enmeshed with research, but that in everyday pursuits of people, science is irreducibly enmeshed with politics, aesthetics, farming, activism, and so forth.

As part of our work, we keep extensive fieldnotes, video tape Henderson Creek watershed related activities, keep newspaper clippings related to the watershed, and interview local residents about their views on the activities surrounding the watershed. To provide readers with an idea of how science is enacted as part of living in a community, we report on the building of a riffle in one of the local parks traversed by the creek.

Background for Building the Riffle

The goal of the group is to "protect and enhance the Henderson Creek stream system" (Proposal, p. 23) to provide sufficient water for both the ecological and human needs of the watershed. As part of enhancing the stream system in the Henderson Creek watershed, the group decided to introduce a series of riffles in a large tributary of Henderson Creek, Gordon Creek. The following is a presentation and analysis of some of the aspects of building the first riffle in Gordon Creek.

Project Proposal: An Undertaking Based in Science

Prior to building the riffle, the Project performed a surveying and sampling regime to map out the area they were interested in enhancing. The results of this research were presented in a document, which was part of a package submitted to the municipality in order to secure permission to access Gordon Creek as it flows through Community Park.

This document includes color photos of the segments of the creek under contention, road maps, technical maps, aerial photographs, and tables of stream characteristics (i.e., dissolved O_2 levels at different points along the stream). The stream is described in terms of features such as length, slope, mean bankfull width, depth and width/depth ratio. Appendices listing the technical advisory committee—affiliates with the Pacific Geoscience Centre, Ministry of Environment, Lands and Parks, and the local university are included. The project has a strong association with Federal Marine Research Institute (FMR).

As they discuss different sections of the stream ("Reach 1, 2 and 3"), the linguistic resources drawn on are of technoscientific nature.

> The lower 55 meters of this reach are relatively undisturbed, with vegetated banks, cobble- and gravel-dominated substrate, stable undercut banks, and 2 small pools… The transition between Reach 2 and Reach 3 is marked by a decrease in slope from 2.6% to 1.7%, and increase in channel width, and a shift in bed composition from boulder, cobble and bedrock to sand, gravel, silt and cobble. The stream morphology becomes fairly straight and is composed of a 70 m long pool-riffle sequence downstream of the 16 m pool" (Proposal, p.17)

Here, the activists clearly use a scientific repertoire (genre, register) to make an argument for building the riffle. There are not just numbers and metric units (though Canada has converted to the metric system, much of everyday life is dominated by the imperial system), but some of these numbers include decimal notation. The creek does not just have a width, but a "channel width"; the creek is not just filled with rocks, but there is a "bed composition" including boulders, cobble, bedrock, sand, gravel, and cobble. Thus, in writing their proposal to the government agency and to the community leaders, the activists draw on a scientific repertoire. Whether or not they had "prior knowledge" of such repertoires, they knew that their proposal would be more convincing if it drew on the appropriate repertoire, and in the appropriate form. As part of their riffle-related activities, they enacted science both in the content (register) and argumentative form.

Why a Riffle? Why the Park?

Thus goes the riffle discourse: Riffles are stream sections characterized by steeper slopes, higher velocity, and shallower water depth. In stream restoration work they are structures made of stone which are essentially artificial rapids. Their major purpose is to dissipate the energy of the stream's current, thereby reducing its potential to erode banks. They also serve to oxygenate the water; this increase is known to be good for two indicators of stream health, trout and benthic invertebrates. Thus, a riffle addresses a number of the key assessed issues[4] facing Henderson Creek—it helps to reduce siltation both through acting as a silt trap and by reducing the energy of the stream's current, which will reduce erosion of downstream banks, and it helps to oxygenate the water.[5] They create pools upstream of the riffles that can be layered with spawning surface—sand and gravel, and thus provide crucial spawning habitat for the fish. With the goal of stream restoration in mind, putting riffles in Henderson Creek makes good scientific sense.

But where along the Creek should a riffle be inserted? The Project's steering committee chose the tributary of Henderson Creek, Gordon Creek, as it flowed through

---

[4] Henderson Creek is beset with a variety of problems common to streams passing through twentieth-century humanized landscapes. There is high siltation due to erosion, flash flooding and drying out due to storm sewers, fecal contamination from horses and cattle, channelization, denuding of the banks, re-routing, burying, pollution from storm sewers and industry, etc.

[5] Trout need relatively high levels of dissolved oxygen to survive.

Community Park. Community Park is a local park of approximately 40 hectares, about half of which are wooded second growth stands of cedar, fir, hemlock, aspen and maple. As it runs through the park, the creek is protected by this over-story of vegetation, and for the most part, has sufficient bank-side vegetation to have stable banks. Although "adult cutthroat trout have been noted through the park… trapping through the park has failed to note a significant presence" (Proposal, p. 9). The park is directly upstream of the best cutthroat trout habitat in the entire stream system. This system is a stretch of about 1512 m of "natural, sinuous channel characterized by riffle-pool sequences, deep pools, stable undercut banks, overhanging vegetation, gravel beds, and habitat features such as large woody debris and boulders." "Trapping and electroshocking through these reaches indicate cutthroat through all age classes" (citation, year, p. 7). If stream restoration could be performed successfully on the 600 m of stream that runs through the park, it would represent "a 34% increase in trout rearing, spawning and feeding habitat." The fact that Gordon Creek in Community Park, with many of the conditions necessary for trout life, is contiguous with the best trout rearing habitat in the creek makes it an ideal location to begin restoration work.

As presented, this is a tightly woven scientific argument. In fact, trout and the need for a riffle mutually stabilize each other within the argument: Without trout, there is no need for a riffle, but the riffle creates and improves habitat for the trout.

Networks and Actors

But scientific validity was not the only aspect of the situation taken into consideration when choices were made about where to act on the stream. In the executive summary of the proposal, the site choice is justified by its "high public profile, its mix of public and private land ownership" (citation, year, p. 3). The riffle was part of a plan to generate a network of support for the stream enhancement project.

Community Park is very popular park. There are a number of playing fields with stands, a lawn bowling club and a treed picnic area included within its bounds. The trails through the wooded section of the park are well traveled—they are a common destination for dog walkers, and it is not unusual to see a horse galloping up the footpath in the ravine. Putting a riffle in Community Park would ensure two things: a large section of the community would notice it. And the park was well known and easily accessible, so people, learning about the riffle, could come down for a look. With the introduction of interpretative signs, extensive publicity for the project could be generated.

Five sites in Community Park were identified as appropriate for placing riffles (proposal, p. 12). The site closest to the footbridge crossing the creek was chosen. It was closest to the optimal habitat downstream, but was also the most visible to passerbys. Putting the riffle at this site within Community Park brought challenges to the project. There is no single owner of the creek or adjacent lands. The municipality owns one side of the ravine, a series of landowners own the other bank, and the province controls the waterway. By choosing another location with single land ownership, the Project could have reduced the negotiation load.

The riffle is designed to create a deep pool behind it. This pool would have a mixed sand and gravel bottom, and would extend the trout's spawning habitat. The location of the planned pool was also the point at which horse owners train their horses to ford creeks—the bank's slope is shallow, the water is present and moving, but not enough to pose a hazard to the animal. So the riffle and the pool come into direct conflict with the interests of another community of practice.

These two factors were not treated as obstacles to a goal (forces that interfere with the building of the actor network that stabilizes the riffle in the community), but rather as opportunities to engage as many "influential" members of the community as possible. By gaining their support, the project increased its presence in the community, through increasing the size of their network and the strength of its connections. By having the municipality on side, an actor representative of thousands of residents, they significantly increased the scope of their network and recruit a powerful ally. This was made clear that as we finished work on the riffle, municipal workers brought and installed two interpretive signs near the entrance to the footpath next to the riffle—and the activists had not even requested them!

The homeowners represent another kind of ally. Because they are present as "just plain folks" in the community, some of them descendants of pioneer families, their support has a strong effect on those who are not sympathetic to the municipal government. Also, by engaging the landowners, the project again increases the number of actors in its network, stabilizing itself in the process. Since its long-term goal is to be a funding-free organization, this stabilization is crucial.

Meagan, the project leader, sought to engage and persuade the horse community. A horsy person herself, she would be considered an insider within the community, and could draw on her own knowledge and familiarity to be an able negotiator. The issue of the ford crossing was not a pressing one for the riding community—it was perceived as an inconvenience rather than a big problem. So with a minimal amount of conflict, the Project enrolled another supporting actor and the people that made up its network.

Building the Riffle

Riffle construction is diagrammed by the Project using a cutaway view to highlight its different aspects—"crest," "gravel pad" "bedrock" etc. The riffle is diagrammed using triangles as if in a blueprint. The different slopes of the two sides could easily be measured and used to describe the structure—which is a triangle with its longest side on the bottom of the creek, its short, steep side upstream, and a longer side of more gradual slope on the downstream side. This description of the riffle is grounded in science and engineering practices. The experience of building the riffle was a different matter.

> The light is gray. Breath swirls out from our mouths in clouds. The damp, if you're not moving, chills you underneath all your layers of clothing. It is still, the clouds hang limp and sodden, a low gray ceiling. Cedar and fir tower above us a hundred feet or more, leaning over the creek, forming a dark evergreen canopy above us. Green and gray, these are the colors of the Pacific Northwest. We toil, tiny, and try to keep dry and warm. [Fieldnotes, 10/98]
>
> We built the riffle in layers of smooth cobble (no sharp edges to cut the fish), no less than 8 cm in diameter (palm width, no one used a ruler). After we placed a

> layer of rocks down, sand was used to fill in the spaces between them. Wobbling atop the slippery loose cobble, we wash the newly poured sand into the cracks with buckets half-full of stream water—careful not to get our gloves wet. It's too cold to get wet today. So washing the sand into the cracks takes a few pails filled with water. With every wash, silt erupts from the riffle in great tan plumes. It's too tricky to walk along the cobbles and get fresh water, so we draw water from the area we are washing. The water we wash with is dirty. I bend and twist as much as I can without losing my footing to reach cleaner water. [Fieldnotes, 10/98]

Here we glimpse some of the factors that inform our engagement with the riffle. Rather than angles and slopes, we have concerns of balance, keeping warm and dry, approximate "good enough" craftsmanship whose adequacy is not judged by a protractor or surveyor's tool, but by a "feel." "Looks good!" is the criteria. To judge the fitness of our efforts, we would step back and have a look—did the surface look smooth? When we stepped on them, were the cobbles firmly in place? Did our new layer of cobble present an even surface across the face of the riffle? After every few rocks we would step back and ask ourselves those questions. We answered them by feeling, using our intuitive riffle sense, and stepping literally on and pushing the riffle cobbles around in their riffle bed.

> Sand is delivered in ice cream pails, which are handy but not ideally suited to the task at hand—they are liable to break if filled too full. The cold temperature outside affects the application of the sand—we sacrifice accuracy of pouring to keep our gloves dry and our hands warm. [Fieldnotes, 10/98]

By participating in this act of construction we move away from the authoritative certainty of mean bankfall width and slope and learn about a practical sense of placing cobbles and filling the interstices with sand and keeping balance.

> We used the shovels to empty the pickup truck of its load of sand, creating piles on the ground, and then used the shovels to fill the ice cream buckets we used to carry the sand to the riffle. We also used first brooms then our booted feet to clean the sand out from between the ridges on the floor of the box (back of the pickup truck). Meagan had in the box an 8 inch long galvanized nail, which she would run along the crack between the box and the tailgate to clear out the sand that had been packed in there. The tailgate wouldn't close. Meagan told me to just slam it, but it still wouldn't latch on to the truck. I discovered that there were pebbles in the two indentations where the clamps, which clamped onto the body of the truck lay. Looking down on the ground, I found some small sticks and used them to extract pebbles the recess, which held the clamps. [Fieldnotes, 10/98]

In this case, multiple tools and strategies are necessary to get a relatively simple task done. Boots, shovels, nails and twigs were recruited to rid the truck of sand. Their use was highly context dependent—dependent on the progression of the job, where the sand was going and what space was being cleared.

> Later in the day, I hung Fran's keys on her new broom. She had tossed her keys amongst the roots of a cedar tree, and with all the activity swirling around, I was worried that they might get covered up or that she would forget where she'd tossed them. I was also concerned that she might forget to take her new broom home, as it was just tossed off to the side, and she hadn't brought it (Meagan had just purchased it to replace one crushed by boulders). By hanging the keys on the broom, the keys were off the ground and out of harm's way, and she wouldn't forget the broom. [Fieldnotes, 10/98]

In this vignette, the boundary between the mental and the physical worlds become fuzzy. The keys hanging on the broom could be thought to be doing mental work, that is, they are reminding Fran to not forget the broom and protecting the keys from getting accidentally covered by leaves or otherwise lost. These are skills we all use in practice, whether it be running an electrophoresis gel, or arranging the screws and nuts we remove from our bicycle when we fix it.

In much of these activities, we observe an enactment of *sens pratique* (practical sense, translated as "logic of practice") which is characterized by a practical coherence that differs from the coherence of detemporalized, objectifying, scientific coherence:

> Their unity and their regularities, and on the other, their fuzziness and their irregularities and even incoherences, which are both equally necessary, being inscribed in the logic of their genesis and functioning—to the fact that they are the product of practices that can fulfil their practical functions only in so far as they implement, in the practical state, principles that are not only coherent—that is, capable of generating practices that are both intrinsically coherent and compatible with the objective conditions—but also practical, in the sense of convenient, that is, easy to master and use, because they obey a 'poor' and economical logic, whereby no more logic is mobilized than is required by the needs of practice. (Bourdieu, 1990, p. 86-87)

Bourdieu criticizes "objective" theoretical constructs with their "forced synchronization of the successive, fictitious totalization, neutralization of functions, substitution of the system of products for the system of principles of production etc." (p. 86). Because of their conventions and structure (some of which are mentioned above), they lose their ability to describe how things are done. This is problem is relevant to science education because above all, science is an activity, and it is often presented as a collection of objective facts.

The experience of riffle building is shot through with this logic, whether it be placing cobbles where the riffle demands it, or the urgency to complete felt by the riffle builders as the day progressed, the light faded, and the participants got more and more chilled. This is important because it is the logic of not only life in the lab, but also of how things are done in daily practice. Washing dishes—rinse, or not, fill the sink, dry with towel or rack—or cooking a meal in the middle of a busy day—what is wilted, what is fresh, how much time is there left, what people have a hankering for. During the day's work on the riffle, Stuart was continually challenged with situations which demanded my technical improvisation or judgement, and the feedback about the effectiveness of my choices was rapid and concrete (for example, did the pickup tailgate close?). Through engagement fraught with these challenges, students will learn about the art of doing, which is at the heart of science.

Through this intimate act of building and knowing, the participants learn about stream ecology. They see and hear the changes that the riffle makes in the stream. “Spawning habitat” also becomes a clear reflecting pool, “increased oxygenation and reduced stream energy” also becomes a delightful burbling brook, where once a silty trickle slouched towards the sea. Oxygenation becomes an aesthetic value, capable of binding people in a group.

> The riffle had been working its magic, and overnight a pool had built up behind it; the water was probably about three feet in the deepest area. Certainly well above our gum boots. A creek I remember as a trickle[6] (when I helped in the surveying) was now a lovely pond, cascading with a delightful gurgle over a bed of rocks. The creek seemed more alive than it had been. The sound of the water through the riffle was delightful, and we all reflected on how the riffle seemed to make the murky water clean and clear. The sound itself seemed to increase the stream’s vitality. The deep clear pool was serene and somehow seemed fertile, now a rich spot for life (many lives) to spawn and thrive. [Fieldnotes, 10/98]

Through our work, the members of the group learned to trust each other; and through our shared aesthetic satisfaction, reinforced by many visitors’ comments, they came to regard each other in sort of a glowing light. Stuart learned a little about Karen, a water technician, and her down-to-earth, “hands-on-working” values. He had fun playing within my happy relationship with Meagan. He met and chatted with Fran, a woman whose sincerity, love of the land and personal industry he came to admire.

During the course of the day, many people came by to visit the riffle site and therefore became part of the network that stabilized the riffle within the community.

> (1) A photographer from the Times-Columnist (local newspaper) visited. She spent about ten minutes of our time taking pictures of Karen (water technician) and myself picking up the rock, putting down the rock, talking to each other, picking up the rock, putting down the rock. We filled her in a little about what it was we were doing (necessary for the caption). (2) Tom from DFO showed up. He had done a lot of stream restoration work, up on Reay Creek in nearby Northtown. They had been working that creek for about 15 years, bringing back both salmon and trout. Tom had a look at the riffle and the riffle pool, and gave us some suggestions about improvement. (3) Spring came by. He is a sole proprietor of a GIS/GPS company. Things are going a little slow in his business. He has volunteered to do the GIS mapping of the area. (4) Marie dropped by for a couple hours in the morning. She is the wife of a heavy equipment dealer/repairman. She lives nearby. She helped us out with the rock lifting. Her daughter Yvonne was

[6] This section of the stream before the riffle was a tiny trickle of a stream limping its way through barren black mudflats, a collage of rotted leaves and discarded twigs. Fine silt from the winter floods had covered everything. Nothing grew. The black earthscape was punctuated only by the brilliance of the occasional beer can or potato chip bag.

> also there, and stayed with us after her mom went home. (5) Gordon came by. He is an old time resident of the peninsula, is in his seventies and though he walks with a cane, is alive and open and sprightly looking. He was telling all of us stories. (6) Bonnie dropped by for a few minutes, and spent about twenty minutes talking with Fran about the project. They were talking about councilors and civil bureaucrats and what was going on in local politics. (7) Two young girls on horses trotted by as I hauled rocks into the wheelbarrow on the road. Signage had been placed on the road, indicating the creek improvement project—upon reading the sign, one of them said to me "does this mean we can go fishing in the creek?" "Maybe" I enigmatically replied, and they galloped up the hill. (8) Dogs loved the riffle pond. Every retriever who went for a walk that day jumped in. We could only hope we had made some good trout habitat, but we were sure we had created good dog habitat. (9) Lee, from the local newspaper dropped by. Meagan and I posed for pictures, squatting in the pond. (10) Allen also dropped by. He and I and Loreen surveyed the creek bottom a few weeks ago. He and Meagan argued about some points regarding the riffle, some technicalities. (11) Martha, 50-ish, came by and lifted rocks for an hour or so just before lunch. I think she just came by to help. Seems she lived nearby. (12) In the afternoon, two steering committee members dropped by. Meagan had neglected to inform them the regular meeting was cancelled. So they decided to have a look at the riffle which they had spent so many hours in planning. (13) Two other guys (techy types) dropped by to check on the progress Meagan spent 10-15 minutes discussing the riffle, pool, and plans with them. (14) Another woman, whose name I forget, but who works at the nearby Federal Marine Research Institute in toxicology dropped by to see how things were going. We chatted about the lovely nature of lab jobs. (15) Karen is a water technician hired by Oceanside farm. We shoveled sand/gravel out of the back of Meagan's pickup truck all morning. She left after lunch, around two o'clock. [Fieldnotes, 10/98]

In this passage we see the diversity of interests and connections to the stream and the riffle that converge on our construction project. The newspaper photographers are actors who can stand for hundreds of thousands of people. Three months later I am still reminded by acquaintances of my photo appearing in the daily paper.

Tom and the two unknown techies come by and spend close to half an hour discussing riffle particulars and probable consequences of certain actions (whether or not to infill under cut root caps. Are they likely to provide useful habitat, or will they likely be further eroded, and result in the loss of the tree? What would happen if we put a large log in the pool to reduce the force of the current as it approaches the riffle? Where would the water be directed, what impact would it have on the surrounding banks? Through these informal exchanges we learn about the active riffle in the actual stream. They reassure us that the riffle is looking good and is doing what it should.

We meet others who have been working on the Henderson Creek project and come to know them in a context where it is clear that I support the project, and this gives me common ground with them. This is important for me as a newcomer and helps my being accepted into the group. It is also fun. Because we are building something tangible, enacting our plans, finally doing something towards our long term goal of restoring the stream to "health," the spirits are high, and there is lots of opportunity for storytelling and humor which bring us closer together. We met many members of the community and their encouragement and admiration and questions and interest helped me learn about the social environment within which I was participating. The stories told by the people who dropped by the riffle while going for a walk was an education in the community's concerns and history.

The participant in such a situation learns about the community in which he or she is embedded, the history, priorities, mistakes, and conflicts that have happened and continue to happen over time. We get a sense of participation within a greater whole, a sense of knowing that cannot be separated from the accents, inflection and pacing of the conversations we hear and later carry on with others in the same locale. Rather than being some abstract concept, it is a process of absorbing the practices and concerns of a community at large, while having a definite place within the community (the creek restorationists) that helps to position us with respect to our conversations with others and lends us an identity. This is especially important for children, who are often seen as irrelevant in terms of contribution to the community, and may give them identity as active agents.

> Meagan told the story of how this riffle was achieved politically. First, she solicited support from DFO (Federal Department of Fisheries and Oceans), then MELP (provincial Ministry of Environment, Lands and Parks) through her contacts. She worked a lot with the people who owned the banks on one side of the creek and persuaded them to support the riffle. Then she presented council with the project and all the community support. It was instantly approved on Monday, and here we are, finishing it on Friday.
>
> But later, Meagan told us the second half of the story. And that is that she did not have explicit approval from MELP. She was trying to float the application through on a rapid approval technicality "section 9" which is normally reserved for government projects. Although she was told her project would have no problem getting quick approval, the ministry wouldn't grant it, even by Tuesday evening. Meagan wanted the riffle in very soon, (it was mid October) before the winter rains came and made the work impossible. So with all the volunteers ready to go on Wednesday, but without MELP approval, Meagan decided to go for it anyway. She gambled (I am guessing it is bad to break provincial watercourse law), hoping her personal connection in MELP and technicality connection to DFO would combine to allow her to receive fast-track approval. Disregarding bureaucratic imperative, she forged ahead and began the work, only to find out a bureaucrat had misinterpreted her application—the bureaucrat thinking that the federal research institute was a private foundation, instead of a federal research institute. [Fieldnotes, 10/98]

Once again, we learn the crucial role that networks play in enacting science. Both the informal network of residents Meagan recruited and the structured network of provincial civil servants charged with regulating watercourses. Without Meagan's efforts at bringing residents "on board," the riffle project would never have left the report and entered the Creek. Through animal health, biosafety, hazardous waste and other committees, limits are put on what scientists can study—their world is constrained by the demands of the bureaucracy. In this situation, the bureaucracy misfired, withholding approval, and putting the project at risk. Meagan's sense for the discourse of the regulations and regulators supported her in her decision to ignore the blockade set up.

> Gordon, an old-time resident of the peninsula and the owner of a farm downstream from the park, was telling us stories. How people used to get up early before work, catch their limit of salmon by 8:01, and then head off to work. Now a salmon is rare sight in the inlet. He told us how there used to be schools and schools of herring churning the waters, but not anymore. We learned how there was a deep pool at this site, one where the children used to swim. The municipality had it filled in for safety reasons during the fifties. [Fieldnotes, 10/98]

Through storytelling, Gordon informed those present of the natural history of the region. These are the kinds of nature lessons that no textbook or video can give. We learn from someone while we are present in a space, about that space. We can ask questions about what we are interested in, or for more stories. We learn about the past, and this gives us ties, through our vision and ability, to the future. It engages us in the flow of time.

Gordon's stories instilled a deep sense of sadness and anger within me at how arrogantly, ignorantly and violently we had treated our natural surroundings. His stories strengthened my resolve to keep this restoration work going and to educate myself, to participate more fully, and thereby be able to educate others. Maybe one day my work would contribute to a return of some herring to the inlet, or maybe salmon.

In this chapter, the story of the riffle is bounded by the constraints of written publication. In the life of the community, there was no clear beginning to the riffle story (though we can always construct some criteria according to which we can define a beginning). The story really continues because the riffle has become part of the life of the community (including the Grade 7 students who we present in Roth and Lee, this book).

Is this Literacy?

Upon reading an early version of this paper, a colleague remarked that what we were describing was interesting, but why call it science education? This is an important question to answer considering that that this experience looks very different from the one we are used to: students poring over textbooks, taking notes, doing simple experiments designed to demonstrate a concept like "pH." We scaffold our analysis on Fourez's (1997) recent work on scientific/technical literacy. In it, he suggests that scientific literacy consists of the right use of a variety of scientific resources: specialists, black boxes, simple models, interdisciplinary models, metaphors, standardized scientific knowledge, translations, and knowledge and decisions. How many of his criteria did we fulfill? Could this activity be justifiably claimed as strong scientific literacy? What would legitimate peripheral participants learn on a day at the riffle?

Right use of specialists: From its inception, specialists' advice guided the project. Stream biologists advised and enacted the initial surveys, as mentioned in the case study, Tom gave important advice about what to do and referred Meagan to another specialist, Chris, her co-worker. The project has had extensive support from its technical advising committee.

Right use of black boxes: This is the ability to judge when not to open a phenomenon up to analysis, but rather to just let it do its thing. That is, we do not need to know how a computer keyboard informs the CPU of the letters I am pushing, I am happy to use it as a black box). There were not many technological black boxes used in the riffle construction, as it did not rely on the use of high technology. But the empirical evidence, which resulted in the decision to build the riffle, could be considered a black box; as we did not question the need for a riffle, nor the theory that suggested what it would do for the habitat.

Right use of simple models: This is knowing when a situation needs to be explained theoretically for example "what model would be appropriate to work out when it is convenient to pull and when to push a wheelbarrow?" (Fourez, 1997) In this case, simple models about water flow and stream behavior were continuously modified as we discussed rock size to place in the riffle, effects of sand fill, where silt would accumulate, etc.

Right use of interdisciplinary models: This notion refers to "the invention within the context of a specific project, of an adequate model—fairly simple but using knowledge stemming from various disciplines as well as from the know how of everyday life" (Fourez, 1997). There was not much call for these types of models in the project, as the construction of the riffle did not require the expertise of specialists from different disciplines.

Right use of metaphors: Metaphors of relationship to land, of the nature of the stream and so on permeated the discussions all day long.

Right use of standardized knowledge (scientific disciplines): This means "inducting students into established views and methods that have been successful and without which it would be practically impossible to communicate within a scientific and technical society." (Fourez, 1997) The riffle itself and the justifications for building it were embedded within the standardized knowledge of restoration ecology. In this case the standardized discourse was used "economically" (Bourdieu, 1990); we weren't trying to 'learn ecology,' we were learning enough to get the job done. The practice of ecological restoration is grounded in the Western scientific notions of prediction, control and experimentation. By participating with the group, enacting change and believing that our informed actions are doing good, we live out a master narrative of Western science.

The right use of translations: This is the skill of translating standardized knowledge into representation of everyday life—and vice versa, analyzing our everyday life situation in terms of standardized knowledge. Trout were the theoretical constructs of a successful riffle and also physical beings we sought to discover resting in the pool. Logs and bankside trees became "large woody debris" and undercut bank became "habitat." The talk around the riffle building was rich with these translations.

The ability to contrast the understanding of a technology with the understanding of its scientific principles: This refers to the difference between understanding how to use a fax machine, what it is useful for as opposed to e- mail or telephoning (technological understanding) and the scientific principles behind its operation. There was not much of this discourse at the riffle site, as the technology involved was simple and non-problematic.

Right use of knowledge and decisions, “how do we teach young people to relate scientific and technological knowledge to ethical and political decisions?” (Fourez, 1997). At the riffle site our discussions continuously turned around this topic: what the creek’s problems were, who was responsible for them, what was it about the political economic climate that encouraged the problems. After a day at the riffle, students would be well versed in many versions of how science and decisions have been related over the years.

The experience of building the riffle was strong in terms of the following categories: specialists, simple models, metaphors, translations, knowledge and decisions. It was moderate in terms of black boxes, standardized knowledge and not a great learning area for interdisciplinary models or the distinction between science and technology. This reflects the relatively simple technological nature of the task, which did not require much use of instrumentation or drawing specialists from a wide variety of disciplines.

Overall then, with 6 of Fourez’s 10 categories strongly represented in the riffle-building experience, we are justified in our claim that this is a good way to teach students practices that would result in scientific literacy.

Practice

Throughout the history of the riffle construction, the practice of this science-based activity is significantly different from that performed in classrooms. The science was purposeful; it had a strong goal that it supported which had nothing to do with the advancement of science or “getting it right” to please an authority. The goal of enhanced watershed and stream health determined the type of the science carried out in the project. And in return the results of the science shaped the actions and discourse of the activists.

The science enacted in this case study is aptly described by Bourdieu’s “economy of logic” (Bourdieu, 1997)—no grand narratives were constructed and painstakingly checked and double-checked. Science was used as a tool to help people determine what was appropriate action to take. People’s activity while building the riffle was directed toward working in community to build a structure that functions properly. There were no authorities withholding marks for not doing it fast enough or in exactly the right fashion or not understanding the underlying concepts—as during the Initiation, Response, Evaluation sequences of teacher-student interaction (Poole, 1994) that reify notions of science as a body of fact. Peoples’ activities were guided by the by what needed to be done next in the construction sequence. The fading of the daylight and threat of oncoming winter rains gave the project its urgency rather than by an impending bell signifying an authority’s decision about what to do next. Thus, the experience of time while working on the riffle was closer to that of the practice of both professional and everyday science based activities. In these activities, urgency is embedded in daily rhythms (meals, bed time) and activities determined by the next step necessary for the successful completion of an experiment, design project, or course of treatment. The activities embodied the fuzzy and economical logic described by Bourdieu (1990) and were rich in improvisation, adaptation and embodied knowledge. Based on this view of the nature of practice, participants gained a legitimate experience of scientific practice, and of practice in general.

Connections

One of the most outstanding aspects of the science enacted by the activists was its connectedness to its community. Geographically, technically, and discursively the science was profoundly influenced by its relationships. This science was not confined within four walls. It traveled to multiple locations: municipal council, landowners' living rooms, Henderson Creek, committee meetings, etc. Through its travels it changed its meaning and its form, from an inconvenience discussed between individuals to the horse community, to the formal presentation of data in a technical report to the municipality to a group of people building a riffle. Each site and corresponding community contributed to and shaped the project.

The science as enacted was determined entirely by the community. Its land-use practices created the "problems" to be solved, the funding available determined the extent of work that could be done and the people who participated in and supported the project allowed it to happen. However, science provided a legitimate description of the problems, and justified the group's actions. "Stinky ditch" becomes a channeled stream bed with elevated coliform counts, high turbidity, low dissolved oxygen levels and a dearth of native riparian vegetation. Inasmuch as this description is likely to convince people that action is needed, science defines the community and guides its' action.

As was exhaustively demonstrated earlier, the riffle construction was tightly woven into the community. Many people came by to help, visit or advise. Through these stories, we become more deeply rooted in our community, absorbing its language and rhythm, priorities, and history. As the participants come to know a place—its people, its history and politics—a sense of belonging develops which is a crucial ingredient for being able to inhabit a place as a Heideggerian dwelling. Sensitivity to biogeographical surroundings develops a feel for shared cultural history and the forces that shape our habits and assumptions. We learn about that part of us which is the land - its needs for proper treatment, its native tendencies and become intimate with it by sticking our hands in it and shaping it. Therefore, the ultimate learning that goes with this type of activity is one of a relation of Self to Other, a becoming in the world.

By participating in the project, even for a day while building a riffle, one becomes an increasingly empowered social actor. Much of the talk during the day at the riffle deconstructed taken-for-granted practices (ditches, storm sewers, etc.), and opened them to critiques. Through participating in this discourse, we begin to analyze and critically think about our place rather than passively accept whatever some authority decrees.

In Conclusion

The kind of science we have described in this chapter is quite different from that being currently taught in schools today. We do not mean to say “this is the only way,” but rather to provide a different framework with which to understand scientific literacy and show some opportunities available to them to help their students develop meaningful relationships with scientific practice. We flesh out beginnings of a different science education in another chapter (Roth & Lee, this volume). Although we are still far from where we want to go with students, we are hopeful that such beginnings can change the tide. We want to afford students to contribute knowledge to the community at large through their engagement. And we want to get more students to participate not in the science of scientists, but in science as it permeates everyday activities in our communities. We envision a school science that includes purposeful projects, multiple sites, a wide range of literacy skills, and a focus on practice. We see beyond the “cold” science of facts stripped of politics and passion to a science densely woven into the interests that shape it and in return are shaped by it. We see science education not as a preparation for a future life, but as an active legitimate participation in a community.

Acknowledgments

This research was supported by grants 410-96-0681 and 410-99-0021 from the Social Sciences and Humanities Research Council of Canada. The views represented in the chapter are our own.

References

Bourdieu, P. (1990). *The logic of practice*. Cambridge, UK: Polity Press.

Brookhart Costa, V. (1993). School science as a rite of passage: A new frame for familiar problems. *Journal of Research in Science Teaching, 30,* 649-668.

Eisenhart, M. A., & Finkel, E. (1998). *Women’s science: Learning and succeeding from the margins*. Chicago: University of Chicago Press.

Epstein, S. (1995). The construction of lay expertise: AIDS activism and the forging of credibility in the reform of clinical trials. *Science, Technology, & Human Values, 20*, 408-437.

Epstein, S. (1997). Activism, drug regulation, and the politics of therapeutic evaluation in the AIDS era: A case study of ddC and the ‘Surrogate Markers’ debate. *Social Studies of Science, 27*, 691-726.

Fourez, G. (1997). Scientific and technological literacy as a social practice. *Social Studies of Science*, *27*, 903-936.

Fuller, S. (1997). *Science*. Buckingham, England: Open University Press.

Gieryn, T. (1996). Policing STS: A boundary-work souvenir from the Smithsonian exhibition on “Science in American Life.” *Science, Technology, & Human Values, 21*, 100-115.

Haraway, D. (1995). Situated knowledges: The science question in feminism and the provilege of partial perspective. In A. Feenberg & A. Hannay (Eds.), *Technology and the polititics of knowledge* (pp. 175-194). Bloomington, IN: Indiana University Press.
Hazen, R. M., & Trefil, J. (1991). *Science matters: Achieving scientific literacy*. New York: Doubleday.
Knorr-Cetina, K. D. (1981). *The manufacture of knowledge: An essay on the constructivist and contextual nature of science*. Oxford: Pergamon Press.
Knorr-Cetina, K. D. (1992). The couch, the cathedral, and the laboratory: On the relationship between experiment and laboratory in science. In A. Pickering (Ed.), *Science as practice and culture* (pp. 113-138). Chicago, IL: The University of Chicago Press.
Latour, B., & Woolgar, S. (1986). *Laboratory life: The social construction of scientific facts*. Princeton, NJ: Princeton University Press.
Latour, B. (1993a). *La clef de Berlin et autres leÁons d'un amateur de sciences [The key to Berlin and other lessons of a science lover]*. Paris: …ditions la DÈcouverte.
Latour, B. (1993b). *We have never been modern*. Cambridge, MA: Harvard University Press.
Law, J. (1994). *Organizing modernity*. Oxford, UK: Blackwell.
Lemke, J. L. (1990). *Talking science: Language, learning and values*. Norwood, NJ: Ablex Publishing.
Longino, H. E. (1995). Knowledge, bodies, and values: Reproductive technologies and their scientific context. In A. Feenberg & A. Hannay (Eds.), *Technology and the polititics of knowledge* (pp. 195-210). Bloomington, IN: Indiana University Press.
Pickering, A. (1995). *The mangle of practice: Time, agency, & science*. Chicago, IL: University of Chicago.
Poole, D. (1994). Routine testing practices and the linguistic construction of knowledge. *Cognition and Instruction, 12,* 125-150.
Roth, W.-M. (1998). *Designing communities*. Dordrecht, Netherlands: Kluwer Academic Publishing.
Roth, W.-M., Boutonné, S., McRobbie, C., & Lucas, K. B. (1999). One class, many worlds. *International Journal of Science Education, 21,* 59-75.
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.
Roth, W.-M., & McGinn, M. K. (1997). Deinstitutionalizing school science: Implications of a strong view of situated cognition. *Research in Science Education, 27,* 497-513.
Roth, W.-M., & McGinn, M. K. (1998). >unDELETE science education: /lives/work/voices. *Journal of Research in Science Teaching, 35,* 399-421.
Roth, W.-M., McGinn, M. K., Woszczyna, C., & Boutonné, S. (1999). Differential participation during science conversations: The interaction of focal artifacts, social configuration, and physical arrangements. *The Journal of the Learning Sciences, 8,* 293-347.
Roth, W.-M., McRobbie, C., Lucas, K. B., & Boutonné, S. (1997). The local production of order in traditional science laboratories: A phenomenological analysis. *Learning and Instruction, 7,* 107-136.

Tobin, K. (1990). Research on science laboratory activities: In pursuit of better questions and answers to improve learning. *School Science and Mathematics, 90*, 403-418.
Tobin, K., & Gallagher, J. J. (1987). What happens in high school science classrooms? *Journal of Curriculum Studies, 19,* 549-560.
Winograd, T. (Ed.). (1996). *Bringing design to software*. New York, NY: ACM Press.