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Deinstitutionalising School Science: Implications of a Strong View of Situated Cognition

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Abstract

Psychological models of learning have been shaped by information processing models for four decades. These models have led to teaching models based on information transfer from teachers to students. However, recent research in many fields shows that information processing models do not account for much of human competence in everyday scientific and lay contexts. At the same time, situated cognition models have been developed that better account for competence in widely differing situations. The implications of situated cognition are rather different from those of information processing. Teaching and learning are no longer conceived simply in terms of information transfer but as increasing participation in everyday practices. Conceiving of science learning as a trajectory of increasing participation asks educators to rethink the purpose of science education from preparing scientists to preparing citizens to participate in public enactments of science, and this entails deinstitutionalising school science to take science beyond the classroom walls.

In a letter to educators that accompanied a free copy of "Science Matters: Achieving Scientific Literacy" (Hazen & Trefil, 1991), the President of the Carnegie Institution noted:

> Science and technology are revolutionising our world. These developments directly affect each of us every day. As citizens we have to reach informed opinions in order to take part in our country's political discourse. More and more, scientific and technological issues dominate national debate—from the greenhouse effect to the economic threat of overseas technology. (Maxine F. Singer, March, 1991)

Science educators also argue that students should learn science because "there is a need for everyone's understanding in technology and science because the world is dominated by science and technology" (Brickhouse, 1994, p. 404). Despite such rhetoric, many science educators (and others) deplore the general state of scientific illiteracy (e.g., Hazen & Trefil, 1991). Adding to the seriousness of the problem from the perspective of many, the Third International Mathematics and Science Study (TIMSS) showed that by year 8, many students show little interest in learning science (Robitaille, Taylor, & Orpwood, 1996).

Lack of technological literacy is sometimes framed in terms of statements such as "The average new employee has no idea how to use a computer" or "The average American is dependent on technology but can't even program a VCR to record when no one's home." Our everyday experience, however, tells us otherwise. We can do perfectly well and lead happy lives without knowing much about science and technology.[1] We competently operate computers without understanding the physics of "pnp" and "npn" transistors, electron donors, holes, or electronic energy states in semi-conductors; we drive cars without understanding the combustion of compressed gases, mechanics of force transmission from engine to tires, or tire manufacturing technology. Similarly, for nearly a decade, many in the field of science education have sneered at those Harvard University graduates who, as shown in the film *A Private Universe*, did not provide canonical scientific answers to questions about the universe. Yet many of these graduates are likely to lead happy lives and make considerable amounts of money. If we, as science educators, take elitist views on the matter—such as that every citizen needs to know that summers are associated with the tilt of the earth's axis rather than with the (plausible) closeness to the sun—we are likely to continue with a science education that many students consider irrelevant.

What then are the purposes of science education? What kind of science education do we want future generations to have? What science should informed citizens be able to know and do? How should they learn what they should know? and, At what time should distinctions be made between training scientists and becoming literate citizens? We frame our answers to these questions in relation to current models of learning, arguing for the prominence of situated cognition over information processing.

Information Processing

Theoretical Perspectives

Over the past four decades, research on cognition has been dominated by the information processing paradigm which co-emerged with the advent of computers. According to the information processing paradigm, the brain is a computer that manipulates physical symbol systems (e.g., Anderson, 1985; Newell & Simon, 1981). Because of the co-emergence with computers and the interests of information processing scientists (artificial intelligence, cognitive science, cognitive psychology), the discourses about computing and thinking overlap to a great extent. For example, much like in a computer, the brain is said to store information as physical symbols in long term memory; from there it is called up by a central processor which is divided into short-term storage space and operating space (e.g., Brainerd, 1983; Case, 1985). In information processing theories, classical logic constitutes the central processor's basic operational mode. Conditional reasoning and production systems are excellent examples where reasoning was equated with information processing. As an example, consider the following conditional syllogism used to represent the solution process for a graphing problem related to population ecology from a recent study (see Figure 1a; Bowen, Roth, & McGinn, 1997):

1. IF the birth-rate is greater than the deathrate, THEN a population grows
2. The birth-rate is greater than the deathrate
3. THEREFORE, the population grows

Or, more abstractly, this form of syllogistic reasoning can be represented in the form:

1. $P \supset Q$
2. P
3. $\therefore Q$

Conditional syllogisms of this form are called production rules, defined as sets of rules of the general form IF. . . THEN. . . . These production rules are combined with rule interpreters (control modules that determine which rule to activate) and working memory to form a production system (Baumgartner & Payr, 1995). As data driven control structures, production systems are easily implemented in list processing (LISP) programs. For population graph problems such as that in Figure 1a, a production system could be structured as follows:

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SCAN graph from left end to right end in increments INC
IF    birth-rate greater than deathrate
THEN     population increases
draw line CONST * (birth-rate—deathrate)
draw arrow pointing right
IF    birth-rate less than deathrate
THEN     population decreases
draw line CONST * (deathrate—birth-rate)
draw arrow pointing left
END SCAN
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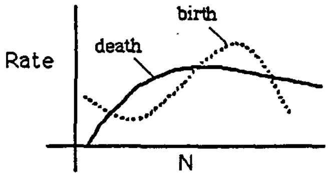
Implementing this production system with specific values for CONST and INC would yield the diagram displayed in Figure 1b. Here, performance is modelled by assuming that information relevant to the problem is processed according to deterministic rules and classical logic. For example, birth-rate, deathrate, and population size are declarative knowledge; the comparison "greater than" and the instruction "draw vector" are procedural knowledge. The IF. . . THEN. . . structure is a formal operation according to classical logic. Whereas the information (declarative and procedural knowledge) is called up from long term memory, the solution process is assembled in short term memory.

a. You have collected data that gives you the following birth and death rates in Atlantic cod, in relation to population size. Discuss the data in relation to cod population dynamics and management.



b.

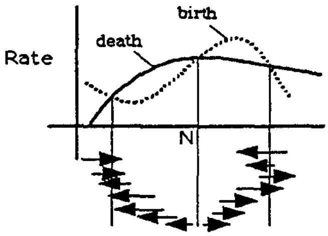


Figure 1. (a) Typical "problem" from a second year university ecology course which students had to work during seminars and examinations. (b) Illustration of an information processing approach to interpretation by drawing arrows that indicate the change in population size at different points along the horizontal axis. Two population size "attractors" or points of stable equilibrium can be observed at the left and right intersection points of the birth-rate and deathrate curves.

Once the arrows are drawn as in Figure 1b, one can easily "see" that there is a tendency for the population to move towards the population size corresponding to the left most or right most intersection of birth-rate and deathrate curves. These are the points of stable equilibrium for the population size. There is also a tendency to move away to the left or right from the population size corresponding to the middle intersection between deathrate and birth-rate curves. This is a point of unstable equilibrium for the population size.

This information processing analysis suggests that graph interpretation is a rational exercise in which the interpreter moves step by step from problem statement to solution. Our production system would only be part of the solution. To have a complete problem solving system, our production system would be embedded in a larger production system in which solutions are constructed using one of several problem solving heuristics. The most important aspect, however, remains the context-independent problem solution process and product. Furthermore, information processing approaches generally do not differentiate problem solvers according to their ordinary practices other than classifying them along a singular dimension ranging from novice to expert. In a later section, we return to this example with an alternate theoretical explanation.

Information Processing and Impact on Science Education

Information processing models have focused educators' attention on attempts to impart context-independent information (declarative and procedural knowledge) into students' long term memories (Hall, 1996). Lectures are typically consistent with the notion of information provision by the teacher and information uptake on the part of the student. In addition, information processing models suggest that practice in doing problems trains the operational assembly of solutions (Adey & Shayer, 1992). According to information processing accounts, students' major task is to learn how to apply context-independent knowledge in specific situations. Application is facilitated because knowledge is not randomly stored but organised in terms of scripts (Anderson, 1985) or conceptual frameworks (Chi, 1991). The conceptual change tradition has placed particular emphasis on learning (and therefore effective teaching) as reconfiguring conceptual structures.[2]

This focus on external information that has to be acquired much like a computer acquires its information has had tremendous impact on teaching. Teacher control of subject matter information that had to be given to students in "bite size" chunks has been the order of the day as it was during behaviourism. Teacher lectures and demonstrations dominate science classrooms. In this form of schooling, students' own science-related knowledge is devalued (Brickhouse, 1994; Lemke, 1990). Teachers and textbooks have unilateral control over the nature and frequency of scientific questions that are worthwhile answering (Poole, 1994). Students are asked to reproduce ideas of teachers and textbooks—the authoritative sources of correct information to be processed—rather than producing their own ideas. Whereas students' cultural productions may be valued in other subjects such as poetry and art, original questions and ideas are usually not valued in science education until well into graduate or postdoctoral years. Until then, students typically reproduce preconfigured and "correct" sequences of actions (as answers to word problems, as completion of standardised laboratory activities). The metaphor of mind as a computer which has emerged with the information processing paradigm relegates students to processors of disembodied—and unbeknownst to many, meaningless—information. But school experience shows that this approach does little to assist students in becoming better processors of information (e.g., during problem solving). Rather, many colleagues in faculties of science complain that in their lifetimes, information processing and therefore problem solving capabilities of their students have decreased.

Information processing scientists, aware of the differences in reliability between humans and computers have had to introduce a number of features in an effort to save information processing theories. For example, reasoners tend to operate on representations at the lowest level of precision that permit task-relevant responses (Reyna & Brainerd, 1995). That is, detailed nuances of problem information are not central to reasoning so that memory for numbers is unrelated to reasoning and exact information can be removed from standard problems without removing standard effects. To save information processing in the face of evidence that much thinking is done without precise information—as computers would require—some researches have constructed a "fuzzy-trace" theory (e.g., Reyna & Brainerd, 1995). Fuzzy trace theory explains the independence of reasoning and memory in terms of (a) reasoning performance which is based on gist representations not verbatim representations of memory performance and (b) randomness of retrieval errors.

Information processing accounts also fail on other fronts. First, it is impossible to teach or know everything of importance (Wiggins, 1989). Even highly trained scientists in one domain do not know the most basic "facts" in another domain. For example, only 3 of 24 physicists and geologists could explain the difference between DNA and RNA (Hazen & Trefil, 1991). Second, traditionally, artificial intelligence and cognitive science researchers assumed information was stored independently from the way or circumstances in which it was acquired (Brooks, 1995) and independently from the subjective experience of physically engaging with the world (Brooks, 1994). These assumptions have not been borne out which led, in the late 1980s, to a large-scale shift in artificial intelligence research and cognitive modelling from physical symbol systems to parallel distributed processing and experience-based knowledge in robots (Brooks, 1995; Churchland & Sejnowski, 1992; Olazaran, 1996; Reeke & Edelman, 1988).[3] Both conceptions of knowledge—parallel distributed processing and experience-based knowledge—are closer to the situated cognition paradigm discussed in the next section than to the classical physical symbol (information) processing paradigm in that learning is not achieved through the transfer of information but through experience with many concrete examples by being-in and moving-through the world.

Now, critics from outside the fields of cognitive science and artificial intelligence (e.g., Dreyfus, 1992; Lave, 1988; Lave & Wenger, 1991; Suchman, 1987) are joined by an increasing number of insiders in questioning the suitability of the physical symbol processing model of cognition (Agre, 1993; Brooks, 1995; Chapman, 1991; Clancey, 1993; Hutchins, 1995; Winograd & Flores, 1987). Furthermore, studies of everyday work in scientific laboratories show that, during discovery work, scientists do not reason in the way production systems suggest (Gooding, 1990; Knorr-Cetina, 1981; Latour & Woolgar, 1979/86; Lynch, 1985; Pickering, 1995).[4] These different lines of criticisms show that much of human knowledge and competence is not represented in mind alone. Many people participate competently in professional and everyday conversation without knowing much about grammar; we often know to do things with our word processor without being able to explain them to someone else in situations where computer and program are not present.

Situated Cognition

Theoretical Perspectives

In recent years, researchers in cognitive anthropology, cognitive science, artificial intelligence, and cognitive studies in education have begun to work out a new theoretical framework for understanding human activity, knowing, and learning: situated cognition (Agre, 1995; Brown, Collins, & Duguid, 1989; Chapman, 1991; Clancey, 1997; Hutchins, 1995; Lave, 1988; Roth, 1996a; Suchman, 1987). Situated cognition questions assumptions about the context-independence of competence. For example, how will knowing how to factor polynomials (i.e., finding that $x^2 - x - 6$ can be expressed as $[x - 3] * [x + 2]$) help anyone become a better shopper, complete an income tax form, make profit from stock investment, keep track of baseball statistics, calculate recipes for a different number of people, or any other mathematical activity people engage in their professional or private lives. Detailed analyses of mathematical performance in out-of-school situations have shown that years of schooling are not related to everyday mathematical competence on the street (Lave, 1988; Saxe, 1991; Scribner, 1986). Having acquired more mathematics-related information in school has not led to higher performance in everyday mathematics activities. This should raise questions about the validity of the information storage and information processing metaphors of mind. However, assumptions about knowing and learning are so deeply rooted that we have difficulties imagining models other than those based on processing information. Yet many thinkers have long argued on various grounds— including pragmatist (e.g., Dewey, 1933), phenomenological (e.g., Heidegger, 1977), and Marxist grounds (e.g., Bourdieu, 1997)—that much of what we know results from our experience of acting in the world and in terms of the community of which we are necessarily part.

Situated cognition approaches decenter traditional cognitive research: they no longer limit their investigations to mental processes, but explicitly focus on participation in activities as these are shaped by individuals-acting-in-settings. That is, structural properties of activities as they arise from the interaction of multiple aspects of a setting including psychological, material, social, historical, political, and economic factors as these are seen by the actors themselves. That is, situated cognition not only takes a different view on the nature of cognition but also makes clear distinctions between the ontology of some focal situation as viewed by the researcher and researched.[5] Researchers thereby explicitly allow for different perspectives on a situation and therefore non-normative views of what constitutes appropriate action in a particular situation.

In several research projects, we provided substantial evidence that different students saw different phenomena and events although they observed the same situation; what the teachers saw was also different in many cases (Roth, 1995a, 1996b; Roth, McRobbie, Lucas, & Boutonné, 1997a, 1997b). Teachers often *see* focal events in science classrooms *as* specific instances of a physical phenomenon in the way it is theorised within canonical science frameworks; their knowledge informs them how to separate some signal as foreground against other signals that are noise (background). Students, on the other hand, do not bring the same theoretical commitments so that they face problems trying to separate signals from background noise before actually knowing the theory that makes such separations plausible. That is, although the underlying event was assumed to be the same—all participants agreed that they looked at the same focal situation—what was seen turned out to be different. However, for participants to realise that they had different views, they had to engage with each other. We showed that teachers developed lectures mistakenly believing that students had made a particular observation whereas our research showed that students and teachers viewed the focal situations in different ways (Roth et al., 1997b; Roth & Tobin, 1996).

An important aspect of situated cognition approaches are the socio-cultural aspects of a situation as perceived by the agent. From this perspective, social practices rather than individual actions are central to the structures of cognition. Thus, from a situated cognition perspective, we examine human activities in terms of: (a) *standard practices* by means of which the characteristic activities of the domain get done; (b) ready-to-hand *material resources*, such as tools and equipment, that members use as part of their standard practices[6]; (c) *linguistic resources* that members use to make distinctions important to competent and efficient activities of the field; (d) *breakdowns*, interruptions of standard practices and slow-down of an activity's progress that evolve from breaking or absent tools or changes in familiar contexts; and (e) sets of *ongoing concerns* of members include common missions, interests, and fears (Denning & Dargan, 1996). These different components constitute a map for analysing activities, and provide us with a framework to help guide our interpretations. That is, this map—which constitutes our domain ontology—constitutes a conceptual frame for interpreting recurrent actions in a particular domain (cf., Winograd & Flores, 1987). This conceptual frame has been shown to be useful for investigating activities in the workplace, designing computer software, and analysing expert systems (Coyne, 1995; Dreyfus, 1995a, 1995b; Winograd, 1996).

When students' activities are analysed from a situated cognition framework, one can see how the products of their work are heterogeneous assemblies of a range of elements including standard practices, material and linguistic resources, sets of breakdowns, and ongoing concerns that characterise the students' community (Roth, 1996a; Roth et al., 1997a; Roth & Welzel, 1997). As students engage with their situations (task definition, activities, materials) they develop increasingly complex actions, differentiated ontologies that include more and more complex elements. For example, we showed how students engaged with the distance of a weight from the fulcrum of a balanced lever only after building up distance as a variable from rudimentary notions of location and the actions of moving weights along the lever arm (Roth & Welzel, 1997).

Before closing this section, we want to add a note of caution and emphasise that situated cognition demands a radical rethinking of the nature of cognition. Currently, some people want to craft situated cognition onto traditional models of mind and thereby uphold a Cartesian division of mind and situation. In this view, two independent constructs—the individual minds and the setting—are seen to interact with each other. As we present it here (in agreement with recent work in AI and cognitive science), situated cognition is irreducible to Cartesian minds, situations, and the interactions between these two entities. It is not appropriate to use the concepts of situated cognition to design new and different learning environments but with the same goal of filling students' head with information, only differently. For example, a common misinterpretation of situated cognition leads to the use of "contextual word problems." Teachers and researchers increase the stem of a textbook problem and assume that, because the text may refer to some everyday context, students' activities are immediately compatible with situated cognition theory. But such context is typically "con-text" (Roth, 1996c) that is, as the etymology of the syllable "con" (= with) suggests, additional text and information of the same de-contextualised form, devoid of the goals, concerns, tools, and resources; it necessarily leads to the same practices as before. In a recent study, we found that students' interpretations of ecological data changed considerably when collected by (a) themselves or (b) someone else and augmented by a word problem stem (Roth, 1996c). Based on this study, we concluded that both can be valuable learning situations if the meaning of "context" is changed. Rather than referring to the situation described by the word problem's cover story[7], a word problem should be termed *contextual* if it gives rise to intelligible scientific and mathematical practices embedded in a wide range of other mathematical and scientific practices. Here, students' scientific and mathematical activity is not something happening in individual minds but a witnessable social event with associated collectively-sensible products.

Four Practising Scientists Interpret a Graph: An Example of Situated Cognition

To exemplify our situated cognition approach, we look at the responses practising scientists from four different fields enacted while working on a problem nearly identical to that in Figure 1 (Bowen, Roth, & McGinn, 1997). The four scientists[8] involved in this study engaged in the ongoing concerns (e.g., types of questions to ask and relevant examples from their experience to consider) and practices (e.g., ways of focusing on important features of an inscription and the relevance drawn from that focus) of their respective fields. They also drew on considerably different resources to make sense of the graph. These different concerns, practices, and resources resulted in varied interpretations from the different scientists, although their responses were consistent with their fields' concerns and practices.

When the field ecologists interpreted the graph they drew on a large number of resources in terms of actual populations and population histories that assisted in their sense-making activities:

white fish in the Great Lakes, right whales, starlings, elephants, spruce budworms, elk, Peruvian anchovies, and salmon. When these two field ecologists experienced breakdown, it was related to questions about whether the graph corresponded to phenomena which they could actually observe in nature. Thus, they evaluated the graph in terms of its accuracy to describe real populations.

The theoretical ecologist and physicist, on the other hand, were little concerned with the match between the graph and actual populations. Both drew mainly on mathematical resources during their discussion of the question—resources that both field ecologists suggested they did not have—but rarely used animal examples. For example, the theoretical ecologist made only two references to actual populations including a comment on generic "disease agents" and an aside about a pregnant snowshoe hare that was found in a very large area without any male snowshoe hares. The physicist's ongoing concern was the nature of the representation (graph) and, as part of his response, he transformed it into another representation where he suggested that the underlying concept of stability/instability of population size was at once better represented and more similar to representations in chemistry and physics. In this endeavour, the physicist drew on computer and mathematical modelling software which he, in a ready-to-hand manner, used efficiently and rapidly in his transformations. One transformation did not yield an expected graph, a breakdown in his activities. But, as he later recognised, he had constructed the mirror image of the sought-for representation so that, by adding a minus sign (another standard practice), he was back on track again.

This example shows that although the graph (Figure 1) appears trivial—being used in a second year ecology course as a sample problem and examination question—there were considerable variations in the nature and content of scientists' interpretations. Scientists' activities made sense in the context of their daily activities with the concomitant concerns, practices, resources, and breakdowns from their fields. Scientists' activities are context for the practices, resources, concerns, and breakdowns they experience much in the way year 8 students' mathematical activities were context for their social practices (Roth, 1996c). In most schools, however, variations in interpretation that reflect individual concerns and different prior experiences are disallowed and students are penalised when they deviate from the one "right" solution. As Roth and McGinn (1997) argued, such rigid approaches to the question "What constitutes an appropriate interpretation of a graph?" are not only found in science classrooms but also in the research literature.

Situated Cognition and Science Education

Theories of situated cognition provide different recommendations than information processing theories for learning school subjects such as science or mathematics (Brown, Collins, & Duguid, 1989; Collins, Brown, & Newman, 1989). Two major concepts are communities of practice and legitimate peripheral participation (Lave & Wenger, 1991). Practices are patterned ways of doing the tasks; people who share practices form more or less open communities of practice. Participation in practice usually changes along trajectories from legitimate peripheral participation to core participation in a community. To achieve trajectories characterised by continuities rather than discontinuities between school practices and professional and lay everyday practice, poses certain requirements on problems and solutions, and the tools available to students (Brown & Duguid, 1992). Tools are considered useful and appropriate only when they permit learners to engage in practices that, as learners become more proficient, lead directly to the practices of the field. However, if tools are used to distinguish between newcomers and old-timers, legitimate peripheral participation and trajectories of learning are disrupted (Brown & Duguid, 1992).

In one of our learning environments (Roth, 1992, 1993), year 11 and 12 students used mathematical and statistical modelling tools commonly used by practising scientists. Over a two-year period, physics students developed great competence modelling physical phenomena. At present, many university science programs disrupt students' learning by forcing them to use outdated tools (paper and pencil, unprogrammed calculators). Some of the students from our learning environment rediscovered the mathematical and statistical software of their high school years in masters degree programs (Ralf Riekers, engineering physicist, February 1996). Furthermore, the same mathematical modelling tool was used by year 4 students to learn about equivalent fractions (Roth, 1998). In this case, the same mathematical modelling software designed for physicists and engineers was used by students in years 4, 11, 12 and a masters degree program.

Situated Cognition and the Goals of Science Education

Our discussion of the concerns, practices, resources, and breakdowns which contextualise the activities of scientists and provide scientists with a good sense of the reasonableness of their work raises questions as to the goals of science education. In the past, many science educators assumed that students should experience "authentic science" (e.g., Brown, Collins, & Duguid, 1989; Roth, 1995b). Authentic thereby meant that students engage in practices—reasoning about scientific objects and events, doing experiments, presenting findings rhetorically—in ways that resemble, in some deep way, those practices that characterise science and scientists. However, authentic science is not something one can put on like a hat. Rather, one has to engage it for protracted periods of time and participate in a culture of science. Furthermore, it has to be questioned whether the goal of science education should be for many students to do "authentic science" in schools if this means to act like scientists. Rather, there are other science-related activities that could be thought of as valuable, life-long pursuits including bird-watching, engaging in environmental activism, or gardening. Students could be introduced and engage these science-related pursuits in authentic ways from early ages, and thereby traverse trajectories of science learning that continue throughout their adult lives. Doing "authentic science" at school therefore would mean that persons already participate in the practices during their formative school years.

There is a tension in the assumption that students need to be introduced to the practices of scientists rather than other common science-related activities. The focus on academic science (and mathematics) leads to a conception of school science as a propaedeutic[9] activity—school science as preparation for university science. The trajectories of practice are then conceived as leading from children's early practices to those of scientists. However, few students will actually become scientists or engineers. Conceiving of school science as legitimate peripheral participation to scientists' practices may therefore do little to improve the current situation of low participation rates in science. Rather, authentic practice may have to be conceived in terms of everyday science-related activity by non-scientists such as, for example, those of activists (ecology, environment, medical research, nuclear technologies, chemical industry, etc.).[10] As we show in the next section, such a conception of science and scientific literacy would allow legitimate peripheral participation from early ages. This conception would allow students to begin a trajectory of legitimate peripheral participation in a community where they appropriate concerns, practices, and resources as they participate in their community's activities.

Deinstitutionalising School Science

A survey of major reform documents (American Assocation for the Advancement of Science (AAAS), 1993; National Research Council (NRC), 1996) and books (Hazen & Trefil, 1991) shows that scientific literacy seems to be interpreted such that the goal of science education is for students to acquire scientists' ways of knowing, canonical knowledge.[11] Given that only a small fraction of students eventually become scientists or engineers, one has to question traditional models of delivery which make science education a propaedeutic effort; that is, a preparation for the profession of scientists. Some readers may ask, What other reasons could there be for science education? Research in science and technology studies shows that people from all walks of life, even without scientific or technological training, can have an enormous shaping influence on the nature of scientific inquiry including the determination of validity, reliability, and appropriate testing protocols (Blume, 1997; Epstein, 1995; Solomon & Hackett, 1996). A survey of 430 recombinant DNA scientists engaged in research showed that only 6% thought that public attention has not had an impact on their work (Rabino, 1991). Fourty-four percent of the scientists thought that the impact has been beneficial while the remainder suggested that the impact has been harmful (24%), or equally beneficial and harmful (27%).

There is considerable evidence that shows how AIDS treatment activists have constituted themselves as credible actors in the shaping of legitimate research related to the disease (Epstein, 1995). Contrary to popular beliefs according to which science is an autonomous arena, interested individuals and organisations with little formal training but vested interests can contribute to the construction of science and scientific knowledge. AIDS activists have gained different forms of credibility and thereby become genuine participants in the construction of scientific knowledge and change agents in therapeutic medical care techniques and in epistemic biomedical research practices. In a similar way, French activists were able to shape the political debate about auricular implants and thereby affect scientific work in the field (Blume, 1997). Furthermore, scientific validity is not something exclusively determined in laboratories by those who have gone through years of training. It has been shown that judges (and scientists who act as expert witnesses) contribute to the construction of scientific validity (Solomon & Hackett, 1996). In one case, the plaintiffs wanted to show that Bendectin, a drug intended to alleviate morning sickness during pregnancy, caused birth defects. Many of the briefs submitted to the case stressed the ability of the legal system to evaluate this scientific evidence without deferring to scientific authority. Here, what is science and how scientific research is to be evaluated is no longer an issue exclusively decided by those with long specialised training but by people whose formal education in science may include but a few courses at high school and university, if any.

The situated cognition framework suggests that, if educating activists was the goal of science education, students would be best to engage in some form of activism. There are already small projects in place in various counties that show that participation in the collection and interpretation of data can be a lifelong endeavour. For example, in the Vancouver (Canada) area, elementary students participate in seeding a new green corridor with butterfly pupa, high school students monitor pollution levels in a nearby inlet, hikers sample biodiversity before logging companies enter an area, nature enthusiasts actively engage in counting bird populations, and environmental activists block loggers' access routes to the beautiful Clayoquot Sound.

In one specific example of activism, concerned citizens challenged the scientific data used to justify a project that would allow a fen[12] to become a containment system for treated sewage from a golf course, housing development and condominium project.[13] Water levels would be raised nearly three meters during the winter and the treated sewage would be pumped back up to irrigate the golf course during the summer. The rich riparian zone around the fen would be alternately drowned and then sucked dry which would disrupt the fen's natural beauty and wildlife habitat, and sewage would negatively impact groundwater in the area. Concerned citizens filed appeals explicitly questioning the scientific data in an effort to have the permit for the containment system revoked. In the end, the project did not receive approval.

Other forms of environmental activism are less combative. In the Coquitlam Green Links Project, the Institute for Urban Ecology sponsors citizens' involvement in establishing a connected park system throughout the community.[14] This project is intended to connect and nourish the biodiversity of the area through the creation of urban ecological corridors. Citizens participate by creating natural wildlife habitat in their backyards—planting indigenous or native plants, creating butterfly gardens, installing nesting boxes for birds, putting in bird feeders, and so forth. At the community level, citizens engage in the removal if invasive plants, stream enhancements, refuse clean-ups, and so on. After completion of each project, the Institute for Urban Ecology oversees a long-term stewardship program.

Although most citizens in such groups are not trained scientists, they often successfully challenge scientific data and scientific authority. The people involved in all of these projects share a commitment to actively participating in science without necessarily having completed formal science coursework. When co-participation in science takes forms as described here, legitimate peripheral participation and trajectories of competence are readily conceivable. There are only small steps from finding out how to seed a green corridor with butterfly pupae to monitoring the pollution levels in a marine inlet and contributing to the establishment of baseline data for biodiversity assessments.

In this way, science is no longer confined to the four walls of a classroom. Although children may begin with activities as part of school science, these activities do not need to remain confined to the institutional walls. Rather, these activities can become part of public and political processes: the butterfly project makes the local newspapers and high school students' pollution data may influence policy making processes in the communities along the inlet much in the same way that biodiversity projects make the newspapers and environmental activists shape the political process around logging. In the process, school science and science learning would be deinstitutionalised and enacted in everyday life.[15] Authentic science would mean that students participate in activities that contribute to the community at large.

Rather than measuring understanding of science in terms of the degree to which students can reproduce canonical science, scientific literacy and competence can then be evaluated in terms of students' contributions to a better world and school science can become part of a "philosophy-of-wisdom" (Maxwell, 1992) or "applied ethics" (McDonald, 1989) inquiry in which the discourses of music, literature, drama, politics, science, religion and philosophy are treated at the same level. Such a science would allow students to discuss some of the key problems we face, but which are traditionally addressed only from a scientific-technological perspective without yielding viable solutions. Among these problems are all those which have the potential to threaten the survival of our planet as it presents itself today. The end result of such an approach in which science/technology and ethics are taught on an equal footing "is neither more expert opinions in arcane areas of knowledge nor moral diatribes against the forces of evil; it is rather a better understanding of the major moral issues before us" (McDonald, 1989, p. 124).

There may be a tension in such a change of education. Some argue that schools are institutions which force compliance, produce obedient bodies that fit into highly structured society, and stratify society by producing hierarchies (Foucault, 1975; Roth & McGinn, 1998). In the past, science education mainly stratified school populations and thereby served as a selection mechanism for university science programs (Brookhart Costa, 1993; Eckert, 1990). Activist movements, however, undermine traditional forms of (political and epistemic) power by questioning the ways (a) political decisions about nuclear and chemical wastes are made; (b) scientific decisions about the testing of drugs, auricular implants, or ecological assessments are shaped; and (c) education is traditionally "delivered." Scientific literacy, may not be in the interest of politicians, scientists, industrialists, and teachers when it means that an increasing number child citizens begin to question them. Resistance to change can therefore be expected by all of these groups.

Conclusions

In this article, we argued that the underlying assumptions in current science education practices have their roots in information processing theories of learning. These theories by and large implied teaching as information transfer and training in context-independent reasoning processes that are based on classical logic and inference. Mounting evidence shows that reasoning in everyday professional and lay contexts does not take the forms that underlie information processing theories. Rather, the evidence of research on cognition in everyday situations points to situated cognition as a more suitable paradigm for understanding competence and expertise. Situated cognition theories, however, conceptualise learning as legitimate peripheral participation in authentic practices which are always meaningful against a background of social, material, political, historical, and economic contingencies of agents' lived situations.

Given that few students actually become scientists, we argued that the authentic practices to be fostered in schools are those of lay scientific pursuits such as those in nature clubs and environmental activist groups not just the practices current in scientific laboratories. Such a reconceptualisation changes school science from a propaedeutic effort that aims at training scientists to a continuing participation in everyday science-related activities. In this new conception, continuous trajectories of learning and membership compatible with a strong view of situated cognition are possible and feasible. Such changes would entail a deinstitutionalisation of school science where activities are evaluated in terms of their contribution to a common good rather than in terms of individual memory and intellectual prowess for processing information.

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Notes

1. In fact, many designers argue that if technology cannot be used without specialised knowledge it is not well designed (e.g., collection in Winograd, 1996). Thus, the problem could be said not to lie with technologically illiterate people but with poorly designed technology that cannot be used in transparent ways.
2. In this way, conceptual change approaches necessarily take an engineering perspective to teaching focusing on the ways students' conceptual structures can best be reconfigured.
3. Olazaran (1996) and Reeke and Edelman (1988) provide accounts of the history of this shift from physical symbol processing to parallel distributed processing. Within a couple of years, parallel distributed processing proposals in the USA increased their NSF grant allotments from negligible amounts to 500 million dollars.
4. Students, because they do not see phenomena in canonical ways and do not know canonical theories are always in "discovery" mode. The problem of expert-novice studies lies in the fact that they do not compare reasoning per se on level playing fields. Rather, experts usually reason in familiar terrain, in a Kuhnian (1970) "normal" mode, whereas novices are asked to reason in unfamiliar terrain, Kuhnian "discovery" or "revolutionary" mode.
5. Here, "ontology of the focal situation" refers to the collection of things, events, and relations that constitute the focal situation from an individual's perspective. As the following paragraph

shows, researchers (a) should study teaching and learning presuming differences between participants' ontologies and (b) must show on the basis of empirical data that the ontologies of two or more individuals can be taken as the same.

6. A tool is ready-to-hand if a member uses it transparently, focusing on the task rather than the tool (Roth, 1997).
7. As argued earlier, the addition of text in a cover story is con-text; that is, it is text that goes with other text, rather than being context in the sense that it situates authentic practices. Scientists and mathematicians do not solve word problems. Thus, adding more text to the stem in Figure 1a does not automatically constitute a problem which is more contextual (Roth, 1996c)
8. These included a management-oriented field ecologist, a conservation-oriented field ecologist, a theoretical ecologist, and an experimental physicist.
9. "Propaedeutic" means studies (e.g., at the high school level) that prepare for later, for example, university studies. Thus, high school science teachers' comments that they want to or have to prepare their students for university studies makes science education at this level a propaedeutic effort but not necessarily one that prepares scientifically literate citizens.
10. It is well-known that the number of women in science is relatively small. It is therefore interesting that two thirds of the participants in activist movements are women (Martin, 1997).
11. This trend is probably not surprising given that so many scientists participate in the construction of these reports and books. Among scientists, classical notions of learning the facts first and then applying them are prevalent.
12. Fens are artesian lakes with a floating reed mat surface and are essential habitat for migrating birds and other animals.
13. On the webpage [http://opus.freenet.vancouver.bc.ca/local/wcel/otherpub/bcen/vol_v/7660_reg.html], interested readers can find specifics on this case and many other cases of activism in British Columbia. Similar sites exist around the world.
    The page [http://csvax.cs.caltech.edu/~adam/LEAD/active_links.html] provides links to activist groups around the world.
14. Information and contacts for the Douglas College Institute for Urban Ecology can be found at their home page: http://www.douglas.bc.ca/iue/title1.html.
15. Authentic in the sense that learning occurs continuously along trajectories of increasing legitimate participation; non-authentic learning occurs when there are discontinuities between successful practices inside formal learning institutions and those enacted outside (Brown & Duguid, 1992).

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References

Adey, P., & Shayer, M. (1992). Accelerating the development of formal thinking in middle and high school students II: Postproject effects on science achievement. *Journal of Research in Science Teaching, 29*, 81-92

Agre, P. E. (1995). Computational research on interaction and agency. *Artificial Intelligence, 72,* 1-52.

American Association for the Advancement of Science (AAAS). (1993). *Benchmarks for science literacy.* New York: Oxford University Press.

Anderson, J. R. (1985). *Cognitive psychology and its implications.* San Francisco, CA: Freeman.

Baumgartner, P., & Payr, S. (Eds.). (1995). *Speaking minds: Interviews with twenty eminent cognitive scientists.* Princeton, NJ: Princeton University Press.

Blume, S. S. (1997). The rhetoric and counter-rhetoric of a "bionic" technology. *Science, Technology, & Human Values, 22,* 31-56.

Bourdieu, P. (1997). *Méditations pascaliennes* [Pascalian meditations]. Paris: Seuil.

Bowen, G. M., Roth, W.-M., & McGinn, M. K. (1997, March). *Learning to interpret graphs through small group interactions in a second-year university ecology course.* Paper presented at the annual meeting of the American Educational Research Association, Chicago, IL.

Brainerd, C. J. (1983). Young children's mental arithmetic errors: A working memory analysis. *Child Development, 54,* 812-830.

Brickhouse, N. (1994). Bringing in the outsiders: Reshaping the sciences of the future. *Journal of Curriculum Studies, 26,* 401-416.

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

Brooks, R. (1994). Building brains for bodies. *Autonomous Robots, 1,* 7-25.

Brooks, R. (1995). Intelligence without reason. In L. Steels, & R. Brooks (Eds.), *The artificial life route to artificial intelligence: Building embodied, situated agents* (pp. 25-81). Hillsdale, NJ: Lawrence Erlbaum Associates.

Brown, J. S., & Duguid, P. (1992). Enacting design for the workplace. In P. S. Adler & T. A. Winograd (Eds.), *Usability: Turning technologies into tools* (pp. 164-197). New York: Oxford University Press.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32-42.

Case, R. (1985). *Intellectual development.* New York: Academic Press.

Chapman, D. (1991). *Vision, instruction, and action.* Cambridge, MA: The MIT Press.

Chi, M. T. H. (1991). Conceptual change within and across ontological categories: Examples from learning and discovery in science. In R. Giere (Ed.), *Cognitive models of science: Minnesota studies in the philosophy of science* (pp. 129-186). Minneapolis: University of Minnesota Press.

Churchland, P. S., & Sejnowski, T. J. (1992). *The computational brain.* Cambridge, MA: MIT.

Clancey, W. J. (1993). Situated action: A neuropsychological interpretation response to Vera and Simon. *Cognitive Science, 17,* 87-116.

Clancey, W. J. (1997). *Situated cognition: On human knowledge and computer representation.* Cambridge: Cambridge University Press.

Collins, A., Brown, J. S., & Newman, S. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. In L. Resnick (Ed.), *Knowing, learning and instruction: Essays in honor of Robert Glaser* (pp. 453-494). Hillsdale, NJ: Lawrence Erlbaum Associates.

Coyne, R. (1995). *Designing information technology in the postmodern age: From method to metaphor.* Cambridge, MA: The MIT Press.

Denning, P., & Dargan, P. (1996). Action-centered design. In T. Winograd (Ed.), *Bringing design to software* (pp. 105-120). New York, NY: ACM Press.

Dewey, J. (1933). *How we think.* Boston: Heath.

Dreyfus, H. L. (1992). *What computers still can't do: A critique of artificial reason.* Cambridge, MA: MIT Press.

Dreyfus, H. L. (1995a). Cognitivism abandoned. In P. Baumgartner & S. Payr (Eds.), *Speaking minds: Interviews with twenty eminent cognitive scientists* (pp. 71-83). Princeton, NJ: Princeton University Press.

Dreyfus, H. L. (1995b). Heidegger on gaining a free relation to technology. In A. Feenberg, & A. Hannay (Eds.), *Technology and the politics of knowledge* (pp. 97-107). Bloomington, IN: Indiana University Press.

Eckert, P. (1990). Adolescent social categories—Information and science learning. In M. Gardner, J. G. Greeno, F. Reif, A. H. Schoenfeld, A. diSessa, & E. Stage (Eds.), *Toward a scientific practice of science education* (pp. 203-217). Hillsdale, NJ: Lawrence Erlbaum.

Foucalt, M. (1975). *Surveiller et punir: Naissance de la prison.* Paris: Gallimard.

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

Gooding, D. (1990). *Experiment and the making of meaning: Human agency in scientific observation and experiment.* Dordrecht: Kluwer Academic Publishers.

Hall, R. (1996). Representation as shared activity: Situated cognition and Dewey's cartography of experience. *The Journal of the Learning Sciences, 5,* 209-238.

Hazen, R. M., & Trefil, J. (1991). *Science matters: Achieving scientific literacy.* New York: Doubleday.

Heidegger, M. (1977). *Sein und zeit* [Being and time]. Tübingen, Germany: Max Niemeyer.

Hutchins, E. (1995). *Cognition in the wild.* Cambridge, MA: The MIT Press.

Knorr-Cetina, K. D. (1981). *The manufacture of knowledge: An essay on the constructivist and contextual nature of science.* Oxford: Pergamon Press.

Kuhn, T. S. (1970). *The structure of scientific revolutions* (2nd ed.). Chicago: The University of Chicago Press.

Latour, B., & Woolgar, S. (1986/79). *Laboratory life: The social construction of scientific facts.* Princeton, NJ: Princeton University Press.

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

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

Lemke, J. L. (1990). *Talking science: Language, learning and values.* Norwood, NJ: Ablex Publishing.

Lynch, M. (1985). *Art and artifact in laboratory science: A study of shop work and shop talk in a laboratory.* London: Routledge and Kegan Paul.

Martin, B. (1997). STS and social activists. *Technoscience, 10*(1), 11-12.

Maxwell, N. (1992). What kind of inquiry can best help us create a good world? *Science, Technology, & Human Values, 17,* 205-227.

McDonald, M. (1989). Ethics versus expertise: The politics of technology. In J. Nef, J. Vanderkop, & H. Wiseman (Eds.), *Ethics and technology* (pp. 119-124). Toronto: Wall & Thompson.

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

Newell, A., & Simon, H. A. (1981). Computer science as empirical inquiry: Symbols and search. In J. Haugeland (Ed.), *Mind design* (pp. 35-66). Cambridge, Mass: MIT Press.

Pickering, A. (1995). *The mangle of practice: Time, agency, & science.* Chicago, IL: The University of Chicago Press.

Olazaran, M. (1996). A sociological study of the official history of the perceptrons controversy. *Social Studies of Science, 26,* 611-659.

Poole, D. (1994). Routine testing practices and the linguistic construction of knowledge. *Cognition and Instruction, 12,* 125-150.

Rabino, I. (1991). The impact of activist pressures on recombinant DNA research. *Science, Technology, & Human Values, 16*, 70-89.

Reeke, G. N., & Edelman, G. M. (1988). Real brains and artifical intelligence. *Daedalus, 117*, 143-173.

Reyna, V. F., & Brainerd, C. J. (1995). Fuzzy-trace theory: An interim synthesis. *Learning and Individual Differences, 1*, 1-75.

Robitaille, D. F., Taylor, A. R., & Orpwood, G. (1996). *The TIMSS-Canada Report* (Vol. 1: Grade 8). Vancouver, BC: Department of Curriculum Studies.

Roth, W.-M. (1992). Bridging the gap between school and real life: Toward an integration of science, mathematics, and technology in the context of authentic practice. *School Science and Mathematics, 92*, 307-317.

Roth, W.-M. (1993). Problem-centered learning or the integration of mathematics and science in a constructivist laboratory: A case study. *School Science and Mathematics, 93*, 113-122.

Roth, W.-M. (1995a). Affordances of computers in teacher-student interactions: The case of Interactive Physics™. *Journal of Research in Science Teaching, 32*, 329-347.

Roth, W.-M. (1995b). *Authentic school science: Knowing and learning in open-inquiry science laboratories*. Dordrecht, Netherlands: Kluwer Academic Publishing.

Roth, W.-M. (1996a). Art and artifact of children's designing: A situated cognition perspective. *The Journal of the Learning Sciences, 5*, 129-166.

Roth, W.-M. (1996b). The co-evolution of situated language and physics knowing. *Journal of Science Education and Technology, 3*, 171-191.

Roth, W.-M. (1996c). Where is the context in contextual word problems?: Mathematical practices and products in Grade 8 students' answers to story problems. *Cognition and Instruction, 14*, 487-527.

Roth, W.-M. (1997). Being-in-the-world and the horizons of learning: Heidegger, Wittgenstein and cognition. *Interchange, 28*, 145-157.

Roth, W.-M. (1998). *Designing communities*. Dordrecht: Kluwer Academic Publishers.

Roth, W.-M., & McGinn, M. K. (1997). Graphing: A cognitive ability or cultural practice? *Science Education, 81*, 91-106.

Roth, W.-M., & McGinn, M. K. (1998). >unDELETE science education: /lives/work/voices. *Journal of Research in Science Teaching, 35.*

Roth, W.-M., & Tobin, K. (1996). Aristotle and natural observation versus Galileo and scientific experiment: An analysis of lectures in physics for elementary teachers in terms of discourse and inscriptions. *Journal of Research in Science Teaching, 33*, 135-157.

Roth, W.-M., & Welzel, M. Learning about levers: Towards a real time model of cognition during laboratory activities. *Cognition and Instruction.* (Submitted)

Roth, W.-M., McRobbie, C., Lucas, K. B., & Boutonné, S. (1997a). The local production of order in traditional science laboratories: A phenomenological analysis. *Learning and Instruction, 7*, 107-136.

Roth, W.-M., McRobbie, C., Lucas, K. B., & Boutonné, S. (1997b). Why do students fail to learn from demonstrations? A social practice perspective on learning in physics. *Journal of Research in Science Teaching, 34*, 509-533.

Saxe, G. B. (1991). *Culture and cognitive development: Studies in mathematical understanding*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Scribner, S. (1986). Thinking in action: Some characteristics of practical thought. In R. J. Sternberg, & R. K. Wagner (Eds.), *Practical intelligence: Nature and origins of competence in the everyday world* (pp. 13-30). Cambridge: Cambridge University Press.

Solomon, S. M., & Hackett, E. J. (1996). Setting boundaries between science and law: Lessons from Daubert v. Merrell Dow Pharmaceuticals, Inc. *Science, Technology, & Human Values, 21,* 131-156.

Suchman, L. A. (1987). *Plans and situated actions: The problem of human-machine communication.* Cambridge: Cambridge University Press.

Wiggins, G. (1989, November). The futility of trying to teach everything of importance. *Educational Leadership, 46,* 44-48, 57-59.

Winograd, T. (Ed.). (1996). *Bringing design to software.* New York, NY: ACM Press.

Winograd, T., & Flores, F. (1987). *Understanding computers and cognition: A new foundation for design.* Norwood, NJ: Ablex.