

Toward a Dialectical Concept and Praxis of Scientific Literacy

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Abstract

The received conceptualizations of scientific literacy are grounded in the notions of knowledge, concepts, skills, or practices and the idea that science students have to acquire, appropriate, or construct or have to be enculturated into the associated community of practice. All of these notions articulate scientific literacy in a static form, which, as I argue in this paper, does not correspond to the dynamic nature of literacies that can be observed in society generally. I propose a dialectical notion of scientific literacy, which makes thematic its situated, distributed, collective, emergent, indeterminate, and contingent nature. In the process, I articulate the idea that knowing a (scientific) language is indistinguishable from knowing one's way around the world. As a consequence, the goal of science education can no longer be to make individual students exhibit particular forms of knowledge but to provide them with contexts in which it is more important to deal with, select, and negotiate different forms of expertise and knowledgeability than knowing Newton's third law of motion, the Krebs cycle, or the chemical formula of benzene. This leads us to think of science education as but a part of a democratic liberal education that allows students to become competent to participate in any conversation that includes others with different forms and levels of expertise than their own.

Fully half of the [Harvard University] seniors who filled out our scientific literacy survey could not correctly answer the question "What is the difference between an atom and a molecule?" . . . [W]e are all turning out scientific illiterates, students

incapable of understanding many of the important newspaper items published on the very day of their graduation. (Hazen & Trefil, 1990, p. xiv)

Following their account of a study of scientific knowledge displayed by Harvard University graduates on the day of their graduation, the authors of my introductory quote highlight what they consider to be a considerable problem: Both high school and university students do not know basic scientific facts. Statements such as “The average person is dependent on technology but cannot even program a VCR to record when nobody is home” frequently are used to suggest that scientific illiteracy is pervasive. Similar statements are made about the usage of computers and the lack of scientific or technological literacy that it provides evidence for. Yet such arguments generally overlook or consider irrelevant that (a) we do not need to know anything about a combustion engine to drive a car or use a lawnmower and (b) children often display tremendous technological and other literacies without knowing basic facts. Why is knowing the difference between an atom and a molecule so much more important than knowing to repair a lawnmower or making homemade bread to participate in, be a member of, and contribute to (post-) modern society? Why are basic facts of science—Newton’s third law of motion, the Krebs cycle, the chemical formula of benzene—to be privileged over knowing how to cook a meal (which would make you independent of buying greasy burgers), growing your own vegetables (which would make you independent of Monsanto’s genetically modified crops), or knitting/sewing your own clothes (which would make you less dependent on the fashion and clothing industry)?

Scientific literacy is a slippery, hard-to-define concept and science educators often disagree over exactly what it is. But there is widespread agreement among science educators that the purpose of science education is to become scientifically literate. There also appears to be widespread agreement that scientific literacy is something that can be measured by giving a person a (written) test or by interviewing an individual about some (scientific) concept. Underneath these conceptions are buried epistemological presuppositions: to know means to

carry (procedural) knowledge, concepts, skills, or practices around in one's body (head) and to apply/enact this knowledge/skill in a variety of settings. The unit for analyzing and theorizing scientific literacy is the individual mind rather than the person-in-setting. After having conducted aptitude research for a lifetime, the late Richard E. Snow (1992) realized that the person-in-setting unit is irreducible to the individual or the setting; and Lev Vygotsky (1934/1986) already realized that knowing cannot be abstracted from emotions. Having conducted research on knowing and learning in everyday settings—scientific laboratory and field research, environmentalism, fish hatching, electrician practice—I have come to the conclusion that scientific literacy is, at a minimum, an emergent feature of distributed collective praxis.

(Scientific) Literacy as Emergent Feature of Distributed, Collective Praxis

In contrast to the dominant view, according to which literacy is defined in terms entities (knowledge, skill, practices) owned and displayed by individuals, scientific literacy can be defined as an emergent feature and product of distributed, collective praxis (Roth, 2003). Here, the term *distributed* means that phenomena, such as scientific literacy, are properties of situations rather than individuals; and the term *collective* implies that scientific literacy is a property of a collective, of interactions, and therefore irreducible to any one individual. An example that embodies both concepts are conversations, where participants point to the things in their setting while speaking—making perceptual gestalts integral aspects of communication—and who neither do nor can know beforehand all the topics that will have been covered (Roth, 2004). In this sense, scientific literacy then is an emergent—that is, indeterminate and indeterminant—feature and outcome of a process spread across people and settings. While studying a controversy about an environmental assessment, a researcher would ask “To what extent is the collective entity (group, village, city, state, country) allowing scientific knowledge to come to bear on the issue?” rather than “Does this or that person involved know the difference between an atom and a molecule.” In fact, even conversations in scientific laboratories and science classrooms require, exhibit, and give rise to hybridized forms of knowledge without

which no so-called scientific communication or scientific literacy could exist. An example of the hybrid forms of literacy required in everyday setting comes from a five-year ethnographic study of science in one municipality and which focused, among others, on the controversy about getting access to the water grid (e.g., Roth et al., 2004).

In the neighborhood of Senanus Drive, the houses have their own wells because, to date, the village has not yet extended the water main that supplies all other homes with water from the reservoirs located 40 kilometers away. Because the water supply is minimal and because it is contaminated with a variety of corrosive metal elements and coliform bacteria, especially during the dry summer months, the residents of Senanus Drive have wanted to be connected to the water grid for almost a decade. They enlisted consultants—scientists, engineers, doctors—to test the water from their wells for quality and quantity, petitioned the municipal government, addressed the regional health board, and voiced their concerns in the local newspapers: all with no avail. The politicians continue to reject an extension of the water main based on the opinions of their own engineers, a water task force, medical doctors, and those of scientist consultants that they hired for their own purposes.

The various scientists and medical boards have been disagreeing with respect to the state of the water. Some argue that there were no problems with the water based on measurements taken during the median ground water level; there were only “aesthetic concerns” with some elements. These concerns, however, lead to a diminution of the quality of life in the area, as the residents suffer from the very corrosive properties of the water—pipes and appliances corrode within a few years, flowers and lawns die, skin develops scales, and so on. Others argue that during the summer months, the water levels fall below a certain threshold where the concentration increased to the extent that the critical level as specified by the Canadian government are in fact exceeded.

As the situation unfolds, it has become quite clear that it is complex, involving many different dimensions and not just science. The real and articulated motive for the politicians to resist the request for extending the water main was to prevent the residents at Senanus Drive to develop their properties and increase their values. At issue were not only the water but also the

requirement that the water pipeline had to be of sufficient size to also fire hydrants to be installed. The farms near the pipeline, too, have been interested in obtaining much-needed access to water for irrigation purposes. There are ethico-moral dimensions as well: according to the principles of social and environmental justice, democratic societies provide equal access to basic environmental resources to all of its citizens rather than making some suffer for the excesses of the other. In a truly democratic society, all of these issues have to come to bear on the issue to come up with a fair, equitable, and just solution. To debate the issue, forms of literacy are required that go far beyond traditional definitions of scientific literacy.

As my research showed, the kind of scientific literacy required from the residents cannot be one defined in terms of knowing the difference between atoms and molecules, Newton's third law of motion, or the Krebs cycle. The kind of scientific literacy required is distributed, collective praxis. Participants in public and private forums where the issue was debated need to be able to communicate with others who have very different forms and levels of expertise, including politicians, engineers, geologists, doctors, business people, farmers, and ordinary citizens. We might want to extend this list and argue that experts in ethico-moral issues, sociologists, historians, and educators also ought to be part of the debate in the process of framing and reframing the problems and to articulate/find corresponding solutions.

Purpose

Although this research was important for me to push the boundaries of what we might mean by talking about scientific literacy, my earlier framing of it as emergent feature of collective praxis does not go far enough. It fails to cover some important dimensions that are observable in the almost-daily, spontaneous emergence of new literacies. In this chapter, I push the boundaries even further by proposing a way of thinking about (scientific, technological) literacy that highlights the emergence of new literacies as the central feature of literacy. In fact, I propose that the very way in which we go about rethinking literacy ought to be an emergent practice, a literacy of developing theories of literacy. Because of my ontological and epistemological

commitments to praxis, I begin with descriptions and analyses of cases that exhibit features not captured in received notions of (scientific, technological) literacy; these cases serve as touchstones, as practical cases for developing theory much in the same way that (other) practical cases are required for testing the transportability of the proposed notion of literacy. I then articulate culture and literacy in terms of a dialectical praxis, which always has an emergent and transformational character. This leads to a rethinking of literacy and the issues of power/control and change of educational practices. I conclude with an appeal to rethink science education in terms of the contributions it can make to a liberal education for responsible citizenship.

Touchstones: Praxis of Literacy

Received notions and inculcated habitus steer educators to look for and perceive legitimized “knowledge,” “concept(ion)s,” “skill,” and “practices.” In science education, this means that teachers and researchers look at the degree to which students reproduce (a) the words, descriptions, and explanations that can be found in science textbooks and lectures and (b) the received ways of using equipment. This focus on received ways of enacting science—discourse, manipulative practices—prevents science educators to see innovative behavior and willingness to be innovative, both of which are prized in the work of industrial and academic scientists. But we only have to be willing to open our eyes to see that especially younger students exhibit innovation and willingness to innovate. To set the stage for my rethinking of (scientific) literacy, I describe and analyze three cases that exhibit features not yet accounted for in received theories of (scientific) literacy.

Case 1: One study of learning science through the design of architectural structures shows how new resources and tools were rapidly taken up and the associated practices were rapidly produced and reproduced (Roth, 1998). For example, teachers initially instructed the fourth- and fifth-grade students to use pins only for joining two straws; however, the students soon evolved new practices, such as cutting the end of a straw and inserting it into another and using clear adhesive (Scotch) tape to strengthen their joints (Figure 1a). When one student brought a glue

gun from home, he and his peers soon discovered, evolved, and spread new practices. For example, while attempting to glue two straws, someone found out that the hot glue gun tip burned a hole into straws when he attempted to join two of these materials. Rather than abandoning the practice, the student constituted this hole as a new opportunity for acting. He inserted another straw and then quickly dropped two beads of glue on the side of the inserted straw to prevent it from slipping (Figure 1b). Another student proposed to his teammate to rapidly bring a straw to a spot on a second straw, which he had heated so that the material began to melt; this led to the evolution of a new joint construction practice based on the fusion of the materials themselves (Figure 1c).

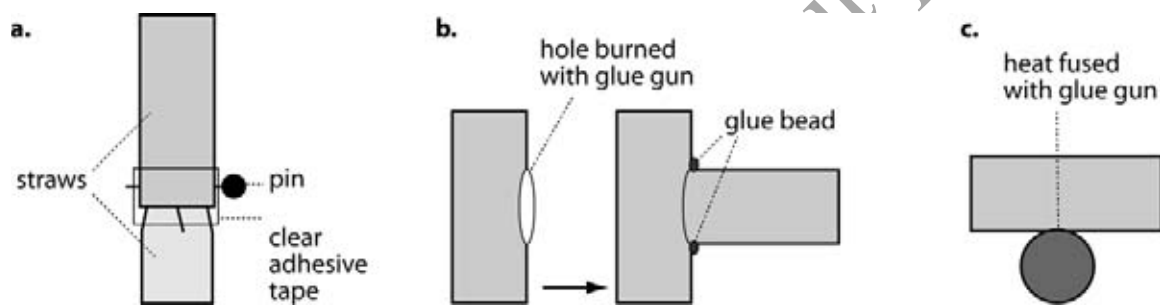


Figure 1. A new tool such as a glue gun creates new possibilities for designing “strong” joints. a. Initially, students only used pins to join two straws, then added clear adhesive tape. b. The glue gun afforded the burning of holes into which another straw was inserted. c. The glue gun also could be used to melt the material and heat-fuse two straws.

Case 2: Mobile telephones gave rise to rapidly emerging new forms of interaction among young people, who increasingly have brought them to school. In particular, the possibility in sending text messages (SMS) led to a rapid rise of new forms of connecting, new forms of identity (formation), and new forms of getting work done. The mobile telephone in general and the SMS feature in particular far from constituting unwieldy technology have become social artifacts that led, among others, to the creation, evolution, and use language, that is, to the emergence of new forms of literacy. Thus, the SMS medium provided possibilities for creating new expressions that rapidly found their way into non-SMS communicative forms such as LOL

(laugh out loud; or lots of love), GR8 (great), and CUL8R (see you later). I even found a website, where a visiting professor ponders what to do after one of his students submitted a culture and communication essay, where all key points were written in SMS.¹ A report in the *Straits Times* (Singapore) notes that SMS “has crept into examination scripts of school students.” Another website advertises for its translation service from English to SMS lingo or vice versa and invites potential new customers with the following pitch:

“transl8it! iz simpl 2 uz! jst typ n yor SMS o TXT lingo & lt transL8it! cvert it 2 pln eng o typ n a frAze n eng & cvert it 2 TXT lingo! bcum a mمبر 4 frE & U cn submit yor defintnz o dl ringtoNz”² (www.transl8it.com/cgi-win/index.pl?convertPL)

Case 3: A phenomenon with some similar features was related to me recently during a trip to Oslo, Norway, where researchers studied the use of held-hand devices as tools in the acquisition and processing of mathematical and scientific data (Mifsud, 2005). In the course of using the devices, the students in a sixth- and seventh-grade classroom found out that the tool was not only useful to upload data to the teacher-controlled, shared platform, but also to communicate across the classroom without the teacher’s knowledge and to send each other drawings that the teacher found to have inappropriate content. More so, students in the class evolved new forms of language, for example, by creating Norwegian forms of English expressions; they subsequently used these expressions not only with the mobile devices but also in their Norwegian vocabulary outside of the classroom context. They evolved new forms of technological discourse in a similar manner. More so, the teachers, though they initiated the use of hand-held mobile devices ended up asking children when technological problems emerged; frequently, the latter already had or came up with workable solutions. That is, the children evolved new forms of communication,

¹ <http://calamur.org/gargi/2003/09/12/sms-as-language/>

² transL8it! it is simple to use! Just type in your SMS or TXT lingo and let transL8it! convert it to plain English OR a phrase in English and convert it to TXT lingo! Become a member for FREE and you can submit YOUR definitions or download ringtones!

some of which eschewed the teacher's control, who, after discovering what the students were into, made all efforts to reassert her control and to prevent the new practice from taking hold, proliferating, and leading to the emergence to even more possibilities.

* * *

All these cases share several features that received theories of (scientific) literacy do not have the conceptual tools for articulating and explicating. First, new action possibilities specifically, and new (technological, linguistic, communicative) literacies more generally, emerged without being planned; they were spontaneously invented and developed by students themselves. The fourth- and fifth-grade students evolved and developed new joints and joint-making techniques; the Norwegian youth found and used a new mode of communicating and spontaneously developed a new form of community; youth around the world more generally evolved new literacies once the mobile phone also had the capabilities for sending text. The very possibility for the coming to life of the new possibilities resided in the dialectic of the extant possibilities and the technologies at hand. These new possibilities in fact constitute developments of an existing culture or lead to the emergence of new cultural forms; these new possibilities therefore constitute new forms of knowledgeability, ways of doing things, using language, and interacting. They constitute new literacies.

Second, the new literacies and cultural forms emerged on the grounds of an individual|collective dialectic. Thus, new communicative forms *presuppose* possibilities to be collective: there is no communication possible if there is only a sender. New forms of communication inherently are collective phenomena. But, as all collective phenomena, individuals have to concretely realize (enact) the new communicative form: there is no "sender" unless some concrete individual actually sends a (SMS) message and another person receives it (rather than a blip or unintelligible gibberish).

Third, the new literacies *emerged contingently*, that is, they were not planned or designed, though made possible by extant, designed artifacts/tools. In other words, the artifacts and tools were indeterminate in the sense that there were more uses possible than that the artifacts and

tools originally were designed for. The indeterminate nature of an artifact then provides possibilities for new forms of use. One can also say that there was an *excess* of meaning in these situations, which provided opportunities for the emergence of new, inherently intelligible literacies. The notion of *contingent emergence* also underscores that we cannot attribute some innovation to one individual or another. My research in the fourth- and fifth-grade classroom shows that the new forms of using artifacts and language sprung up here, there, then everywhere, in unpredictable ways and forms. Sometimes a new practice was mediated by contact between students, at other times I was able to identify rudimentary forms of a cultural practice much earlier and they only developed rapidly a few weeks later, as if they needed a period of incubation prior to their pervasive production and reproduction across the entire classroom. That is, the emergence and evolution of literacies has a rhizomatic character, they are non-linear, anarchic, multiplicitous, heterogeneous, and nomadic.

Fourth, the emergence, invention, and development of new cultural forms developed *outside* the confines circumscribed by the planned curriculum. By being outside, these new forms of literacies eschewed the control of the teachers, who, in the case of the fourth- and fifth-grade negotiated with the students but then ceded; in the case of the Norwegian students the teachers *reacted/responded* by forbidding the new communicative form (Mifsud, 2004). In the third case, Singaporean educators generally “believe that SMS-speak is bad English and that students use it out of laziness or when they are short of time,” and therefore want to get the phenomenon under control. A working group within the Singaporean ministry of education attempted to bring the SMS messaging *into* the curriculum to gain control over the new communicative means. That is, the new literacies emerged outside of the sphere of control, *out of control*, becoming noticed as a danger to the planned curriculum only after they are already established.

These descriptions and my explication exhibit features that traditional notions of literacy do not or are not able to address: emergence, rapid evolution, change, anarchy, hybridity, and contingency. This inability derives from received notions that theorize *culture*—a notion we need when thinking of literacy in terms of praxis and practice—and *language* (meaning) in static

rather than dynamic ways. In the following two sections, I articulate the two notions from such a perspective.

Culture

Culture is one of the two or three most difficult notions of the English language (Williams, 1983). The term is generally used (a) as a “theoretically defined category or aspect of social life that must be abstracted out from the complex reality of human existence” or (b) as a “concrete world of beliefs and practices” (Sewell, 1999, p. 39). Both notions, however, are essentially static. Thus, culture is rather stable and new members are conceived as “newcomers” that are “socialized” and “enculturated” to it along trajectories that range from peripheral to core participation, at which point they are part of a group of “old-timers” (Lave & Wenger, 1991). The associated notions of practice and practices, which are the (stable) patterns of actions that characterize what participants do as they pursue the characteristic activities in which members are involved. Such notions, however, focus on the reproduction of cultures and communities and highlight too little the continuous transformation of culture that is brought about not only through active change of the ways of going about the tasks at hand but also by accepting new participants who, because they have not yet evolved stable forms of specific habitus and are less constrained by what more seasoned participants recognize as the affordances of different types of artifacts (including language) and tools. Coincident with a static conception of culture (or community of practice) are the notions of “authentic science” and “(cognitive) apprenticeship.” Both notions are used to set up learning opportunities that focus on legitimized forms of knowing, the “right” ways of engaging in, talking about, and using instruments and artifacts. These right ways are presupposed to be the condition for being (scientifically) literate.

The concept of affordance was created to describe the range of action possibilities artifacts provide to users (Gibson, 1986). Chairs afford sitting; doorknobs afford turning, pulling, and pushing; and teapots afford being filled, pouring, or being held and carried. The original conception of affordances was based on the idea that the structure of a material itself provided

certain possibilities for action while resisting others. However, this conception neglects that individual experiences and collective understandings shape perceptions. More so, the concept of *practice* has sharpened the focus on those ways of using and deploying artifacts and tools in the ways they were designed, that is, in the culturally typical (i.e., “canonical”) ways. Thus, a glue gun is used to dispense hot glue to join two pieces. The more familiar we are with a culture the less likely we will be to use an artifact in non-idiomatic ways, for example, using a glue gun to burn holes into a materials or to use it for melting and fusing. Conversely, neophytes often diverge from the established ways. In education, however, such divergence is framed in a negative way: as something to be overcome, eradicated, worked against. For example, the “non-canonical” use of scientific terms—often referred to as “misconceptions,” “naïve conception,” “spontaneous conception,” etc.—is a typical target for “remediation.” More so, cognitive “conflict” is a state or strategy for engaging students in changing the ways in which they manipulate scientific tools/instruments and language.

A stable conception of culture is not very useful and fails to describe cultural dynamics, such as the emergence and proliferation of new practices and new literacies. Here, a dialectical concept of culture does a much better job for describing and explicating what happens in real science classrooms particularly and in society more generally. In a dialectical approach, culture is not merely what an anthropologist can observe, the practices and artifacts in use. The current state of a culture is given by the totality of practical actions currently viewed as possible by its members (Roth & Lee, in press). This definition has several implications. First, culture always exceeds the sum total of observable actions and artifacts. Each time there is a new technology, instrument, tool, or devices, we can observe practices and forms of culture emerge that the designers had not planned and explicitly designed. There always exists an excess of possibilities, which becomes apparent as users adopt new artifacts. There always exists an excess of literacies, some of which emerge as a matter of course.

Second, actions not only reproduce culture but also, in their concrete productions, create resources for subsequent actions and thereby expand action possibilities. Because no action ever

is the same, as was already known to the ancient Greek, culture continually evolves, even if this is not always perceived immediately (Lee & Roth, 2005). The excess of possibilities leads to continual evolution and development. Third, culture is a dialectical concept, because generalized, universal action possibilities always are action possibilities for concrete individuals. Although universal, action possibilities are always concrete, that is, one of the next steps that can *actually* rather than only theoretically be taken. Fourth, universal action possibilities inherently are possibilities for more than one person such that each individual “sees the *other* do the same as it does; each does itself what it demands of the other, and therefore also does what it does only in so far as the other does the same” (Hegel, 1977, p. 112). Thus, concerning communication, even new practices always presuppose and require more than one person: (communicative) practices are inherently distributed and collective.

Based on a study of science among kindergarten children, we proposed to describe and theorize the continual emergence of new forms of participation (practices) by means of materialist dialectics. Rather than thinking of participation in terms of trajectories from peripheral to core legitimate practices and transcending the concept and praxis of apprenticeship, we developed the notion of margin|center (Roth, Hwang, Lee, & Goulart, 2005). All actions simultaneously are marginal and central: margin and center are but one-sided expressions of participation in general such that each action provides the possibility for new cultural forms to emerge from the *inner* contradictions embodied in margin|center. That is, this concept not only explains why and cultures change but also why cultures may be replaced by new cultures as the polarity of what constitutes marginal and central practices come to be reversed (jazz gave way to rock, rock gave way to hard rock, and hard rock gave way to rap as the dominant form of musical literacy among young people). That is, a less established habitus provides more opportunities for *new* habitus and practices to emerge than a more strongly and longer established habitus. Thus, innovation is more likely to come from “newcomers” than from “old-timers” with their established ways of doing things, more likely to come from children than from

(older) adults, and more likely to come from less disciplined (non-conforming) than from the more disciplined (conforming).

Educators often assume that students need to “know the basics” prior to engaging in the more complex and interesting aspects of a discipline. Thus, science educators want students to know the difference between atoms and molecules, Newton’s third law of motion, and the Krebs cycle prior to engaging in other, more current topics such as the atomic bomb and nuclear energy or the physics and biochemistry of sports. Educators also presuppose that certain “skills” are required in case of the failure an artifact or device in which skills are in fact crystallized. Thus, mathematics educators still require students to learn longhand division, although calculating my longhand is as little required in the age of computers as the ability to walk 40 kilometers a day in the age of car and mass transport. A dynamic, dialectical approach to culture allows us to understand that the real purpose of education ought to be the utilization of extant artifacts and instruments and the extension of such utilization into new forms. To my knowledge, there is no research to support the contention that in the age of computers and hand-held calculators, the competence in doing long-hand division is a necessary and prerequisite condition for participating in more advanced forms of mathematics and science. There is no inherent necessity to reproduce older forms of utilizing artifacts and instruments and their precursors to develop the competence to use and extend usage of them. Thus, when I do not have a calculator at hand or the battery runs out, I can always use a spreadsheet, the addition features in my word processor, or borrow a calculator from someone else.

Language, Meaning

Central to all cultural forms is the use of language, or rather, sounds and scribbles that we hear and read as words, sentences, and text. Language is a central component of human praxis and therefore of all literacies—though not in the sense that it is often taken. As feature of culture, language—and therefore the associated concept of meaning—has to be rethought when we think of culture dynamically.

Science educators frequently refer to language as a tool either standing between thought and the world allowing conceptions to be articulated for others (teachers, interviewers) or as a tool that also mediates thought: written, print-based language is considered to be the *essence* of science (e.g., Yore, Bisanz, & Hand, 2003). In this approach, science content knowledge, somehow encoded in individual minds, is considered to be the most important aspect for the display of scientific literacy. Language is considered to encode (new) information, which scientists and other scientifically literate persons incorporate in and update existing knowledge.³ While it is often acknowledged that language is a means of doing science and to appropriating/constructing scientific understandings, the fundamental conceptions and theories about what it means to know largely have remained untouched: language is theorized at the level of the individual.

Words really are sounds that prove to be useful to get things done. They simultaneously do and do not have a special status. They do not have special status in the sense that there are other semiotic resources—pointing gestures, iconic gestures, body movements, body orientations, salient perceptual structures in the setting—that are equally constitutive of (workplace) communication (Roth, 2004; Roth & Pozzer-Ardenghi, 2005). They are special, because they can be used to reflexively describe and theorize processes and contents of ongoing activity. Being literate means that we competently deploy all these resources, linguistic and otherwise to interact with the social and material world. Literacy therefore is the same as inhabiting a meaningful world; there is no more difference between knowing a language and knowing your way around it generally. Literacy is something that I do, singular, but also something that inherently is intelligible to others, plural.

³ We know on constructivist and enactivist grounds that a person cannot take up information from the environment generally.

Language as Dialectical Phenomenon

Language, however, never is the affair of individuals. Language is a collective, cultural phenomenon in which we participate—even the most radical linguistic innovation presupposes that what has been said or written is intelligible and therefore already shared by others as possibility. Human participation in communicative acts both produces language in ever-novel form and reproduces it, in processes similar to other cultural forms. Language therefore not only is a collective (social, societal) phenomenon, but also an emergent one. This is also the case for science, where, for example, the language of Aristotle's (*De Motu*) or Galileo's (*De Motu, Discorsi*) work on motion would be considered arcane, cumbersome, and exclusionary. For example, Galileo's prove for the proposition "If a moving particle, carried uniformly at a constant speed, traverses two distances the time-intervals required are to each other in the ratio of these distances." begins like this:

Let a particle move uniformly with constant speed through two distances AB, BC, and let the time required to traverse AB be represented by DE; the time required to traverse BC, by EF; then I say that the distance AB is to the distance BC as the time DE is to the time EF. Let the distances and times be extended on both sides towards G, H and I, K; let AG be divided into any number whatever of spaces each equal to AB, and in like manner lay off in DI exactly the same number of time-intervals each equal to DE.

(http://www.mpiwg-berlin.mpg.de/Galileo_Prototype/DHTML/D101.HTM)

Today, students are given the formula $d = s t$ (distance equal speed times time), from which, using simple algebraic rules, they may derive the content of Galileo's proposition in an easier, more mathematical language: $d_1/d_2 = t_1/t_2$. Students do not have to be competent in the forms of literacy common in Galileo's days to be competently participating in doing puzzles involving speed, distance, and time.

An important but largely unexamined concept in the discussion of language and literacy is that of *meaning*. In the science education community, the term is used to denote something in, attached to, or an attribute of words and texts; or it is used to denote some other, unspecified aspect of life. Thus, students are said to “take meaning from texts,” “use words with their accepted scientific meanings,” “generate individual meaning,” “find their meanings,” “interpret their meanings,” “construct the meaning of words, concepts, or big ideas,” “construct models of a text’s meaning,” “create meaning through negotiations with authors,” or “construct meaning.”

This approach has limitations, in particular because it does not address the fact that we always and already find ourselves in a world shot through with meaning; it also does not address the fact that we do not inhabit our lifeworlds like robots, constantly calculating (cogitating, interpreting) what to do next. Rather, we perceive most actions of others as inherently intelligible and meaningful without doing an iota of thinking. Take the following episode noted during a recent plane ride.

Michael: ((Turns head to the side, generally toward the window))

Passenger: I am in your way?! You want to look outside?

Michael: ((Shaking head sideways.)) Just thinking about the talk I am going to deliver tomorrow.

In this episode, the passenger next to me perceived as realizing a particular action, a request to move so that I could look outside. That is, although I was simply thinking about a presentation I was to give the next day, he assumed that I made a request. He did not have to interpret what I was doing—there was insufficient time between my turning the head and his question to deliberate or interpret what I had intended to do. The *social nature of the intention* is an integral part of my *embodied* performance. In a different setting—e.g., a tenure and promotion committee meeting—the same movement will be perceived very differently, for example, as a sign that I am actually attending to what my neighbor says. The same movement no longer constitutes the same

action, as I was seen to be *requesting* in the first example but to *being attentive* in the second. In return, to respond to my neighbor in an appropriate fashion, I did not have to interpret what he was saying and then deliberate, construct a plan for what I was saying. Rather, I oriented toward him and responded—much in the same way that to walk I do not have to think about placing my feet but simply walk. The words and repeated sideways head movement sprung forth from this orientation until I had the sense of having completed to say what was a required and intelligible response. That is, my response had an emergent quality: I did not know beforehand which words it would consist of, how long it would be, and what its exact content it would realize. After the fact we can attribute an intention to it, both responding “no” (shaking head) to the question about wanting to look outside *and* providing an explanation why I was looking in the general direction of the window *without* intending to look outside.

A second aspect of language is stands out in situations such as the airplane encounter: it is both mine and not mine. At the very moment that I articulated what I was doing, my language was not mine because it exists at the very heart of the dialectical relation in which individual and collective exist:

[I]n any case we speak only one language—and we do not own it. We only ever speak one language—and, since it returns to the other, it exists asymmetrically, always for *the other*, from the other, kept by the other. Coming from the other, remaining with the other, and returning to the other. (Derrida, 1998, p. 40)

These dimensions also characterize literacy observable in scientific laboratories, as the following episode recorded during the first few days of my ethnographic work with biologists focusing on fish vision.

Michael: So you are bleaching now?

Tom: Yes, we are bleaching now.

Carl: Take a look here through the ocular. You can see how the outer segments lit up.

Michael: Oh, yeah. Um.

Tom: Do you want the sixty or the one-twenty seconds?

In this situation, we are in the middle of a data collection episode. Something was going on— which the biology professor Carl and his technician Tom had articulated and announced as “bleaching.” My question renders evident that I do not know what is going on and the fact that the announced process is already under way. Tom, on the other hand, understands that what had been announced is in fact already in process describing what is going on as “we are bleaching now.” Carl then invites me to look through the ocular of the microscope, where I detect a photoreceptor lit up by a beam of light, just as Carl describes it. Tom then exhibits another aspect of his familiarity with the situation (i.e., the literacy concerning it) when he asks whether Carl wanted “the sixty or the one-twenty seconds.” He used the definite pronoun, which means that there are specific events in the setting—as denoted by the definitive article (“the sixty,” “the one-twenty”)—that can be denoted by “sixty seconds” or “120 seconds.” In fact, what he has to do depends on what Carl says, which here means that he has to stop exposure of the cell to light after 60 or 120 seconds. Two aspects of language stand out: it has an *in-order-to* (in order to ask a question; in order to invite) and an *about* dimension (describing the process, what can be perceived). Another dimension, namely the one (over-) emphasized in science education (because least observable in scientific praxis), is that of theorizing the natural phenomena under investigation.

Meaning in Situation: Embodied and Cultural Aspects

Though many scholars interested in the question of (scientific) literacy may not think about such episodes in terms of this concept, they nevertheless provide an excellent paradigm for thinking about the phenomena and what we have to theorize. Literacy means to successfully participate in situation of which one is a constituent part. In this situation, both my airplane

neighbor and I exhibited (culturally appropriate) literate behavior, as shown by our intelligible ways of acting and responding in the setting. Here, too, we enacted general cultural literacy, then and there, in public, and as a social phenomenon rather than finding it in his or my head. The very situation provided the resources for understanding the turning head as a request and a shared language to respond and explicate the gap between the intention he perceived and the (lack of) one inherent in my performance. To understand literacy, language, and meaning, we need to take a look at the different layers involved in social phenomena.

In dialectical approaches, individual and social phenomena like culture and literacy are theorized simultaneously—there are no psychological processes formed independently of social processes nor are social phenomena separate from human psychology (Leont'ev, 1978). Neither can be reduced to the other despite the long, disciplinary balkanization of the fields of psychology and sociology. Thus, productive human activity heuristically may be analyzed at three levels simultaneously: activity, action, and operation (Figure 2). Historically evolved, societal activities such as farming, art, engaging in environmentalism, or urban gardening are associated with a conscious, collective (social) motive; actions, such as sowing fields or measuring water levels in the creek are coextensive with conscious individual (group) goals; and (embodied) operations, such as shifting the gear while driving a tractor or reading the output of a dissolved-oxygen meter are linked with the conditions, which are perceived in particular but unconscious ways. Although produced at the individual level, operations (e.g., perception, words) are deeply cultural, for they have been copied via mimetic processes or have been previously conscious actions that have become subsumed into the unconscious. Operations therefore correspond to that unconscious collective consciousness that has emerged from the embodiment of experiences in an inherently social and material world.

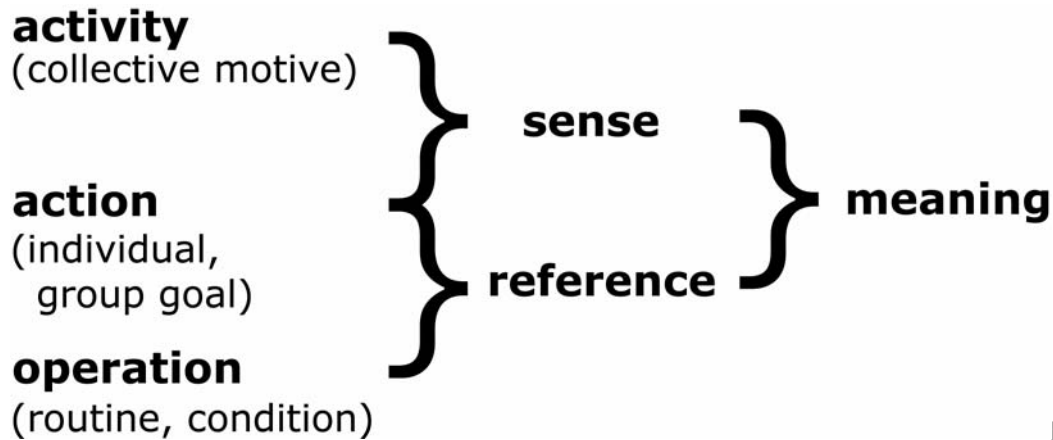


Figure 2. Sense, reference, and meaning are relations in a triarchic model of human behavior. Neighboring levels are dialectically related.

These three levels of human productive activity are not independent but connected in the form of two relations that arise from the dialectic of an action; that is, when analyzed, every action has a double orientation (Figure 2). First, every action is synthesized from sequentially assembled operations, which themselves do not have conscious goals. That is, the relation between action and operation is one of *reference*, the former orienting the production and sequencing of embodied operations, for example, the choice of individual words in a speech act that had not been prepared beforehand such as the conversation with my neighbor on the plane or the conversation with the scientists in the laboratory. This aspect of actions in general, and the *pragmatic* production of language in particular, underscores that talking and writing are forms of work. Traditional science education work on language and literacy—in its singular focus on written words, sentences, and text—fails to theorize the pragmatic, performative, and therefore embodied aspects of language and literacy.

Second, the relation of sense links each individual action and the collective activity that encompasses it. An action is meaningful—though never in an exhaustive way—when the individual who produced the action (e.g., an uttered directive, a material action) and the generalized others in the collectivity who perceive it attribute *sense* to the action. My neighbor on the plane perceived my turning head as a request to provide access to the window, and my

explanation completed my “no” response to his query as in need of an explication. In other words, human beings perceive (discursive, manipulative) actions in terms of its intentions, or account for it as realizations of actions they could have produced. Seen in this manner, each patterned action involves the dialectic of self and other, arising from a self, which itself is the product of a double historicity (see below) and providing a resource to the collectivity, self and other (community).

Finally, *meaning* is the relation between sense and reference; that is, meaning is both grounded in the bodily synthesis of operations into actions, and in the social significance of actions with respect to the encompassing activity. Perhaps the most important point is that sense and reference, and therefore meaning, are associated with *actions* rather than things; that is, for example, words or representations have neither sense nor meaning. Sense, reference, and meaning emerge in and are the results of utterances, as when a biologist instructs some students “Turn the dial to ‘dissolved oxygen’!” Here, the words surface from his unconscious and the sentence they constitute, heard as an instruction, leads the students around him to immediately engage with the black equipment box in front of them.

In this approach, language is not primarily *about* the world but *in order to* realize inherently intelligible activities. *Meaning*, then, is but another name for a familiar, intelligible world. In such a world, words, concepts, theories, and other texts *accrue to* meaning rather than having or receiving it (Heidegger, 1996). Scientists’ interpretation of graphs may be taken as a paradigmatic case in support of this phenomenon. Thus, in an expert/expert study, we asked biologists to talk about a selection of graphs that had been culled from an introductory course in ecology (Roth & Bowen, 2003). It turned out that rather than getting (taking) information *from* the graphs or attributing meaning *to* them, scientists articulated aspects of their already familiar worlds in the context of which the graphs might be useful. In cycles of interpreted effort, they tested the nature and extent of this usefulness. That is, meaning constitutes existing networks of relations to which new words, concepts, representations, etc. can be associated that, in turn, partake in and constitute meaning.

Literacies and Beyond

Our experiences in and of the everyday world (games, SMS, image-handling phones, etc.) and some of the research conducted in inquiry classrooms shows that new literacies continually emerge, nature, spread like wildfire, are taken up, and take their course. Younger generations show to be adaptive, rapidly accepting and developing a new form of communication, new forms of expression, and new idioms. Or perhaps, because younger generations are less fixed by habitus and perceiving affordances, they are more likely to emerge and evolve new forms of habitus. Received theory and praxis of (scientific) literacy—grounded as they are in ideas of “canonical scientific knowledge” and the reproduction of legitimized forms of knowledge—prepares future generations for the world of yesteryear. Similarly, “authentic science” focuses on the reproduction of culture rather than on producing it in new ways and therefore constitutes a notion that serves conservative agendas. This chasm between educators and future generations is well exemplified in the fact that many (even new) teachers are not or little computer literate, whereas many of their students have transcended simple computer uses and have evolved and continually evolve new forms of literacies involving this medium.

Rethinking Literacies

Based on the arguments provided here, we can begin to rethink and redefine (scientific) literacy. Recently I had proposed to rethink literacy in terms of rethinking language: knowing a language is indistinguishable from knowing your way around the world more generally (Roth, 2005). In this framing, being literate could be interpreted to mean knowing your way around the world as the powers-that-be defined it. I now know that this reframing of scientific literacy did not go far enough. Being literate has to imply that one is ready to produce new cultural forms, new communicative forms, ever new resources that expand our possibilities for acting and interacting with others. I say “has to imply,” because the continual production of new cultural resources inherently leads to new contradictions, problems, and challenges; to solve these, we will require new literacies the nature and content of which is as indeterminate as that of the action

possibilities that arise with novel cultural productions. Only a few years ago, we there was no need to think about the ethico-moral dimensions of (a) having women bear children at an age where they and others may be grandmothers; (b) receiving a face transplant; or (c) the potential for cloning, especially cloning human beings. These new forms of literacies have to transcend scientific literacy and discourse in the classical sense—scientists were the first to absolve themselves after the horrifying events of Nagasaki shifting responsibility to politicians and society.

In the sense of literacy as the competence to evolve new literacies, the children and students in my examples, both in and out-of school, display tremendous levels of literacy. Technological literacies—because of their ties with concrete artifacts and because, in comparison with language, are less characterized by myths about their special nature—may constitute good paradigms for engaging in efforts in rethinking and enacting scientific literacies that we might want to facilitate. Literacy as I think of it now constitutes (can be defined as) *competence in increasing action possibilities, for participating in the emergence of new forms of literacy*.

Literacy as conceived here means producing new affordances rather than reproducing (being enculturated to) the same old affordances. It means willingness to evolve new forms of expressions and relations. And thus conceived, literacy implies the evolution of new forms of habitus, to the point of evolving a habitus for changing habitus. That is, this concept of (scientific) literacy I propose is open-ended, developmental, adaptive, tends toward changing the world rather than merely understanding it (as Marx stated in his eleventh thesis on Feuerbach). Changing the world rather than merely accepting and understanding it is exactly what the students in my examples have been engaging in.

Scientific and technological knowledge as it is represented in relevant textbooks must never be accepted to constitute the natural order of things. Instead, as a society we need to know that every piece of scientific and technological knowledge—from a (DNA, benzene) molecule to an IQ test to a mobile phone—is a product of a particular economic and political context and carries with it a program, an agenda, and a philosophy that may but does not have to be life-enhancing

and may, but does not have to, open up new possibilities for acting in an increasingly complex world. The most important contribution formal education can make to the education of future generations is, therefore, “to give them a sense of coherence in their studies, a sense of purpose, meaning, and interconnectedness in what they learn” (Postman, 1992, p. 186). And, I might add, schools have to provide resources that allow students to develop a sense of solidarity, the competencies of interacting with others, who embody very different forms of knowledgeability, to arrive at solutions to problems, which they, too, are going to articulate and evaluate collectively. The new literacies allow students to begin with their familiar world and practices, and open up new possibilities for acting from there. It is their familiar world that is shot through with meaning, which is exactly that “what gives us a sense of our own identity, of who we are and with whom we ‘belong’—so it is tied up with questions of how culture is used to mark out and maintain identity within and difference between groups” (Hall, 1997, p. 3).

Power, Control

We cannot rethink literacies in the way I articulate it here without also rethinking the issues of power and control. In traditional societies, existing structures and members constitute conservative forces in that they preserve extant culture, that is, the status quo in their focus on the reproduction of structures and practices. In their attempts to teach facts and skills or to enculturate students, teachers take part in reproducing conservative aspects of a society. New practices are by definition the opposite of “canonical” practices, and therefore fall outside of the purview of educational endeavors. At different institutional levels, educators therefore find themselves in the continual attempt to forbid, create laws, police, and control the proliferation of new practices. The teachers in the fourth- and fifth-grade engineering classroom attempted to forbid or steer children away from practices that undercut their preconceived ideas of how one learns about the stability and strength of architectural structures. The teacher in the Norwegian science classroom developed measures to forestall students’ communication in ways that she could not control. And teachers generally obviate the use of TXT/SMS lingo by threatening

students with low grades should they use a language other than in the “canonical,” standard, and legitimized forms.

In some instances, innovative teachers, schools, school boards, and even provincial or state ministries (departments) of education attempt to reappropriate some innovation or innovative practices and thereby subjugate what is novel to the existing powers. Thus, for example, there are attempts by educators to catch up with the emergent cultures, such as creating more avenues for students to express themselves using, for example, SMS language to write poetry and enter poetry competitions as this has been proposed in working groups of the Singapore Ministry of Education.⁴ In such cases, however, it is likely that as quickly as educators catch up, new forms of communication and new literacies will emerge. A much better way of going about the phenomenon of cultural evolution of literacies is to explicitly build them in the curriculum, which no longer would be defined by specific learning outcomes but rather by the indeterminate nature of the outcomes themselves.

I propose to go at least one step further and foster a climate in which innovation proliferates, which inherently means that we abandon the control over innovation and acceptance of new forms of praxis. In fact, we need to encourage and nourish a climate in which constant renewal and coping with the unforeseen and novel becomes the norm. Unless our students—who constitute the next generation of workers, professionals, teachers, and adult citizens—have developed the competencies to cope with and utilize the continual emergence of literacies and new cultural forms, an increasing fraction of society in general and teachers more specifically will be out of step with the possibilities, continually lagging behind ever new cultural forms. At the same time, our children will continually adapt to, innovate, evolve, and generally become familiar with any new possibility.

⁴ <http://www.moe.gov.sg/press/2005/pr20050216.htm>.

Looking Ahead

The question (science) educators have to answer is, “What do we have to do to prepare students for participating in, creating, and evolving emergent literacies?” I am not trying to throw the baby out with the bath water by suggesting an exclusive focus on agency to the exclusion of the structures that enable the former. An ancient Chinese proverb says, “Theory without practice is sterile, practice without theory is blind.” Accordingly, the spontaneous, non-willful, motivated emergence of unforeseen events is grounded in extant, inherently structured knowing. There is a dialectical relationship between theory and practice, but in the past, (science) educators have emphasized the former over the latter. Now, teachers do not have to be responsible for introducing theoretical aspects of knowing: by preparing structures where students begin to reflect on and interpret the relative usefulness of new forms of practice, new literacies, they come to understand these to a much deeper extent than simply using them. “Why do I use this expressive form rather than another?” or “What are the possibilities of this representation over another?”

There is also a dialectic relating agency and structure, two non-identical expressions of the same underlying middle term that mediates between them. This middle term, which sublates the agency–structure opposition by incorporating it as an inner contradiction, is concrete human praxis. By focusing (science) education on concrete human praxis, teachers are able to prepare for settings and issues that are inherently more interesting for students than “practicing the scales.” Teachers still are in the position of providing (access to) resources just-in-time, when students have identified and recognized the need for extending their action possibilities.

Thinking about (scientific) literacy in the way proposed here, specifically, as collective praxis, also requires us to rethink assessment practices. If literacies are distributed and collective, then examining students individually to find out what *they* know independent of the normal settings within which they normally act are highly inappropriate and ill-conceived—as it would

be to assess any other irreducibly collective phenomenon, such as testing one hand to see how well it claps or to assess an individual dancer to find out how well she dances a waltz.

Coda

In this chapter, I frame (scientific) literacy in ways that it has not been before. My articulation highlights the emergent, spontaneous, individual|collective, situated, contingent, distributed, dynamic, and evolutionary character of literacies that they share with cultural phenomena. It used to be that proponents of scientific literacy used programming a VCR as a paradigmatic case to exemplify a general (scientific, technological) illiteracy. A simple look at Western societies shows that this case misses the target by far. New literacies are constantly emerging in an exuberant fashion, overrunning any previous literacy. Traditional conceptions of literacy, always framed in terms of yesteryear's knowledge, fail to capture the dynamic aspects of the new literacies. My reframing of (scientific, technological) literacy addresses all those aspects that are not part of received conceptions.

If knowing a language is indistinguishable from knowing your way around the world, and if our societies are changing at increasing rates, then (science) education has to loosen its grip on language and literacy to allow students to evolve the competencies to change their participation in an ever-changing world. A few decades ago, most citizens accepted as heroic advances new scientific "discoveries" and technological innovations, including gene technology, computer revolutions, and material sciences. However, what we need for the future are not more citizens following scientific dogma. Rather, we need citizens that engage scientists on ethico-moral grounds concerning the pressing issues at hand, including human-induced climate change, environmental impact of genetically modified organisms, emergent diseases, loss of biological diversity, and intensive agricultural and piscicultural practices. Science and scientists alone cannot handle these issues, as they are frequently at the source of the (ethico-moral, environmental, societal) problems: nuclear arms and power, production of GMOs, or cloning. Technological societies need citizens that engage scientists and engineers critically rather than

remaining under their spell and in their bondage. This does not require forms of scientific literacy as understood in the past—the competency to regurgitate scientific facts, laws, and theories—but rather requires competencies in creating and evolving ever new forms of literacies that are suited to deal with the ever new forms of problems scientific and technological “advances” generate. It should be clear that in advocating new theories and practices of scientific literacy I am not advocating to stop scientists and engineers but to allow the members of future generations to evolve competencies that will be increasingly necessary to cope with the problems that arise from scientific and technological work.

Competently participating in discourses concerning global environmental and societal problems that also involve scientists and engineers does presuppose that needs to know particular facts. Collectively (at the level of Western culture) there exist so many facts, so many competencies that it is impossible to specify just what someone needs to know that is useful in all conceivable situations that they may face in the future. Rather, when needed, such facts can always be located and accessed using a variety of technologies and relevant competencies can be brought to bear on issues by finding appropriate consultants or experts. Scientific and technological innovations lead to the emergence of new (forms of) problems. We therefore cannot specify in advance what the solutions to these emergent problems of emergent innovations will require in the form of new literacies capable to articulate what the relevant issues are.

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