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Scientific literacy as collective praxis

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In this article, we conceive of scientific literacy as a property of collective activity rather than individual minds. We think of knowing and learning science as situated in and distributed across social and material aspects of a setting. To support the proposed conception, we provide several detailed cases from our three-year multi-site ethnographic study of science in one community, featuring different types of citizens who walk a creek, interact during an environment-oriented open-house event, discuss water problems, collect data, and have different conceptions of human-environment relations. The case studies show that collectively, much more advanced forms of scientific literacy are produced than any individual (including scientists) could produce. Creating opportunities for scientific literacy to emerge from collective activity, irrespective of whether one or more participants know some basic scientific facts, presents challenges to science educators very different from teaching basic facts and skills to individuals.

1. Introduction

> Do we teach biology, chemistry, physics, mathematics or do we teach young people to cope with their own world?[1]

As science educators we (the authors) are interested in ways of understanding scientific literacy and public understanding of science that allow us to conceive learning and development in terms of changing legitimate participation. That is, we are not just interested in what scientific literacy looks like *just* in individual adults, or what science education looks like *just* in schools. Rather, we are interested in understanding and theorizing ways of participating in science and scientific literacy that do not have boundaries coincident with formal education and life thereafter. In this effort, we do not believe that models from after school life, such as the concept of "authentic science" derived from studies of scientific practice, ought to be imposed on school activity.[2] Equally, we do not believe that the often narrowly conceived ideas of science and scientific literacy that dominate the current literature in science education ought to be imposed on what and how people should know about science once they have left formal education. Over the past five years, we have engaged in a research agenda concerned with science and science education "in the community," including schools, where the boundaries become dissolved so that students and ordinary people can participate reciprocally in activities that previously have been created for their respective age groups.[3]

The concept of "scientific literacy" plays a central role in recent reform efforts in science education. Science educators and curriculum reformers agree that general scientific literacy

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should be an important outcome of schooling. But despite the nearly 50-year history of "scientific literacy," science educators have not been able to arrive at a precise or agreed-upon definition.[4] For many science educators, efforts to promote greater scientific literacy have been shaped by the image of laboratory science. Science courses are often a means of pushing students into the world of scientists rather than a way of helping them cope with their own lifeworlds.[5] Few within science education have dared question the definitions of science and scientific literacy that are regularly used as templates for science in everyday life.[6] It is therefore not surprising that the Harvard graduates who suggested that it is hot in the summer because the earth is closer to the sun than in the winter, have become the laughingstock of many in the field.[7]

The purpose of this paper is to shift the discourse about science and scientific literacy by considering three propositions. First, we propose that scientific literacy is a property of collective situations and characterizes interactions irreducible to characteristics of individuals. Second, we propose to think of science not as a single normative framework for rationality but merely as one of many resources that people can draw on in everyday collective decision-making processes. Third, we propose that people learn by participating in activities that are meaningful because they serve general, common interests and thus contribute to the community at large, rather than making learning a goal of its own. We support our propositions by presenting five exemplary cases from a three-year ethnographic study of environmental activists and the watershed-related activities of various related groups that show science and scientific literacy in the life of one community.

2. Scientific literacy and collective activity

The concept of scientific literacy has played an important role in defining science education reform agendas. However, reformers have consistently used a limited view of what scientific literacy might be; that is, they always maintained the scientists' version of science while disregarding the version of others.[8] Consequently, scientific concepts, principles, theories, and models as they appear in high school and university textbooks are said to be the prerequisite for appropriately coping in a modern world. The need for a general scientific and technological literacy is often based on the argument that an effective workforce participation in the twenty-first century requires a certain amount of scientific knowledge *on the part of the individual*.[9] Thus, science educators paradigmatically talk about adults who cannot or have difficulties with programming a VCR as paradigmatic examples of scientific illiteracy.[10] Fervent defenders of classical notions of "scientific literacy" seem to forget that many children and students are surrounded by adults who not only make a decent living without knowing any science but also proudly proclaim their scientific ignorance. *Individuals* do well without knowing science because, as an integral part of social life, they have access to different levels of expertise whenever they need it. It is therefore not surprising that the agenda to make science accessible to *all* Americans has brought about little change.[11] Further, science education continues to discourage and actively exclude minorities (e.g., African Americans, First Nations) and women from participating in science.[12]

Although the debate over scientific literacy has been long and ongoing, there remains at least one fundamental assumption that has never been questioned: Scientific literacy is a property of individuals and can therefore be measured by means of traditional forms of individual assessment.[13] There is little evidence that knowing school-like facts and basic skills contribute anything to competent functioning in the everyday world; evidence from ethnomathematics suggests that there is no correlation between levels of schooling and levels of performance in everyday mathematical tasks.[14] Yet the debate over scientific literacy focuses on scientific facts, theories, and processes that individuals ought to exhibit. Most importantly, individual-centered approaches to scientific literacy do not account for the fundamental role of the division of labor in the make-up of society, allowing us, for example, to drive cars without knowing anything about engineering or mechanics, the design of external mirrors to reduce wind noise, or the chemistry of rubber that allows a maximum amount of tire sliding friction. Furthermore, studies in the public understanding of science construct an image of the interaction between scientists and non-scientists that is much more complex, dynamic, and interactive than the traditional opposition between "scientific expertise" and ignorance and rejection of scientific knowledge may lead us to believe.[15] Our own study in a community where different water-related controversies are played out shows that in the everyday world, science emerges not as a coherent, objective, and unproblematic body of knowledge and practices.[16] In practice, science is often uncertain and contentious, and unable to answer important questions pertaining to the specific (local) issues at hand. In everyday situations, citizen thinking may offer a more comprehensive and effective basis for action than scientific thinking.

Our research is concerned with finding possible trajectories of participation in science, reaching from childhood to adulthood, which are not marked by a boundary in the form of school building walls. For several years, we have participated in teaching children who, after reading a newspaper article in which a local environmental activist called for contributions to the communal knowledge base, were inspired to investigate a local creek. The children subsequently reported the results of their investigations, which range from standard science experiments to naturalistic inquiries, during an open-house event organized by the activist group. According to the activists, the impact of the students' participation was considerable, for many of the students' extended families attended the event. The impact for students was elevated by the fact that the results of their research were reported in the local newspaper and on the activists' World Wide Web site.[17]

Having taught children in this way, we began to find salience in the notion of "citizen science" because our studies proved that seventh-grade students can participate in legitimate ways in the knowledge-producing practices of their community.[18] Because citizen science is "a form of science that relates in reflexive ways to the concerns, interests and activities of citizens as they go about their everyday business," science education is no longer separate from the concerns of the community.[19] Rather, science education happens in and is for the community. In fact, together with a group of colleagues, we made an argument for science education as/for sociopolitical action.[20] Our research was not limited to schools, however, but occurred throughout the community. Here, science was related to a variety of contexts, ranging from personal matters (e.g., accessibility to safe drinking water), livelihood (e.g., best farming practices), leisure (e.g., gardening in sustainable, organic ways), spiritual values of water as cleansing, to activism and organized protest.

In our research concerning science in the community, we followed people into diverse settings, including activists investigating a creek or building water-oxygenating riffle structures, people participating in public meetings concerning controversies over water, or visitors in open-house events concerning the environmental health of the watershed. We are interested in knowing and learning, which, as we supposed from the beginning, is always situated in and distributed across the physical and social setting.[21] In this approach, agency, scientific literacy, and learning are not thought to be properties of individuals but are understood in terms of situated and distributed "engagement in changing processes of human activity."[22] Individual agency, scientific literacy, and learning are furthermore understood as personal, concrete realizations of generalized agency, knowing, and learning available at the level of society. This allows us to think of human activities, such as farming or conversations, as irreducibly social phenomena. Society is like a thread in which the individual human being is but a fiber.[23] In our analyses, then, we understand (necessarily collective) activities and interactions, such as public meetings, in terms of fibers and threads. A collective activity is analogous to the thread, and individual contributions are no more than the individual fibers. In this way, scientific literacy is always *achieved* by a collective entity rather than being an individual *property*. Taking account of recent scholarship in science studies, which eliminates the a priori distinction of humans and non-humans, we extend the analogy of thread and fibers to include material objects.[24] Thus, in controversies, science becomes but a fiber among many other fibers such as politics, economics, aesthetics, sociology, philosophy, or everyday know-how.[25] Important to this metaphor is that it is impossible to derive the concrete properties of each fiber (individual) from the thread or infer the properties of the thread from the properties of an individual fiber.

3. Research design

Our study situates itself in the Henderson Creek watershed and in Oceanside, the community that lies within this small coastal watershed in the Pacific Northwest.[26] Henderson Creek drains the north end of the watershed, Gordon Creek the south, and they meet in a valley, forming the main stem of Henderson Creek, which then flows west into the Pacific Ocean. The watershed is located about 25 kilometers from the center of a continuously expanding, mid-sized city, pushing suburbia into the rural and agricultural landscapes. We have now completed three years of ethnographic research in Oceanside, which focused on the role of science in a variety of settings within the community. Specifically, we were interested in science as it related to the precarious water situation that has, as recurrent articles in the local media show, plagued Oceanside for many years.

Water problems in the community

In Oceanside, the climate has long favored hot, dry summers and wet winters, with concomitant shortages and excesses of water available to the community. During many summers, insufficient water supply requires the community to limit the amount available to residents. Other residents, with individual wells that draw on the local aquifers, have found their water biologically and chemically contaminated and sometimes have to get their water from gas stations about five kilometers from their homes. An indigenous community is also located in the watershed, but to date, its inhabitants have shown little interest in participating with the activists in restoring the creek, which historically had been a source of food and a spiritual resource.

Today, water is shed much more quickly than in the past, and the decline in water quality and the extremes of water levels, high in the winter and low in the summer, are in part due to changes in water movement across the land and through the ground. These changes are related to urbanization and include the increase in impervious surfaces (pavement), straightening of the creek, loss of forest cover throughout the watershed and along the stream banks, loss of wetlands and recharge areas, and the loss of natural stream conditions. Small clusters of suburban development are interspersed with the farmers' fields. Storm drains and ditches channel rainwater—along with the pollutants of suburbia, lawn chemicals and car leakage—into Henderson Creek and its tributaries, and away from these newly developed areas. While carefully contained within a four-block boundary, the machine shops and biotechnology laboratories of an industrial park empty their drains into a ditch (affectionately called "stinky ditch"), which in turn, empties into Henderson Creek. To increase its potential to carry away water in a rapid manner, the creek has been deepened and straightened, and much of the covering vegetation has been removed, thereby increasing erosion and pollution from the surrounding farmers' fields. These physical changes have led to increased erosion and silt load in the wet winter months, and are responsible for low water levels and high water temperatures during the dry summer months, when legal and illegal pumping for irrigation purposes further tax the creek.

Data and interpretation

We found out about the events in the municipality by following individuals involved in two major activity systems, environmental activists of the Henderson Creek Project and children and teachers from Oceanside Middle School. In the process, we came to interview and videotape many other individuals interested in Henderson Creek and its watershed. The data sources we collect include extensive field notes, publications produced and appropriated by the activists, videotapes of public events, audio-taped interviews, newspaper clippings, informal interviews, and texts and inscriptions from the region that relate to the issues of watershed management, ecological restoration, and municipal water issues. On several occasions, we videotaped groups of activists and other interested local residents who walked sections of Henderson Creek with different consultants. The activists drew on these consultants for advice on how to improve the creek, find the best trout habitat, and how to expand the healthier sections of the creek. We used two cameras to videotape all classroom instruction—having obtained the equivalent of one entire school year of science instruction, spread over three classes. We interviewed a range of participants in the Henderson Creek Project, students, and local residents—all interviews were audio- or videotaped. Our analyses, grounded in semiotics and hermeneutic phenomenology, are based on the assumption that reasoning is observable in the form of socially structured and embodied activity. In our analyses, videotapes, transcripts, and artifacts produced by the observed individuals are natural protocols of their efforts to make sense of, and impose structure on, their activities. These protocols constituted our texts, which we then elaborated in analyses.

4. Science and scientific literacy at diverse places in one community

As we researched a variety of events involving different members of a community that struggles with issues around water, we came to understand that science is but a fiber in the thread of the social life in the community. Even when scientists participated in an event, their contributions were interacting with those made from different epistemological positions, and therefore were but an aspect of the work by means of which groups and the community as a whole entered into conflict over problems. Our holistic analysis makes it quite clear that Henderson Creek shows up in different activity systems, which focus on different individuals or groups and the means of producing knowledge and making changes in the environment; yet the representations they create, which are the outcomes of the activities, are quite different. Depending on the particular instances of mediating structures, different verbal and written representations were produced and subsequently contributed to a variety of interactional forums.[27] Furthermore, the same individuals often participated in different activities or took different roles in the respective division of labor, leading to different levels of scientific literacy that traditional conceptions would attribute to them. Thus, changes in any one aspect of an activity system change its outcomes—an important reason for us to distrust the results of individualized tests as measures of scientific literacy useful to cultural processes that are truly democratic. We describe five situations that exemplify scientific literacy as a property of situations and collective action. We foreground the emergent and interactive nature of each "literate moment" to build a portrait of what "citizen science" looks like as it is enacted.

Walking the creek in search of suitable trout habitat

One of the central interests of the environmental activists is upgrading Henderson Creek to make it suitable as trout habitat. Suitable trout habitat has all the characteristics of a healthy stream in the Pacific Northwest—meandering channel, plenty of large woody debris and boulders, overhanging vegetation, cool temperatures, and high oxygen levels. Thus, restoring a creek to trout-bearing capacity is also a move to restore many of its other aspects to what they would be were the stream a healthy one. Before beginning this project, the steering committee of the Henderson Creek Project invited a consultant, Tom, to walk the stream with them and suggest rehabilitation strategies. Tom was a member of a group that restored another, nearby stream from a sorry state where there was no water, no habitat, and no fish, to one that had its own yearly salmon run.[28]

Despite his experience, Tom did not attempt to dominate the conversation as the group walked several hundred meters along different parts of Henderson Creek. Tom pointed out that he was not a biologist, but someone with more than 15 years of experience working on another, nearby stream to restore it as a viable salmon habitat. During the conversation, Tom neither claimed to be an all-knowing expert nor did he use his extensive experience to dominate others. Indeed, he answered some questions by suggesting the group consult other sources for their information.

Meagan: What is their lifecycle, Tom?

Tom: I don't know, you'll have to look it up. But certainly, there are two age classes of fish in here. Probably a bit more, there are probably a few big ones in here [pool] too.

During the walk of the creek in search of suitable trout habitat, expertise and scientific literacy were distributed across the group. Bob, one of the activists present to learn from Tom, has a Ph.D. in ecology and used to lecture at the local university. Meagan has a Bachelors of Science degree in environmental studies, is an experienced environmental activist and campaigner, and is the (paid) coordinator of the Henderson Creek Project. Sally works on the steering committee of the Henderson Creek Project and took notes throughout the trip for constructing a report. Karen is also an activist in addition to her job as a (trained) water technician at Oceanside Farms. Geoffrey, as a local farmer, knew about farming practices and particularly about the impact cattle can have when they graze close to the creek.

Together, the group walked areas that could potentially be modified to allow the spawning of trout, and they looked at other spots where they were able to detect the presence of fry of different age classes. As they moved along, participants in the walk picked up bottles and plastic bags that were floating by or hanging in the brush. Tom pointed out particulars of each setting and explained what types of additions would change the existing stream into an ideal habitat for trout ("This is the right kind of stuff for them," "This is all good stuff for them").

Meagan: It [water] is so clear today. Normally, it is so brown.

Bob: When there is a bit of fall of rain.

Tom: The reason is because it is a bit of a steady, like that. But I don't think it is all that bad.

Michael: Do you think that there is enough oxygen for trout?

Tom: Well, it has got water in and water out. But that would be something interesting to do.

Meagan: We've been monitoring the O_2 levels in through here.

Bob: And it's not bad?

Meagan: Well, up in through there, just after it comes through Oceanside Farms' dam it was, you did it the last time, about 10 [ppm]?

Karen: Yeah.

Meagan: But it gets down to about 5 [ppm] when we come down toward that dam.

Tom: So if there was any fish in there, it would be more toward this [upper] end?

Meagan: Yeah.

Tom: The temperature probably goes up down here too.

Bob: Despite of the overgrowth?

Meagan: Yeah.

Tom: I think this has more value just as it is.

Meagan: So you think that they could use this as habitat, but they couldn't spawn down here?

Tom: Oh, no, they wouldn't spawn down in here. There is not enough water supply, there is no gravel, and there is no water coming up through the gravel. But if there are larger fish, they could actually stay in this pool. You have cover over there, and there is lots of riparious stuff in there. I would just leave it.

In this conversation, the value of the stretch of creek emerges from the interaction of all utterances rather than from the analysis and assessment of a single (expert) individual. Bits of information emerge from the question-answer and comment-comment turns. For example, the creek is not only "normally brown," a comment invoking historical knowledge of the creek, but particularly when there is "a bit of rainfall." Oxygen levels have not only been monitored, but in the exchange involving Meagan, Bob, and Karen, specific levels between 5 and 10 parts per million (ppm) became available to the group as a whole. Meagan and Karen had measured these levels during the previous year, using a dissolved-oxygen meter, an instrument that was also used by summer work-study and middle school students. Finally, the temperature of the creek in this reach does not just increase, but does so "despite of the overgrowth" (also "cover" or "riparious stuff") that shaded the spot where the group currently stands. In the final exchange between Tom and Meagan, the entire conversation about the stretch was summarized by its assessment as suitable trout habitat but not as suitable spawning ground.

In this situation, scientific literacy and expertise with respect to the assessment of the suitability of the reach as habitat and spawning ground was distributed across the individuals and situation. Different individuals contributed to the emerging conversation as fibers contribute to a thread. Although the thread does not exist independently of the fibers, the properties of the former differ from those of the latter. Furthermore, the scientific literacy that emerges as the thread of the conversation could not be predicted from the scientific literacy of the individual participant-fibers—scientific literacy in conversational interaction is an irreducibly social phenomenon.[29] This becomes even clearer in the following episode. The social structures—in the form of division of labor associated with participation in conversation, which also includes a different set of rules—change the nature of the activity and therefore the nature of knowing and learning that analysts infer from the situation.

Scientific representations in the community: decentering control

During our research, we witnessed presentations that one or the other "expert" was asked to make. For example, Meagan and Karen frequently talked to a variety of audiences about their work in the environmental activist group or on the farm. Expertise attributable to an individual was, however, rarely visible. Usually, when someone in the respective audiences asked a question, the control over salient issues changed; the thread of the topic then emerged from the interaction between the participants, "speaker" and "audience." Scientific literacy was again a social phenomenon irreducible to individual characteristics. We observed this change of control over scientific representation in different contexts, including the open-house event organized by the Henderson Creek Project and the public meeting described below. Although the various scientists and, in the present example, the water technician Karen, "owned" the slides or some graphical display, what these inscriptions actually meant in the context of the community was no longer under their control. What was relevant at the moment and how the information from the graph related to the world more broadly emerged from the interaction of "presenter" and "audience." Even more pertinent, the level of expertise that emerged from the interaction went beyond that which could have been attributed to any individual participant. Take the following example from our database.

The episode had been recorded near the open-house exhibit that Karen used to introduce members of the community to the variations in the water quantity throughout the year. For this purpose, she had joined end-to-end several rolls of graph paper from a water monitoring station and mounted them on the walls around the room. She guided visitors along the graph, explaining its features and relating specific events (rainfall, opening of a dam) to the particular shape of the curve. In the following transcript, Karen had begun to point to a step-like change in the curve, explaining that on this day the people on her farm began to irrigate the field.

Karen: These very, you know, 90° angles in the lines, that's definitely straight, straight drops. That's definitely irrigation activity, people are all stopping at the same time, starting at the same time. Depending on the conditions, it's dry for a while here. [Points to the rainfall chart.]

Walter: Yeah, a lot of hay, people are into the hay and stuff.

Karen: Yeah, a lot of people cut it at the same time

Walter: Further, you go toward the Fox's farm, down Henderson Creek. Because once you get past Fox's, it stops. There is corn. But of course, nowadays, there is late corn, too.

Karen: Yeah, they grow different varieties.

Walter: I think they grow mostly early corn [Gestures toward earlier parts of the graph] on the fields that are around Henderson Creek.

Karen: Corn definitely has a lot, requires lots of water, doesn't it? Compared to hay.

Walter: Well, say, I guess, as you know, the structure of the material of the soil material in the valley is—So, like they say, it is the best place in the world to have septic fields. From the point of view of a person putting one in, not necessarily for the rest, if all they wanted was go down the first number of feet, they don't necessarily think what else I have to have in.

Karen: Yeah, they don't think beyond that.

Walter: That's right, but it's sort of a lot of sand, and coarse soil so it's—

Karen: A lot of clay in the valley.

Walter: It drains well. So, that's probably why they have to pump so much water here compared to over on Gordon Creek where Marie Flats are. I don't think that they have to pull that much. . . .

As a whole, our recording shows that Karen wanted to move people through the exhibit rather quickly, explaining the parts of the entire chart salient and important to her and move on to the next person. In this interaction, Walter's questions (like those of other people present) codetermined what was interesting and being talked about. Walter was interested in more than simple propositions about step-like changes in the curve that are produced when different farmers simultaneously begin to irrigate. Walter had lived in the community for 17 years. He was familiar not only with farming practices in general but also with the particular crops specific farms along Henderson Creek are and had been growing. That is, Walter was much more familiar with the historical changes that the watershed has undergone than Karen, who had only recently arrived in the area when she took her job as water technician on one of the farms. But we do not want to suggest that knowledge is necessarily attributable to either individual but to highlight the fact that through their interaction, considerable detail about the context that led to the current water crisis in the community was brought to light. That is, scientific literacy emerged indeterminately as a feature of their *collective* engagement with the inscription.

When the conversation is analyzed as an irreducible phenomenon in its own right, scientific literacy becomes a property of the situation. The environmentalist's open house, and Karen's exhibition of the water-level graph, made possible conversations about the water problem in the Henderson Creek and the watershed it drains. Here, then, water levels were mediated not only by farmers who all begin irrigating at the same time, but also by the differences in water needs of different crops. Characteristics of the soil, ideal for septic fields, allow the area to drain well and for farmers to pump more water than in other parts of the watershed (Marie Flats). This excerpt exemplifies our more general observation that when scientific discourse and representations enter public forums, their meaning is no longer in the control of scientists and the restrictive discursive repertoires characteristic of scientific laboratories.[30] Rather, we can think of discourse and representations as being taken up into a more heterogeneous discourse, including many different concerns (ethics, politics, or economics), characteristic of the discourses that emerge over contentious issues. At the level of the conversation as a whole, or discourse as a heterogeneous phenomenon, the scientific repertoire turns out to be no more than one fiber among many fibers—no more or less than other fibers that contribute to the strength of the thread. Here, we understand the strength of the thread as coming from the integration of many different fibers.

Student summer projects

In the community, scientific literacy is not limited to adults. Rather, middle and high school and university students participate in various ways in the production of ecological knowledge about Henderson Creek and the watershed. In the process, these students not only contribute to the production of knowledge consumed in and by an environmentally conscious community, but they also contribute to their own production as members of the community.[31] The local newspapers carry features on students' participation ("Community youth teams join creek restoration project") in Henderson Creek-related restoration projects or in environmental monitoring programs such as *Streamkeepers* or *Shorekeepers* ("Students are active on local shores"). Sometimes, students' participation increases community participation, such as when a parent advisory council funds oxygen canisters or an underwater digital video camera that are used by the students on environmental projects or when student participation in the activists' open house increases adult attendance. In the context of the existing system of environmental activism, with its social and material structures that enable and constrain agency, students are themselves subjects who contribute to the levels of scientific literacy that we observed.

In the summer, the Henderson Creek Project employs high school-, college-, and university-level students to survey the Henderson Creek watershed and collect data for future stream restoration work. One summer, this involved five students. Their work started at Henderson Bight and included profile surveys of the creek bed, cross-sections of the creek, habitat assessments, water-quality testing, and landowner research. The students spent the summer collecting data and then entering them into a database at the Henderson Creek Project headquarters. For the in-stream work, Henderson Creek and its two contributing arms were divided into sections called "reaches." Abrupt changes in landscape, such as a transition from a field to a forested area, or at significant landmarks such as culverts, are used to demarcate a reach. The length of the reaches varied from 70 to 110 meters. In each reach, a series of tests were conducted. The ultimate goal was eventually to assess the entire creek system.

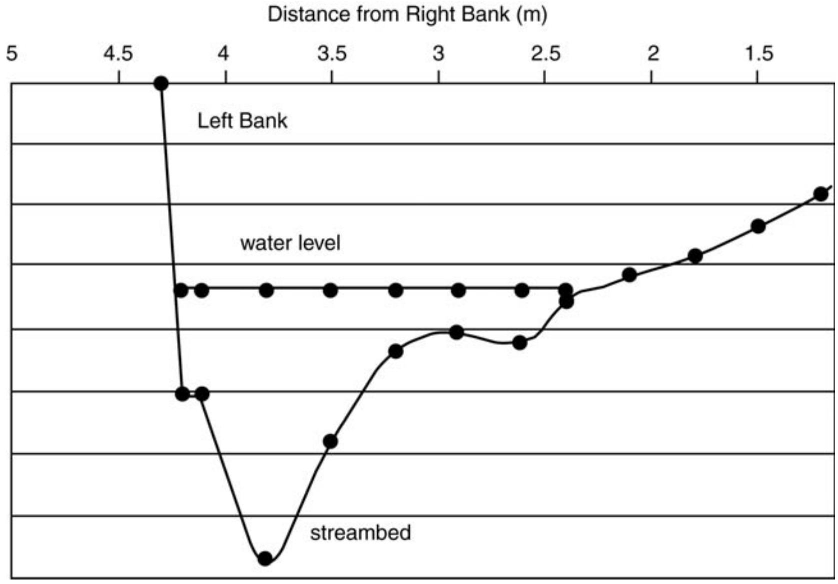
As part of their work, students conducted profile surveys, drew cross-sectional diagrams, assessed habitats, and evaluated water quality. Before they could begin their work, the students had to obtain permission from landowners before surveying could be done in the creek. They located landowners, found out mailing addresses, and sent out letters requesting permission to survey. They did not survey a reach unless full consent had been provided by a landowner.

The objective of conducting profile surveys was to develop an elevation survey of the entire creek, reach by reach, starting at sea level and ending at the headwaters. Students conducted the profile surveys drawing on a variety of tools such as surveyor's level and rod. They took measurements every few meters in the deepest part of the creek, usually going from the bottom of the reach to the top. The number of cross-sections in a reach varied depending on the length of the reach. Usually, there is one cross-sectional survey every 50 meters. Looking at all the cross-sections in order allows the activists to see trends in the creek bed (Figure 1(*a*)).

> We tried to do flow rate and discharge measurement. But this didn't turn out too well because our flow meter was on the fritz.... The bankful you have to kind of guess how high the water gets, because we are not here in the winter. And this is very difficult, because I don't know how high the water gets. (Lynne, university student)

Habitat assessments were done once in every reach. They included information on the percentage of gravel and silt in the creek, the size of the riparian zone, the types of vegetation in the riparian zone, the number of pieces of large woody debris, rooted cutbanks and bank stabilization, and the percentage of channel covered by overhanging branches. Taking all these into account, one can come up with a habitat rating for each reach. Habitat assessment requires many situated decisions, which the students learned to arrive at by working collectively. Students used a variety of forms as tools that allowed them to enter their estimates for the different dimensions that contributed to an assessment. In the same way, attempting to assess water quality could have been an insurmountable task had it not been for the variety of tools available for this activity. Students used pinpoint-, dissolved-oxygen-, and colorimeters in conjunction with different forms that required entry of instrument readings and particular calculations to be done. Thus, the quality of the water in each reach was determined testing temperature, dissolved oxygen, turbidity, and pH (Figure 1(*b*)). As with habitat assessment, a water-quality rating for each reach was obtained by using a form, the water quality assessment form, to combine different readings, conduct calculations, and compare the outcome to an established calculation-outcome to quality conversion.

> Our main ones are oxygen meters, which measure dissolved oxygen and temperature. And you stick them into the water and wave them a little bit around and it gives you



(*a*)

Water Quality Survey Interpretation & Results

Chemical Test	Result	Q Value	Weighting Factor	Index Value
Temperature Change	3.1 °C	83	x 0.10 =	8.3
Oxygen Saturation	76.7 %	80	x 0.17 =	13.6
pH	7.38	83	x 0.11 =	9.13
Turbidity (FTU)	8	80	x 0.08 =	6.4

Total = 37.43

(*b*)

Figure 1. Summer work study students, whose agency was mediated by the social and material resources provided by an environmental group, produced these and other representations of Henderson Creek. (*a*) Creek profile. (*b*) A table containing the measurements of dissolved oxygen, temperature, and turbidity.

> the results. And the pinpoint meters you just stick in and they give you the results. And the colorimeters are the big squinky things where you actually take a sample and you stick it in and it does, I think spectroscopy . . . it does a spectral analysis of the different components. But the colorimeter usually involves a lot of in-lab analysis, you can't just stick your colorimeter into the water. (Lynne)

The results from the students' work were not simply ends in themselves, stored in the Henderson Creek Project office. Rather, they were used as informational sources to guide their creek restoration work, as the basis for discussing the creek with different community members and landowners, and as persuasive tools to get funding agencies to financially support additional projects in the creek specifically and the watershed more generally. For example, Figure 2 shows an excerpt from a proposal written to municipal council, requesting access to the creek as it passes through a local park, drawing on the type of data collected and produced

Water quality tests were taken. Results are recorded in Table 2. The results indicate water quality in Reach 1 to be poorest of the Centennial Park reaches (temperature and turbidity levels the highest and DO was the lowest). This is likely the influence of the open, channelized reach upstream.

Table 1: Channel Characteristics, Reach 1.

length (m)	slope (%)	mean bankfull width (m)	mean bankfull depth (m)	width/depth ratio	mean paving material size (cm)
290 m	0.35	3.26	0.66	4.93	2

Table 2: Water Quality Conditions, Reach 1

Dissolved Oxygen	Temperature	Turbidity
6.34 mg/l (65.6% saturation)	16.5 °C	22 FTU

Limiting Factors for Reach 1

1. *Reduced overall habitat complexity due to channelization*
   The process of deepening and straightening the channel through this reach has removed habitat features such as deep pools, riffles, meanders, and off channel habitat.
2. *Reduced juvenile and adult habitat due to removal of large woody debris and stream bank vegetation.*
   Loss of these features results in an overall reduction in the amount and quality of habitat available to juvenile and adult cutthroat.
3. *Increased sediment transport and decreased water quality due to bank instability and erosion.*
   The vertical banks, lack of rooted vegetation, and loose soils throughout this reach have resulted in severe erosion. Sediments from these banks are deposited in pools and spawning gravel through the reach and downstream, reducing the quality of spawning, rearing, and adult habitat.

Prescription for Reach 1:

1. *Increase pool and spawning habitat:*
   Deepen pools by placing 3 'Newbury' riffle structures where reformation of small riffles is occurring. These features mark the natural deposition and behavior patterns of the stream, indicating the logical locations for enhancement structures. Add spawning gravel at downstream end of pools.
2. *Increase habitat complexity via the addition of large woody debris and boulder clusters:*
   Place woody debris and boulders at appropriate locations within new and augmented pools.
3. *Stabilize banks and increase habitat complexity:*
   Limit the access to stream banks and channel. Plant the stream banks paths with appropriate native vegetation. Provide interpretive signs to explain the restoration objectives, gain public support, and request cooperation from park users in keeping back from the stream channel.

Figure 2. Excerpt from a proposal written for municipal council contains data collected by the work study students who were employed during the summer, paid out of another grant that the Henderson Creek Project had obtained.

by the summer students. Thus, we find information derived from students' cross-section measurements (Figure 1(*a*)) and dissolved oxygen, temperature, and turbidity measurements (Figure 1(*b*)) in Tables 1 and 2 of the proposal (shown in Figure 2). That is, producing knowledge about the creek was not an end in itself. Rather, students learned and enacted scientific literacy in the process of pursuing a worthy goal, representing the creek.

In this example, scientific literacy can be associated with the fact that the representations produced by the students were successfully employed to garner further funding for the Henderson Creek Project. Students' agency, mediated by the social and material structures at hand, were integral to science in the community and the changes that ensued in Henderson Creek and the watershed. However, this scientific literacy cannot be located simply in the students (in their minds). Rather, scientific literacy emerged from the interaction of students with each other and with the members of the Henderson Creek Project and the instruments and tools available for their work. The students did not use these (sometimes unfamiliar) tools in a willy-nilly fashion but (guided by the activists) in a manner consistent with accepted practices; that is, tool use was mediated by the community in and for which the data were generated. Because the community mediates how material resources are used, the outcome is shaped by more than some individual's mind; rather community is an integral part of the product of the students' actions. Here again, scientific literacy was a property of the activity system rather than of the students or the activists on their own. Scientific literacy emerged as a thread including social and material structures and resources and the ways in which these mediated the agency of participants.

Public meeting

Because they have the potential to add balance and depth to information collected by other means such as using surveys, public meetings are an important and widely used mechanism in democratic countries. Over the past decades, it has become increasingly evident that in risk management related to genetically modified organisms, those involved make value judgements at all stages of the risk management process.[32] There exists therefore an "increasing contention that public participation in policy making in science and technology is necessary to reflect and acknowledge democratic ideals and enhance the trust in regulators and transparency in regulatory systems."[33]

One of the many forums documented in our research was a public meeting concerning the water in one part of Oceanside, Salina Point, which was not connected to the water main. During some summers, the groundwater levels are very low, increasing the concentration of biological and chemical contamination in wells to such an extent that the residents have to get their drinking water by driving to a nearby gas station.[34] After six different reports had been issued on the topic, the town council decided that there should be a public meeting at which the sometimes conflicting discourses about cost, municipal intent, historical relations, and scientific details could be clarified in a situation in which many of those involved were present.

According to some residents, the town council was heavily influenced by the majority report of the Water Advisory Taskforce, which, in turn, had based its report on the report by an independent consultant, Dan Lowell. In this dispute, the scientists generally attempted to restrict the discursive repertoires to a decontextualized kind of discourse that does not account for the particulars of the situation.[35] Further, what were real concerns in the everyday lives of the people affected by the unusable water became mere "aesthetic objectives" in the discursive repertoire of science. Because public meetings, as all dialogic forms of interactions, involve many different people, who bring their own quite different concerns and ways of understanding, the public meeting, as an interactional forum, allowed the emergence of rich forms of collective scientific literacy. To illustrate this, we pick one controversial issue from the meeting, the problem of high chromium levels in the drinking water.

The chief environmental health officer, whose report had recommended connecting Salina Point to the water main, suggested that when he and his team had taken measurements in the well, there were unacceptably high levels of chromium.

> We had a problem and a high level with our chromium levels. Chromium can be a problem when it combines with chlorine and goes to the trivalent state. This is when a carcinogen is formed. Chromium as it generally occurs in the water system is fine. It is a nutrient. But when we have to chlorinate a water system that's where we have the potential for some problems. (Chief environmental health officer, regional health board)

The consultant, Lowell, hired by the Water Advisory Taskforce, reported that he had not found excessive chromium levels and recommended that any metal contamination, which he called to be mere "aesthetic concerns," to "be treated with in-home treatment systems." When the public came to ask questions and make comments, Lowell's report came under close scrutiny. In the first four utterances in the following exchange, which involved Lowell and a resident (Naught), a claim to scientific expertise was constructed.

Naught: Let's turn to treatment of downstream water. Are you—is that your area of familiarity and expertise?

Lowell: I've worked with groundwater and water treatment for over 25 years.

Naught: So, so you, so you would consider yourself an expert in that area?

Lowell: Not in all aspects. An environmental engineer who's an expert in water treatment would know more about it than I do.

Naught: Would, do you know, for example, whether chromium can be treated?

Lowell: Yes, yes I do.

Naught: Successfully?

Lowell: Yes, it can with ion exchange filtrate, a filter. I phoned the manufacturers of certain systems and they assured me that that can be done.

Naught: And that's good enough for you?

Lowell: Well, I read it in publications as well.

Naught: Oh, there's a publication that we have here that says it has, that says there is no commercial treatment for chromium.

Lowell: Again there wasn't any concern for chromium identified. So I'm not sure what point you're making.

Naught: Well it seems to me that the report is relying, Mr. Magee's [WATF majority] report is relying very heavily on your information which would suggest that it doesn't matter what the problem is with water, it can be treated. I would beg to differ on that because I think that when you do something to the water, you affect it regardless of what the treatment and where the treatment. And that it affects the water in another fashion. And so therefore this business of treating water is only a marginal thing with respect to water qualities.

The subsequent exchanges construct the possibility that chromium contamination can be successfully treated. Lowell claimed to have called manufacturers and read publications whereas Naught pointed to one concretely available publication that suggested the contrary. Lowell's response that there was no chromium contamination attempted to shift the issue; but in his response, Naught pointed out that the non-negligible effect of Lowell's report on the decision-making process warranted greater attention to the nature of the recommended treatments. Chromium had been found in the first sampling episode done by the scientists from the regional health authority. The claims that there were no problems with chromium levels contrasted not only those of report by the regional health authority, but also were further mediated by information subsequently entered into the meeting by other residents. For example, one resident said that the water samples taken from her home were "beyond the one that was done by Mr. Lowell, have always tested very high in the negative areas, the one in particular is chromium." She elaborated, saying that she learned

> about chromium after reading the [health board's] report that said it could possibly be carcinogenic... Part of the poisoning was through skin absorption, which was exactly what happens with the chromium in its carcinogenic state.... The high pH encourages scale formation and decreases the efficiency of chlorine in disinfecting the water, which we can't use anyway because of the high chromium content. [Resident]

Similar to the contributions by other residents, some of whom had hired their own consulting firms, this resident's comments contributed to the construction of problems relating to chromium. When the public meeting is considered as an irreducibly social phenomenon, rather than consisting of the sum total of individual contributions, we understand high chromium levels as a contested issue with multiple dimensions. There are both pros and cons to the presence of high chromium levels. It was not only the chromium levels that were contested but also the claims that chromium could be treated. Finally, even the very status of scientific expertise was contested in contradictory claims about what the scientific literature says about the possibility of treating high chromium levels in drinking water. In our approach, we are less interested in how Lowell, Naught, and other participants might have done on a test of civic scientific literacy or what each of them said taken out of context. Rather, we are interested in the collective achievement of scientific literacy, which gave rise in this situation to a more complete, but also more heterogeneous, view of chromium levels and their impact on life at Salina Point.

Where is scientific literacy in this public meeting? Is it restricted to the scientists present, some of whom have master's degrees in their field? Is scientific literacy an attribute of residents such as Naught and others who interrogated Lowell in ways that another presenter called a "cross-examination?" Here, we take a different route to scientific literacy. We suggest that scientific literacy exists throughout the public meeting and the other situations that we described. Every person in these episodes is in some way related to scientific literacy as it emerges from the situation; and yet this scientific literacy enacted in and as everyday praxis, cannot be reduced to any single individual. Every participant is a part of the choreography that produces moments of the public appearance of scientific literacy, which lies in the debate rather than in any single contribution. Scientific literacy, rather than being confined to an individual person or to several persons, emerges from the dialectic relations among the entities that constitute the activity system. Thus, we suggest looking for scientific literacy not in the mind of the scientific expert consultant Lowell or in the heads of Naught and other participants in the public meeting but in the thread of the conversation that dialectically (and irreducible socially) relates all participants (fibers). Such an approach also has policy implications that are fundamentally democratic in the sense that, as a society, we no longer look for just one type of expert to inform but seek to bring together groups of diverse individuals (including those affected) to deliberate the contentious issues at hand. Solutions will (unpredictably) emerge from the weaving together of the individual fibers into a coherent but heterogeneous thread.

The W̱SÁNEĆ: an aboriginal (cultural historical) perspective

In our deliberation of scientific literacy as an emergent form characteristic of collective life, we do not want to omit consideration of individuals and groups that are or find themselves, for one reason or another, at the margins of ongoing debates and concerns. In our community, the local

First Nations band constitutes one such group. Different forms of scientific literacy emerge when we consider the aboriginal community that lives in the watershed and whose reservation borders Henderson Creek on the final kilometer before it sheds into the ocean. The W̱SÁNEC′ people (also "the saltwater people") have lived there for centuries. Henderson Creek, the ocean shores where it drains, and the surrounding ocean have been central to their way of life. Their expertise reflects this long history. Yet in the local media, the W̱SÁNEC′ and their elders seldom feature as the principal agents of activism. All efforts to restore the Henderson Creek watershed appear to be initiated and driven by non-natives; at best, aboriginal elders are featured in supportive roles in projects and meetings organized by others. Nowadays, as the environmental activists have found out, the W̱SÁNEC′ are difficult to enroll in their efforts to restore the creek to the habitat it had been decades ago. The reluctance of the W̱SÁNEC′ to become involved can be understood as the outcome of historical processes that valued Western approaches to dealing with the environment at the detriment of their own ways of knowing.

One day, we are standing with Dan Daniels, an elder from the local First Nations people, looking down over the watershed to the hillside where the reservation reaches down to Henderson Creek and over the nearby inlet that bears the name of his people. Dan talks about the different ways in which the W̱SÁNEC′ people related to Henderson Creek, the watershed, and the ocean into which the creek flows. Dan emphasized that their knowing is based on the oral tradition. Within the context of the oral tradition of his Nation, place names are irrevocably related to their narratives, which are teaching stories and historical accounts at the same time. Each name that is evoked in narrative stands for an idea that is more general than the actual account told by the storyteller. Furthermore, the meaning of words and stories do not reside in the story or the intent of the storyteller. Rather, the meanings are thought to be stored in the listener and therefore in the community as a whole, the only source of the wisdom. Because family histories expressed through oral tradition are often intertwined, each family maintaining its unique perspective of a shared event, the history of a people exists only in and as the collective.

> Once, long ago, the ocean's power was shown to an unsuspecting people. The tides began rising higher and higher than even the oldest people could remember. It became clear to these people that there was something very different and very dangerous about this tide. [. . .]
>
> The seawaters continued to rise for several days. Eventually the people needed their canoes. They tied all of their rope together and then to themselves. One end of the rope was tied to an arbutus tree on top of the mountain and when the water stopped rising, the people were left floating in their canoes above the mountain.
>
> It was the raven who appeared to tell them that the flood would soon be over. When the flood waters were going down, a small child noticed the raven circling, and the child began to jump around and cry out in excitement, "NI QENNET TŦE W̱SÁNEC′"—Look what is emerging! Below where the raven had been circling, a piece of land had begun to emerge. The old man pointed down to that place and said, "That is our new home, W̱SÁNEC′, and from now on we will be known as the W̱SÁNEC′ people." The old man also declared, on that day, that the mountain that had offered them protection would be treated with great care and respect, the same respect given to their greatest elders, and it was to be known as ȽÁU,WEL,ṈEW̱—"The place of refuge." Also, arbutus trees would no longer be used for firewood.[36]

The W̱SÁNEC′ have a deep respect for the Henderson Creek watershed and all the plants and creatures inhabiting it, including themselves. That is, the culture and land of the W̱SÁNEC′

are inextricably bound together. The rich resources of the Inlet have fed the W̲SÁNEC′ for hundreds if not thousands of years. The environmental activists recognize that the knowledge of the W̲SÁNEC′ with respect to seasonal cycles, tides, and water movement was essential for their survival and have set the goal of incorporating this knowledge into restoring the health of Henderson Creek and as an important part of their own future planning.

In the past, the W̲SÁNEC′ depended on Henderson Creek and the wetlands in its watershed for their food, everything from ducks to sources of medicinal plants and weaving materials. It is therefore not surprising that the W̲SÁNEC′ were considerably affected by the draining of the wetlands and other changes to the watershed over the past 140 years. As one elder recalled his mother's comment, "This place [Henderson Creek watershed] will be no more good to us."[37]

> The availability of seafood, a traditional food source for West Coast First Nations, has slowly dwindled over the last couple of decades. Contaminated shellfish beds and fish-bearing streams have become all too common. Although many traditional shellfish closures result from the naturally occurring contamination of certain marine organisms, or biotoxins, other contaminants such as sewage, oil, antifreeze, detergents, paints and solvents are all finding their way into the marine environment and causing a different kind of contamination. (Peninsula News Review, December 13, 2000, p. 12)

To the W̲SÁNEC′, Henderson Creek was not only a place for food but also a place of cleansing, and therefore an integral part not only of their physical environment but of the very definition of themselves as people.[38] The cleansing ritual was related to "skwinengut" (basic spirit). If a person did not have the basic spirit, that individual was considered to be an "empty shell." Because the seeker of skwinengut had to be clean, sexually and physically, as she or he was before seeking skwinengut, usually by retreating to the nearby mountain, that the individual would bathe in the saltwater at the mouth of Henderson Creek. Bathing in the creek was also an important part of the rite of passage from childhood to adolescence.[39]

For the W̲SÁNEC′, Henderson Creek is deeply integrated in their ways of living and knowing. Historically at least, the creek is deeply integrated in their activity system. Their local (traditional ecological) knowledge still preserves their ancient ties to the land. The W̲SÁNEC′ are aware that their knowledge arises from their collective relation to the watershed. They know that their activity system includes all human and non-human (physical, spiritual) aspects as agents, by far expanding human forms of life.[40]

The W̲SÁNEC′ know that Henderson Creek is no longer the same place. Major changes have occurred during the past 50 years. These changes include pollution of the water bodies and landforms around W̲SÁNEC′ Inlet, human encroachment in the form of development and resource extraction, and a general invasion of privacy at sacred places and in other traditional-use areas. The changes also include a lack of employment due to loss of subsistence activities within the inlet and other activities such as a viable commercial fishery.[41] The brook trout, which had fed them as far as they their collective histories reach back in time, have gone. So have the humpback and gray whales, and orcas, which had given rise to the aboriginal name, K′ENNES, for the mouth of Henderson Creek. The rich marine environment fed by fresh water from Henderson Creek, among others, has been destroyed by rising levels of chemical contamination (fertilizers and heavy metals) and silting from the quickly draining straightened creeks. No longer does the actual state of the creek inspire cleansing and cleansing rituals as it used to. First Peoples do not need the scientifically measured coliform counts, which are more than 10 times the level appropriate for swimming, to know that the creek is unable to provide and sustain them as it has in the past. For the W̲SÁNEC′, science may have in fact *ended* with the coming of schools. The coming of schools brought a separation of education from schooling. Thus, one elder writes:

> In our homes and in the privacy of our longhouses we continue to observe the wisdom of the past. The more we learn about the old ways the more we realize that science, mathematics and social studies did not begin with schools. For some of us it ended.[42]

In their ways, the W̱SÁNEC′ feel that they have much to offer for an ecological approach to living on the peninsula: "If we bring back a deep respect for nature we can be an example to everyone and prevent our beautiful land from being destroyed."[43] But the W̱SÁNEC′ do not necessarily consider the environmentalists' activities as appropriate. Simply returning the creek to the state in which it had been some 100 years before does not address a more fundamental issue concerning the relationship between people and their lifeworld. An aboriginal friend of ours, who has lived in and is familiar with the situation in the Henderson Creek watershed, made this point very clear.

> The activists are doing the same thing that the farmers did when they first cleared the forests, drained the swamps and channeled the stream. They perpetuate the dynamics of colonialization. They haven't taken the time to educate themselves through dialogue with the Coast Salish people who've lived there for hundreds of years and who probably have stories about the birth of the creek. They've spent a summer measuring it with their meters and yardsticks and now they've got their machines in there, changing it. They haven't taken time to build relationships with the people who first inhabited the land. I do not understand how this can be called a democratic process.

Our friend may perceive the issues more negatively than the indigenous people of Oceanside, and certainly those of W̱SÁNEC′ communities in other neighboring municipalities, who have entered partnership projects with the scientists from a nearby research institute. In these projects, the scientists provide social and material resources to be used in the service of the purposes and motives of the indigenous community. In one project, a scientist has been able to assist a band in revitalizing two streams, one of which had its first salmon return in decades during the fall of 2001.

5. Discussion and implications

In this study, we report and theorize community-based activities in which science was an important, but not exclusive, fiber that contributed to scientific literacy. Knowing and learning were taken as aspects of culturally and historically situated activity, discernible as changing participation in changing social practices. Because interaction and participation cannot be understood simply as an individual acting toward a stable environment, scientific literacy cannot be understood in terms of what comes from and happens to individuals. Engaging with the environment becomes an important social activity to which children can contribute from early on, and which therefore provides a context of apprenticeship.[44] Here we focus on two salient issues emerging from our research. First, we propose viewing scientific literacy as an indeterminate outcome of conversational activity. Second, we propose viewing participation in such scientific literacy as a life-long curriculum.

Scientific literacy as an indeterminate outcome of conversational activity

Dialogue and debate are paradigmatic practices of democratic social systems; so much of social structure is realized and reproduced in ongoing conversation.[45] There are many forms of public involvement in policy-making, such as public hearings or "study circles".[46] Conversation may therefore be a good way to articulate the context in which scientific literacy is allowed to emerge. From our perspective, it is more important that citizens care for and are engaged in these scientific conversations than whether or not and how many do well on some individualized test of scientific literacy. In the process of conversing, the participants draw on (the same or different) discursive repertoires, diagrams, drawings, and graphs (material structures).

In this conversational activity system, scientific literacy is neither a property of the individual participants nor something a priori available in the activity system as a resource. Rather, scientific literacy is a contingent achievement that emerges from local organization of the different conversations. From this perspective, the knowledge-ignorance paradox articulated by Ungar disappears, because in the collective conversation, an increase in specialized knowledge is not causally related to an increase in ignorance.[47] Rather, the opposite appears to be the case, in that the more individuals and specialists participate in a conversation, the greater are the chances for new forms of scientific literacy to emerge in addition to existing forms of scientific knowledge.[48]

In the same way, scientific literacy is produced in conversations that take place in other situations in the community and where individual participants bring different resources based on a variety of socio-, ethico-, and politico-scientific practices. Each contribution to the conversation is not merely outcome but becomes itself a part of the context of the activity; that is, each outcome is reintegrated into the activity system in which it can become a resource available to the community as a whole. Each contribution not only produces the conversation but also contributes to the production and reproduction of the individual qua member of the community.[49] In addition, each contribution is also an aspect of the division of labor taken on by the co-participants in various ways. Because each contribution shapes the context of the conversation in ways that other participants cannot foresee, the unfolding of the topical thread is in principle unpredictable and indeterminate.[50] The settlement of controversial issues as scientific literacy is therefore an outcome of the dialectic and dynamic conversational processes to which the different elements in an activity system contribute.

Scientific literacy can be thought of in terms of the right use of specialists, black boxes, simple models, interdisciplinary models, metaphors, standardized knowledge, and translations and transfer of knowledge.[51] Right use does not imply that decisions have to be made by individuals; right use can be accomplished within collectives that work in their specific ways on the resolution of the problems at hand. That is, right use of the above entities can be made to be a characteristic of situations, such as public meetings or other democratic forums that shape policy-setting and decision-making processes in public arenas. Such a view implies that our task as school and adult educators becomes one of enabling situations characterized by a collective scientific literacy rather than thinking about the individual appropriation or construction of knowledge. Because of this focus on collective activity, we do not require every citizen to know the definition of BSE, how genetic modification is actually achieved, or how the level of chromium is established. Rather, it is sufficient that such knowledge and practice exists within a collective body, in which members have a commitment to open and truly democratic dialogue. Our real problem then becomes one of how to facilitate democratic conversations among individuals with different expertise and with different locations in social space.

Science literacy as lived and life-long curriculum

Current efforts in rethinking scientific literacy have many shortcomings, which impede the development of achieving the goal of broad participation (e.g., the slogan "science for all

Americans"). Ways of enacting the reform agenda also fail to sufficiently address the wide gap between school and everyday, local knowledge, and therefore fail to set up a continuity of life-long learning. The reform documents pay insufficient heed to the fact that students constitute a heterogeneous clientele; it therefore makes little sense to treat citizens as though they were a homogeneous group. In the present study, adults engaged in activities that interested them, drew on those tools that best met their intellectual and motivational needs, and produced a variety of representations of stream and watershed health. Community members, activists, aboriginal elders, scientists, university students, and school children were an integral part of science in the community. Various adults, including parents, high school and graduate students, activists, and aboriginal elders assisted younger children in investigating the creek or painting signs next to culverts; the children, in turn, contributed the results of their investigations to the community at large. Members from the environmental activist group contributed to the community by giving presentations, assisting in teaching kids how to use particular tools and how to do research in the creek, and working with the citizens to attempt to improve the environmental health of the watershed.

In this situation, each individual contributes to the ongoing conversation in the respective settings but also, as we showed earlier, to the context that the setting provides for others, independent of age or levels of claimed expertise. Because of the emergent feature of these conversations, participating in producing and reproducing the changing conditions is equivalent to learning.[52] Of particular interest to us as educators is the fact that the walls surrounding formal learning no longer separated school activities and community activities. This involvement of community members in school and school members in the community therefore integrated a variety of activity systems under the larger umbrella of achieving good for the community. That is, the various activities were motivated by the same concerns that drove the activities of other community members. It is from this overlap that learning opportunities emerged for both children and adults.

Redefining scientific literacy in such ways that community members begin to participate in the community may have important political consequences. Thus, when members of a community construct facts about environmental pollution and also begin naming and publishing the names of individuals, groups, and companies that cause pollution, communities will begin to change. For example, one of our middle school students researched the amount of coliform bacteria, a biological contaminant, in various parts of the stream. He presented his results not only at the school and regional science fairs but also during the open-house event organized by the Henderson Creek Project.[53] His report specifies particular sites of pollution and names the farms that contributed significantly to the contaminant levels.

> There is the chicken farm. It [375 coliform count] shows that because of agricultural use right above the test site, there is a lot of coliform in the water. But you are not allowed to do a test. But at the Geoffrey farm, I found 500 coliform per mil, which was way above what it should have been, compared to what happened at the mouth of Graham. So what I am guessing is that somewhere between the mouth of Graham and the farm of the Geoffreys, there is a lot of extra coliform that gets into the waters that causes the high numbers.

The student concluded that the two farms were major contributors to the coliform count. Whereas we have no indication that the farmers objected (what does "you are not allowed to test" mean?), his and others' contributions to the knowledge resources made available to the community had potential implications for political pressure on farmers and industrialists to change their current practices is evident. We advocate direct participation in community affairs because it allows continuous trajectories of participation that neither stop nor are determined by the walls of institutional learning.

Our way of approaching scientific literacy directly acknowledges the limitations of laboratory science as a model for broad scientific literacy. Acknowledging the heterogeneous and collective nature of scientific literacy in the community opens doors to a richer understanding of science as a "profoundly creative and imaginative activity tempered by a scrupulous honesty in the face of experimental evidence."[54] Such an approach permits groups and communities to create different relationships between traditional scientific and other forms of knowledge, including various forms of situated knowing (e.g., local, traditional ecological, relational). Rather than privileging disciplinary science, we ought to foster situations that allow conversations to emerge in which different forms of knowledge are negotiated and geared to particular problems as these arise in the daily life of a community. Conversational spaces that enable scientific literacy to emerge and permit life-long learning along trajectories not marked by currently prevailing discontinuities when school boundaries are crossed create new instructional possibilities and difficulties that are likely to emerge in non-deterministic ways. Documenting these possibilities and difficulties, as well as the knowing and learning that emerge from them, remains virtually uncharted terrain. Much research remains to be done to study the forms distributed and situated cognition taken in the approach we propose.

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13 In his seminal article on the measurement of scientific literacy, Jon Miller does not even consider any other unit of analysis than the individual. Jon D. Miller "The measurement of civic scientific literacy," *Public Understanding of Science* 7 (1998): 203–223.

14 See, for example, Lave's studies of mathematics in supermarkets or Scribner's study of mathematics in dairy factories. Jean Lave, *Cognition in Practice: Mind, Mathematics and Culture in Everyday life* (Cambridge: Cambridge University Press, 1988); Sylvia Scribner, "Thinking in action: some characteristics of practical thought," in *Practical Intelligence: Nature and Origins of Competence in the Everyday World,* eds. Robert J. Sternberg and Richard K. Wagner (Cambridge: Cambridge University Press, 1986), 13–30.

15 Allen Irwin and Brian Wynne, ed. *Misunderstanding Science? The Public Reconstruction of Science and Technology* (Cambridge: Cambridge University Press, 1996); Sven Sjøberg and Egil Kallerud eds., *Science, Technology and Citizenship: The Public Understanding of Science and Technology in Science Education and Research Policy* (Oslo: Norwegian Institute for Studies in Research and Higher Education, 1997).

16 Stuart H. Lee and Wolff-Michael Roth, "Community Science: What is Essential about this Strange Dialogue?" Paper presented at the conference Taking Nature Seriously: Citizens, Science, and Environment. Eugene, OR (February 2001).

17 See Roth and Lee, "Breaking the spell."

18 We are familiar with the notion through the work of Alan Irwin and his writings on citizen participation in technological decision making. See Allan Irwin, *Citizen Science: A Study of People, Expertise, and Sustainable Development* (London: Routledge, 1995).

19 Edgar Jenkins, "School science, citizenship and the public understanding of science," *International Journal of Science Education* 21 (1999): 703–710.

20 Wolff-Michael Roth and Jacques Désautels, eds. *Science Education as/for Sociopolitical Action* (New York: Peter Lang, 2002). The tenor of our argument is consonant with similar arguments made by, among others, Brian Martin, to radicalize science by involving the community. See, for example, Brian Martin, "The goal of self-managed science: implications for action," *Radical Science Journal* 10 (1980): 3–17.

21 There is a developing literature on the situated and distributed nature of knowing and learning. See, for example, Ed Hutchins, *Cognition in the Wild* (Cambridge, MA: MIT Press, 1995) and Lave, *Cognition in Practice*. The roots of our activity-theoretic perspective lie in the work of Leont'ev. See Alexei N. Leont'ev, *Activity, Consciousness and Personality* (Englewood Cliffs, NJ: Prentice Hall, 1978) and Klaus Holzkamp, "Societal and Individual Life Processes," in *Critical Psychology: Contributions to an Historical Science of the Subject*, ed. Charles W. Tolman and Wolfgang Maiers (Cambridge: Cambridge University Press, 1991), 50–64. More recent discussions and elaborations of activity theory can be found in Yrjö Engeström, Reijo Miettinen, and Raija-Leena Punamäki, eds. *Perspectives on Activity Theory* (Cambridge: Cambridge University Press, 1999).

22 Jean Lave, "The practice of learning," in *Understanding Practice: Perspectives on Activity and Context*, eds. Seth Chaiklin and Jean Lave (Cambridge: Cambridge University Press, 1993), 3–32.

23 Ray P. McDermott, "The acquisition of a child by a learning disability," in *Understanding Practice: Perspectives on Activity and Context*, eds. Seth Chaiklin and Jean Lave (Cambridge, UK: Cambridge University Press, 1993), 269–305.

24 On such a view see, for example, Annemarie Mol and John Law, "Regions, networks and fluids: anaemia and social topology," *Social Studies of Science* 24 (1994): 641–671. An analysis in the same spirit showed how "Dolly," as it emerged from Italian newspaper feature articles, is in fact a (Latourian) hybrid. See Frederico Neresini, "And man descended from the sheep: the public debate on cloning in the Italian press," *Public Understanding of Science* 9 (2000): 359–382.

25 Such an (philosophy of wisdom) approach in which all human pursuits are valued at an equal level with science in problem-solving processes over contentious issues was proposed, for example, by Nicholas Maxwell, "What kind

of inquiry can best help us create a good world?" *Science, Technology, & Human Values* 17 (1992): 205–227. Symptomatically, Miller, "The measurement of scientific literacy," wants to "set aside [. . .] arguments" other than those deriving from science.

26 We use pseudonyms throughout this article for place names and individuals other than ourselves. Only the general name for the First Nations people, the W̱SÁNEC′, consisting of several communities, has been maintained.

27 Stuart H. Lee and Wolff-Michael Roth, "How ditch and drain become a healthy creek: representations, translations and agency during the re/design of a watershed,' *Social Studies of Science* 31 (2001): 315–356.

28 Tom's knowledge about salmon was considered adequate for the group because both trout and salmon are fish of the salmonid family and share a number of habitat requirements.

29 In our analyses, we follow the advice of those who advocate a first-time-through perspective. Thus, the outcome of conversations is not taken as a starting point to analyze its process. Rather, conversations, as all activities, are analyzed (non-teleologically) from the perspective of the participants who do not know what their processes and outcomes will be even a few minutes into the future. See, for example, Harold Garfinkel, Michael Lynch, and Eric Livingston, "The work of a discovering science construed with materials from the optically discovered pulsar," *Philosophy of the Social Sciences* 11 (1981): 131–158.

30 We articulated elsewhere the different forms of "hybrid knowledge" that come about when local knowledge comes to frame and inform formal scientific knowledge. See Stuart Lee and Wolff-Michael Roth, "Of traversals and hybrid spaces: science in the community," *Mind, Culture, & Activity.* In press.

31 In activity theory, consumption is not only consumption of the outcomes in and by the community but also the production and reproduction of community itself. On this point see Yrjö Engeström, *Learning by Expanding: An Activity-Theoretical Approach to Developmental Research* (Helsinki: Orienta-Konsultit, 1987), particularly Chapter 2.

32 See, for example, Alan Irwin, Henry Rothstein, Steven Yearley, and Elaine McCarthy, "Regulatory science, Europeanization, and the control of agrochemicals," *Science, Technology, & Human Values* 24 no. 2 (1999): 241–264; Henry Rothstein, Alan Irwin, Steven Yearley, and Elaine McCarthy, "Regulatory science—towards a sociological framework," *Futures* 29 no. 1 (1997): 17–31.

33 See, for example, Gene Rowe and Lynn J. Frewer, "Public participation methods: a framework for evaluation," *Science, Technology, & Human Values* 25, no. 1 (2000): 3–29; Frank N. Laird, "Participatory analysis, democracy, and technological decision making," *Science, Technology, & Human Values* 18 (1993): 341–361. See also Alan Irwin, "Constructing the scientific citizen: science and democracy in the biosciences," *Public Understanding of Science* 10 (2001): 1–18.

34 Kevin Woodley, "Senanus residents still wait for water," *Peninsula News Review* (December 16, 1998), 1, 5.

35 See, for example, Wolff-Michael Roth, Robin McMillan, Brenda Storr, Donna Tait, Janet Riecken, Gail Bradshaw, Lilian Leivas Pozzer, and Trudy Pauluth Penner, "Accessing safe drinking water: a citizen perspective on the role of science in a contentious issue," manuscript submitted. In other public hearings, such as when one company wanted to install a giant microwave tower, scientists used similar discourses that residents experienced as disempowering but which they countered through public actions such as road blockades. There are other reports that show that scientists often attempt to "bludgeon" the public. See, for example, Nick Brown and Mike Michael, "Switching between science and culture in transpecies transplantation," *Science, Technology, & Human Values* 26 (2001): 3–22.

36 Kevin P. Paul, *The Care-Takers* (Sidney, BC: Institute of the Ocean Sciences, 1995), 2–3.

37 Dave Elliott Sr., *Saltwater People*, ed. Janet Poth (Central Saanich, BC: School District No. 63, 1983), 17.

38 Judy Reimche, "Group is a bridge over troubled waters," *Peninsula News Review*, (December 16, 1998), 9.

39 Diamond Jenness, "The Saanich Indians of Vancouver Island. (Manuscript [No. VII-G-8M] in Canadian Ethnology Service Archives, National Museum of Civilization, Ottawa, 1938).

40 Readers may recognize the similarity between aboriginal views and the actor network approach championed, for example, by Law and Callon. John Law, "On the social explanation of technical change: the case of the Portuguese maritime expansion," *Technology and Culture* 28 (1987): 227–252; Michel Callon, "Some elements of a sociology of translation: domestication of the scallops and the fishermen of St. Brieux Bay," in *Power, Action and Belief: A New Sociology of Knowledge*, ed. John Law (London: Routledge & Kegan Paul, 1986), 196–233.

41 British Columbia Ministry of Environment, Lands and Parks, *Saanich Inlet Study Report on First Nations Consultation* (Victoria, BC: Author, 1995).

42 Earl Claxton, *The Saanich Year* (Brentwood Bay, BC: Saanich Indian School Board, 1993), 27.

43 Elliott, *Saltwater People*, p. 18.

44 In the context of environmental education, Peter Posch has been suggesting such an approach. See Peter Posch, "Research issues in environmental education," *Studies in Science Education* 21 (1993): 21–48. More recently, we have suggested that other social activities such as hatching salmon to stock creeks or engaging in Native American food collection serve the same structural purpose of learning science by participating in societally

relevant activity. See Wolff-Michael Roth, "Taking Science Education beyond Schooling," *Canadian Journal of Science, Mathematics, and Technology Education.* In press.

45 See Deirdre Boden, *The Business of Talk: Organization in Action* (Cambridge, UK: Polity Press, 1994); Randall Collins, *Conflict Sociology: Toward an Explanatory Science* (New York: Academic Press, 1974).

46 In the 1970s, the Swedish government had organized "study circles" as a form of involving the public in the debate about the policy on nuclear issues that it was in the process of shaping. See Dorothy Nelkin, *Technological Decisions and Democracy: European Experiments in Public Participation* (Beverly Hills, CA: Sage, 1977); Rowe and Frewer, "Public participation methods," discuss other forms of public participation that involve conversational activity, including public hearing, negotiated rule making, consensus conference, citizens' jury/panel, citizen/public advisory committee, and focus group.

47 Sheldon Ungar, "Knowledge, ignorance and the popular culture: climate change versus the ozone hole," *Public Understanding of Science* 9 (2000): 297–312.

48 See Steven Yearley, "Making systematic sense of public discontents with expert knowledge: two analytical approaches and a case study," *Public Understanding of Science* 9 (2000): 105–122; Irwin and Wynne, *Misunderstanding Science.*

49 Although he did not theorize citizen participation in the way we do, Irwin describes how citizens are constructed in the process of participating in public deliberations of science-related issues. See Irwin, "Constructing the scientific citizen."

50 Even the responses during the most structured interview schedules or objective tests have to be treated as socially constructed and distributed outcomes rather than as evidence of individual minds. See, for example, Suchman and Jordan or Kvale. Lucy A. Suchman and Brigitte Jordan, "Interactional troubles in face-to-face survey interviews," *Journal of the American Statistical Association* 85 (1990): 232–244; Steinar Kvale, "Examinations reexamined: certification of students or certification of knowledge," in *Understanding Practice: Perspectives on activity and context*, eds. Seth Chaiklin and Jean Lave (Cambridge, UK: Cambridge University Press, 1993), 215–240.

51 Fourez, Scientific and technological literacy."

52 For a similar argument see Lave, "The practice of learning."

53 This student, as everyone else in the community, drew on available resources to get the study done. Although it would be more appropriate to look at the activity system as a whole that produced these results, we attribute them to the student for brevity's sake.

54 Jenkins, "School science," p. 708.

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