Volumes of science: The Internet and information in the science classroom

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ABSTRACT: This paper provides a framework for understanding the role of information in the science classroom. Sources, functions, and transformations of information are considered against a backdrop of historical literature on the use of textbooks and other materials in science classrooms. The familiar genres of information in the classroom provide affordances for teaching and learning which are usually not evident because they are so common. The characteristics of familiar genres have developed over the last century because they solve educational problems. Their affordances include: intellectual and physical boundaries for subject matter; validation of authority and relevance; stability of content and presentation over time; pedagogical context; disciplinary context. This paper illustrates how these affordances provide a lens for understanding the role of information in the science classroom and how teachers make use of information to provide opportunities for students to learn.

Turning scientific knowledge into curriculum suitable for students in K-12 schools has never been trivial. Schwab talks about the “curricular potential” of scholarly materials and points to the many difficulties in identifying appropriate materials and converting them into actual curriculum (Schwab 1978c). Yet, with the arrival of the Internet in schools and classrooms across the country, science teachers find themselves using material from the Internet in their teaching. Though some argue that teachers are always doing the work of curriculum making (Ben-Peretz 1990), it is unusual for teachers to have sole responsibility for identifying materials and creating curriculum as they do when they use the Internet (Clandinin and Connelly 1992). Schwab characterizes curriculum development among the “practical arts” and describes the complexity entailed in bringing the concepts and processes of science into the particular circumstances of a particular classroom in any theoretically defensible way (Schwab 1978b).

How can teachers do this with the Internet, and what does it mean for K-12 science teaching and learning? The first question this begs, and a fundamental issue underlying the use of the Internet in any kind of classroom situation, is this: What is the role of information in the classroom?

“Information” is used here in the broadest sense of the word, including communication from others, data, multimedia representations, and more. The Internet, in fact, exposes this question in a way that traditional materials never have, in part because traditional materials have typically been preselected or developed by “experts” and taken as the starting point for teaching and learning. When the Internet is an instructional resource, though, the boundaries of information available in the classroom may be wide open. Teachers have been encouraged to have students “do inquiry” in order to learn science (National Research Council 1996), and the Internet has been identified as a site for inquiry. Teachers are advised to step back and function
as guides, letting students take center stage. They have been told that they do not necessarily need to know the material students encounter, that they can learn alongside their students if only they have the beliefs and dispositions to do so (American Association for the Advancement of Science 1990; Dede 1998).

Is this right? Can we expect students to learn from whatever information flows into classrooms whether or not the teacher knows what it offers? Should teachers be encouraged to use the Internet in open-ended ways to bring in information? If so, how might that information relate to the curriculum, and how does it function in the science classroom? Answers to these questions all depend on a better understanding of the role of information and the media through which it is delivered. Of course, it is impossible to answer or even address all these questions in the short space of this paper. Within this huge domain, thought, three main questions well be addressed:

- What constitutes information in a classroom setting?
- How does information get into the classroom?
- What do teachers and students do with information in the classroom?

**What constitutes information in a classroom setting?**

In Democracy and Education, John Dewey describes the problem of information overload this way:

> The extension in modern times of the area of intercommunication; the invention of appliances for securing acquaintance with remote parts of the heavens and bygone events of history; the cheapening of devices, like printing, for recording and distributing information – genuine and alleged – have created an immense bulk of communicated subject matter. It is much easier to swamp a pupil with this than to work it into his direct experiences. All too frequently it forms another strange world which just overlies the world of personal acquaintance. (Dewey 1916, p. 187)

**How does information get into the classroom?**

One way of viewing a classroom is as a place where information is transformed into knowledge, where teachers and students work together with information to bring about student learning. In this view, the work of the teacher can be described as transforming information into opportunities for students to learn. Information is a key part of classroom activity, an essential element in teaching and learning. In any classroom, information about a variety of subjects or topics may be available, but what is of particular concern here is information about the subject of the class. In a science classroom, this subject matter consists of facts, processes, concepts, and data relevant to the substance of the class – biology, chemistry, physics, earth science, ecology, or other high school science subjects. What is included within the subject matter domain may be specified by the school or district, or by the discipline itself. It may be well or loosely defined, tightly bounded or open-ended.
But how does this information get into the classroom? Information enters in several forms: curriculum materials provided to the teacher by the school or district; other material resources brought into the classroom by the teacher; material resources brought into the classroom by students; the ideas and thoughts of teachers and students as expressed in the classroom; and contributions from other people who come to the classroom. Figure 1 illustrates how information related to the subject matter of the class enters the classroom: through material resources, both on-line and off-line; through students; through teachers; and through other people. The non-material resources of instruction are the people: teacher, students, and others. The material resources of instruction are all the other sources of information, resources teachers and students can use during instruction as sources of subject matter. Resources provided through the Internet or other software applications, and delivered through computers are included as material resources: they arrive in the classroom through a physical device, as words and images on a computer screen, or audio or video delivered through the computer. In some cases, they are printed out or saved and have a continuing presence in the classroom, while in other cases, they remain virtual - they go away with the click of a hyperlink or the computer’s on/off switch. The model illustrated in Figure 1 portrays only the sources of information – where it comes from – not how it is transformed in the classroom or used by teacher and students over time.

![Figure 1: Resources contributing to subject matter in the classroom](image)

The resources that are not obtained through the Internet are here called “off-line” although some of them may be obtained through computers – CD ROM data, for example – or through other media which make them more like Internet resources than print materials (for example, broadcast television.) The distinction is made here between those resources that are obtained on-line through a networked connection to the Internet, and all other resources. From some perspectives, this distinction may seem senseless. For example, the difference between a magazine article copied and brought into the classroom, and an image of the same article found on the Internet may seem unimportant. However, as discussed below, the focus here is on
differences between classrooms with and without the Internet. Part of the question here is to consider whether and in what way that specific difference matters.

Characteristics of information in classrooms have changed slowly in the course of the twentieth century, from the early textbooks to other print and non-print curriculum materials (Cohen 1988; Cuban 1984; Cuban 1986). Although the pace of change in the kind and amount of information available in society at large and in schools has accelerated in the last few decades, it is not clear what those changes have meant for schools (Borgman 1999).¹ Most recently, information in classrooms has come to include on-line resources, accessed through connection to the Internet.

Next, two images of classrooms are described, one the “traditional” classroom before arrival of the Internet, the other the “connected” classroom with Internet access. These terms are used to refer to the nature of the resources available in the classroom, not to the nature of the teaching that goes on. The two are drawn as prototypes for purposes of contrast, without the assumption that either exists purely in reality, or constitutes a typical classroom in the year 2001. High school science classrooms will be used as the site for this comparison.

The “Traditional” Classroom

Philip Jackson, in his 1968 book Life in Classrooms, describes one aspect of the classroom as follows:

…Teachers attach great meaning to the boundaries which separate their classrooms from the rest of the school and, of course, the community. Teachers deprecate transactions which cut across those boundaries. Walls are perceived as beneficial; they protect and enhance the course of instruction…. A key belief shown in these responses is that attention and response flourish when the classroom is a bounded, protected space. Teachers clearly prefer boundedness. (Jackson 1968, pp. 169-171)

What is inside of these boundaries? The traditional high school science classroom is a place in which information abounds. There are textbooks and other curriculum materials provided by the school or district. There may be charts, maps, and diagrams on the walls, or stored for use at appropriate times. Lab equipment and materials are common, along with instrumentation, reference books, enrichment books, and all manner of teacher-provided materials. Specimens of natural phenomena, projects from past student work, videos and filmstrips may also be in evidence.²

Materials in the traditional classroom include mostly secondary sources, science condensed and interpreted to make it more understandable and usable for students and teachers. Most of the information in the classroom has been reviewed and selected, and it fits into the design of the class. Much of it has been specifically designed for teaching and learning. With varying levels of success, textbook publishers pay close attention to how books and supplementary materials are designed.

The modes of transmission in a traditional classroom are familiar: reading books, listening, watching video, conducting experiments, and talking. The physical objects in which information arrives in the classroom are well known and manageable. Textbooks fit on student desks along with their notebooks and writing materials. They can be transported in and out of the
classroom, to and from home. Video equipment is on mobile carts, or permanently installed in the classroom, and videotapes are now a well-known entity. Lab equipment and electronic instrumentation are usually of manageable proportions and fit into the physical space of the classroom. Other books are of known genres. Encyclopedias, supplemental textbooks, and periodicals each have familiar designs for tables of contents, indices, chapter or article headings, and even charts and tables.

What are the characteristics of information in this traditional classroom? Five characteristics stand out: boundedness, stability, provenance, connectedness, and use. These are shown in Table 1.

First, the information is bounded. Even a classroom packed with information resources, as many high school science classrooms are, contains only what the teacher has brought into the space, or let her students bring in. The boundaries consist of not only the physical space, but also the collective knowledge and interests of the teacher and her students. The information in the traditional classroom is there because someone decided to include it. The teacher may not know everything the information represents, but the boundedness of the information makes it manageable. That is, in the traditional classroom, the information can be within the bounds of what the teacher knows, or knows how to learn. The traditional classroom thus provides both physical and intellectual boundaries, around a space and a subject matter.

Second, the information is stable: it changes little over time, and changes slowly. New textbooks are adopted, but they rarely depart radically from the old. New materials are added to the classroom, but they are added because they are relevant to the work being done. Unless the content of the courses changes, there are no surprises in the constitution of information, and little reason to change it drastically. As detailed by Larry Cuban in his history of teaching, change in the traditional classroom is incremental, a slow transition over time to newly accepted ideas and practices in the disciplines (Cuban 1984).

Third, the information is from known sources – its provenance is established. Textbooks are selected at the school or district level; librarians pick resources for the library. The teacher selects most other information in a traditional classroom. There is little likelihood of random or anonymous information finding a place in the traditional classroom. Part of the selection process acknowledges the fact that much of the information in classrooms resides in materials designed for classroom use. Textbooks and curriculum materials, however ill or well conceived, are meant for teaching and learning. Materials not designed for school use are selected because they seem suitable, to the teacher or librarian or student, for the purposes of the class.
Boundaries | Bounded by the classroom walls, the physical objects in the room, and the knowledge of teacher and students.
---|---
Stability | Stable, changing slowly and incrementally over time.
Provenance | From known sources, selected for classroom use
Connectedness | Related to the purposes of the class
Design Constraints | Age and genre determined by publishing constraints and customs

**Table 1: Characteristics of Information in the Traditional Classroom**

Fourth, the information has a known relationship to the purposes of the class. Although some information in a high school science classroom may be unrelated to the purposes of the class – things like information about the school itself, or about a different class which shares the classroom, or about after-school or community activities – most information is there for a reason related to the work of the class. A high school chemistry class does not suddenly find itself reading books about ancient Greece on the way to studying the periodic table.

Finally, information is constrained with respect to its age and variety by the demands of media: textbooks contain print material updated well before it reaches the classroom; other resources represent information as images or video, but usually a single representation along with text in any given medium, and usually with publication timelines of over a year. Thus, the traditional classroom usually does not include the most current scientific information as part of its information resources, and the variety of representations of information is limited for a given topic.

Even with these uniform characteristics, very different kinds of teaching and learning can occur. A teacher can use these information resources as tools for student inquiry or as sources of content for transmission to students. He can lecture or discuss, conduct open-ended or formulaic labs. The nature of the information and information technologies does not completely determine the nature of the teaching, although it can establish possibilities and limits. Even though science teaching has typically been textbook-bound and teacher-centered, some teachers working in similar information contexts – in traditional classrooms as described here – have created more student-centered, less didactic classrooms (Boyer 1983; Cuban 1984; Powell et al. 1985; Stake and Easley 1978; Weiss 1978).

**The “Connected” Classroom**

The connected high school science classroom is a place whose boundaries are open to a virtual universe. With the Internet, the potential information available in the classroom at any time seems nearly infinite. The classroom is extended to include millions of Web pages, access to people and data all over the world, and a depth and breadth of information quite impossible to find in classrooms without the Internet. Although not all of this information is “in” the classroom at once, its availability through the computer makes it similar to a book on a shelf, there for the taking within the classroom walls. Adding complexity to the picture, the connected classroom includes and incorporates information from the traditional classroom – the textbooks, curriculum
materials, and other information resources described above do not necessarily go away when the classroom is connected to the Internet.

Physically, the connected classroom is a complex place. It includes the well-known objects of the traditional classroom – textbooks, lab equipment, desks and chairs, for example – but it is also equipped with computers and hardware for connecting to the Internet. Whether a single computer, a classroom set of thirty or more, or some number in between, the physical requirements for having computers in classrooms are different than with other objects. The number of computers, their size and placement, and the physical and technical requirements for Internet connection are far from standardized. The genre of classroom computers is new and its development depends more on technological feasibility and cost than on needs of classrooms. Scholars have noted the physical misfit between computers and classrooms. For example, Collins wrote in 1996:

Space is precious in most classrooms. Good teachers line the walls with student work and make lots of materials available to students in their classrooms. They will not turn over their classrooms to a lot of bulky machines - and proposed solutions, such as building computers into desks, are not likely to have widespread application. Nor will it be easy to manage a class in which the teacher must cope with a shortage of machines by arranging for simultaneous activities with some students working on computers and some not. Nor will many teachers be willing to take their students down to a computer lab, leaving all their classroom resources behind and having to compete for time with other teachers. ...The unfortunate fact of life is that the design of the school and the design of the computer are not currently compatible with the widespread use of computers in schools (Collins 1996, p. 60).

Although computers are becoming smaller, more manageable, and even wireless, the physical problems posed for schools by computer hardware will not be resolved easily or quickly.

Several characteristics of information available through the Internet, taken together, make it unique: It provides current & up-to-date information, from weather forecasts to broadcasts from space. The information is both broad and deep, with content about subjects from astronomy to zoology and, within each subject, the possibility of finding detailed data about a given topic. It includes information from primary sources such as raw data from NASA, transcripts from speeches and conferences, images of original documents from the work of scientists. It provides multiple linked representations of information – animations of cells along with written explanations and images from microscopes, for example. It allows for collaboration with other people as sources of information and explanation, from student peers to science experts. Students themselves can provide information to others themselves through publication of Web pages. All of this is available as a local resource within the walls of the classroom, without the need to go to the library or seek expertise in the community (Wallace et al. 1996).

These beneficial characteristics have their problematic side, however. Along with the breadth and depth of information available, for example, comes the chaos of finding the right information in a timely manner. The benefit of the current content is mirrored by the drawback of not being able to know the source; to be sure the information is reliable. Availability within the classroom comes with the frustration of technical problems because of the enduring fragility of equipment and infrastructure.
How do the characteristics of information in the connected classroom contrast to the traditional classroom? In each of the five dimension suggested by analysis of the traditional classroom, differences are apparent, as shown in Table 2. The connected classroom is virtually unbounded; overall, the content is unstable and changes rapidly; it often comes from unknown sources and is unverifiable; it may be extraneous to the purposes of the class; and it may be up-to-the minute and provide multiple representations, but in unfamiliar forms. Although there are Web sites which are exceptions – which are stable and unchanging; from known, reliable sources; and which provide familiar representations – on the whole, the Internet does not provide those features.

Clearly, not all of these features are operational in any particular classroom: what the teacher and students do with and on the Internet can change the nature of the information that actually enters the classroom, just as the teacher’s use of textbooks and other resources modifies the characteristics of the traditional classroom. However, in the extreme, the connected classroom can be seen as open and unbounded, with the benefits and problems that implies. With this openness comes the fact that the information is at least partly unknown to the teacher, and certainly unknowable in its totality. Information brought in via the Internet may be of unknown authorship, and may not have been screened or vetted in any way. It may be authoritative and correct; it may be amateurish and incorrect; or it may be fraudulent and deceptive. Unlike textbooks and curriculum materials, it has not usually been designed for classroom learning and teaching.

As in the traditional classroom, the connected classroom does not require a particular kind of teaching: although there is little empirical evidence to date about teaching in the connected classroom, it is likely that teachers can use the Internet in ways that vary enormously, from teacher-centered to student-centered, as a resource for student inquiry or a source of facts and figures to be memorized. The characteristics differ, and thus one expects the possibilities and affordances may not be the same in the connected and traditional classrooms; however, the differences are only realized in use, as the resources are taken up and transformed by students and teachers.

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<tr>
<th></th>
<th>The “Traditional” Classroom</th>
<th>The “Connected” Classroom</th>
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<tbody>
<tr>
<td><strong>Boundaries</strong></td>
<td>Physically bounded</td>
<td>Virtually unbounded</td>
</tr>
<tr>
<td><strong>Stability</strong></td>
<td>Stable, changing slowly and incrementally</td>
<td>May be unpredictable and rapidly changing</td>
</tr>
<tr>
<td><strong>Provenance</strong></td>
<td>Known and selected</td>
<td>Sometimes of unknown origin, unverifiable validity</td>
</tr>
<tr>
<td><strong>Connectedness</strong></td>
<td>Connected</td>
<td>Possibly not connected to purposes of the class</td>
</tr>
<tr>
<td><strong>Design</strong></td>
<td>Limited media, dated</td>
<td>Can be up-to-date, multiple representations</td>
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<td><strong>Constraints</strong></td>
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Table 2: Characteristics of Information in Classrooms: Summary
What do teachers and students do with information in the classroom?

What happens to information in the classroom? How is it used by teachers and students? Evidence from research suggests that in most science classrooms, a fixed body of information is transmitted to students from the teacher and the textbook by way of lectures, homework assignments, lab activities, and sometimes group discussions. Other information sources and other activities, which depart from what David Cohen calls "whole-class, lock-step, batch processed" teaching and learning, are infrequent and often peripheral to the purposes of the class (Cohen 1988). In connected classrooms, where the Internet is used, it is most often used for students to "do research," a catchall phrase that could mean anything from serious scientific inquiry to random search.

Curriculum developers, software developers, and others who have looked at common curriculum across classrooms have found that the same lesson can look remarkably different in its enactment across multiple classrooms (Blumenfeld et al. 1994; Cognition and Technology Group at Vanderbilt 1994; Doyle 1983; Newman et al. 1989). Even within a single school, what happens in two science classrooms addressing the same student population may be vastly different with respect to tasks assigned, topics covered, and assessments (Duschl and Wright 1989; Sandoval et al. 1999). Research has found that teachers cover less than the whole book; they change the order of topics; and they supplement textbooks with other materials and activities. In his work on content determinants, Porter suggests that teachers make decisions about textbook use in five areas: "how much time to allocate to a subject, what topics to cover, with which student, when and in what order, and to what standards of achievement," (Porter et al. 1986, quoted in Stodolsky, 1989, p. 163).

Although there is variation in how they are used, the textbook and associated curriculum materials dominate classroom teaching and learning, and have done so for many decades. Stake and Easley in their 1977 case studies describe textbook use this way:

The source of knowledge authority was not so much the teacher – it was the textbook. Teachers were prepared to intercede, to explain, but the direct confrontation with knowledge for most students was with printed information statements. Teachers did it differently from classroom to classroom, but regularly there was deference to the textbook, or lab manual, or encyclopedia, map or chart. Knowing was not so much a matter of experiencing, even vicariously (self-knowledge perhaps was not to be trusted), but of being familiar with certain information or knowing how to produce the answers to questions that would be asked…. The preponderance of teaching was to import conclusions from a distant authority through the orderly presentation of the lesson materials. (Stake and Easley 1978, p. 13:59)

The primary mode of teaching in science classrooms is lecture, with some use of labs. Weiss reported in a 1987 study that over 80% of science classroom teachers said they using lectures in their most recent lesson (Weiss 1987). Tye reported in a 1985 study that in science classrooms, the most frequent activities students engaged in were, in decreasing order of frequency, "listen to teacher; watch teacher; do experiments; take tests; write answers; class discussions." (Tye 1985, pp 249). In the same study, Tye reports that these science classrooms, the teacher talked an average of 55% of the time. Teachers were dissatisfied with the amount of control and choice
they had over the materials they were expected to use, and reported that the materials exerted a big influence on what they taught (Tye 1985).

Tye concludes her chapter on classroom activities and materials as follows: “The cumulative impact of these classroom data is remarkable. Students, teacher, and observers agreed that classroom activities in all subjects are primarily passive and traditional; that teachers talk and students listen and write; and that learning materials used in most subjects are discouragingly limited in variety,” (p. 248).

Goodlad, in his 1984 book *A Place Called School*, reported on the same study from which Tye's data were drawn. He described science teacher's use of curriculum kits, provided to supplement textbooks this way:

[The kits provided] not only the objectives, unit plans, and activities but also the tests for evaluating the attainment of objectives. Teachers… using such kits claimed that these enabled them to individualize instruction, but the materials sampled in our study suggest that the only differentiation for students was some variation in time allowed for completion. Every student was expected to complete the same readings, worksheets, experiments, and texts – and to come to essentially the same conclusions. (Goodlad 1984, p. 215)

There is evidence that labs are typically taught "by the book" as step-by-step procedures. Lunetta describes the use of labs in science classes as follows:

Over the years, science educators have sought theoretical organizers to inform curriculum development and instruction. Although the organizers and visions have changed with time, the predominant pattern of science instruction visible in schools has been based on a framework of *telling* the story of science. Within that framework, laboratory activities engaged students principally in following ritualistic procedures to verify the story that had been told. Students have had limited freedom to explore and discover. (Lunetta 1998, p. 251)

“A Study of High Schools” was a large-scale research project completed in the 1980s under the auspices of the National Association of Secondary School Principals and the National Association of Independent Schools. In *Horace’s Compromise*, one of three books reporting on the study, Sizer (1984) characterizes teachers’ approaches to the curriculum as a matter of dividing the content to be covered into smaller and smaller pieces until it is broken down into daily units. They do this using the textbook provided, and sometimes with guidance from curriculum frameworks, ending up with small bits of content that can seem unrelated to the larger purposes of the course (p.92).

In *Shopping Mall High School*, another book from the same study, Powell, Farrar, and Cohen emphasize the negotiations and compromises between teachers and students about what is expected (Powell et al. 1985). How materials get used is often at issue, with students pressing for less complex, more predictable assignments even as teachers may be aiming for complexity and deeper understanding.

Another research program that has looked extensively at teacher’s use of materials is the Third International Math and Science Study, TIMSS. Schmidt and colleagues report that American teachers depend heavily on textbooks, but that textbooks have become so fragmented
and diverse that teachers must make choices and decisions about what to teach (Schmidt 1996; Schmidt et al. 1997):

Textbooks make content available, organize it, supply it with suggested activities, provide supporting materials, and set out supporting tasks for students in one handy location and in a form designed to be appealing to students. They do this with sufficient detail to support day-to-day classroom instruction. Teachers often plan lessons beginning with a segment of the selected textbook on which they reflect and build classroom activity plans cross-referenced to those textbooks. In these very common cases, textbooks are, by default and overwhelming demand, the backbone of 'micro' organization for classroom activities. They provide the fine details of curriculum expressed more broadly and less directly supported in official curriculum documents. Textbooks define the domain of implementable day-to-day curricular possibilities. Without restricting what teacher may choose to do, they drastically affect what U.S. teachers are likely to do under the pressure of daily instruction. (p. 53)

In a review of research on textbook use, Venezky describes some of the ways teachers use textbooks as pedagogical supports:

Textbooks provide a limited content expertise for a topic plus a logical sequencing and a variety of pedagogical supports: activities, questions, test items, and sometimes summaries of expected student difficulties and misconceptions. They help make the curriculum content-oriented and comprehensive while allowing more effective use of teacher time than might occur on the average without them. (Venezky 1992, p. 442)

Other studies of use of textbooks and curriculum materials reach similar conclusions (Sosniak and Perlman 1990; Sosniak and Stodolsky 1993; Stodolsky 1988). Cuban (1993) reviewed studies completed in the seventies and eighties, which generally confirm that teachers depended on textbooks for their teaching, using them to transmit facts and processes which students were expected to learn. According to Cuban, this dependence on textbooks and the conventional method of teaching noted above has changed little over the last few decades. The picture is clear: most teachers in most high school science classrooms use textbooks as their primary information resource, and students are expected to learn the information provided in the textbook. Most of the teaching is based on the premise that students need to know the facts and processes specified by the textbook. Some teachers are able to supplement the textbook with other materials they have acquired or developed; and most teachers adapt use of the textbook to their circumstances, perhaps skipping sections or changing the order.

Information from digital technologies

Where do computers and other information technologies fit into this picture? We know from survey research that 65% of science teachers use computers regularly in their teaching, with 12% of high school science teachers reporting using computers more than twenty times per year (Becker et al. 1999). How do they use these technologies and what do they do with the information provided? Unfortunately, research is not particularly helpful here. The survey work done by Becker indicates that the most common uses of computers in classrooms are first, for word processing; and second, for research on the Internet. In this work, Becker developed a
constructivist teaching scale to evaluate teachers' beliefs and practices with respect to constructivism. This scale correlates highly with computer use in high school academic subjects – that is, more constructivist teachers are more likely to use computers in their teaching (Becker and Anderson 1999). However, these data are not specific to science and do not tell us much about what goes on inside the classroom.

Technology development projects have created software and materials for use in classrooms and then studied their implementation. For example, in developing and deploying their Jasper program, the Cognition and Technology Group at Vanderbilt found that teachers used software, videotdisks, and accompanying print materials in unexpected ways, not anticipated by their design (Cognition and Technology Group at Vanderbilt 1994). As they scaled up use of Jasper into classrooms where they were not present, they included more structure in both the student and teacher materials (Cognition and Technology Group at Vanderbilt CTGV 1997). The quantity and quality of information provided through the materials changed and increased as they responded to teacher needs and adaptations.

In the Middle Years Digital Library research, Hoffman found that teachers’ differing use of curriculum materials resulted in substantially different outcomes for students (Hoffman 1999). The two teachers in Hoffman’s study had different styles of enactment, one pushing students to ask questions and figure out answers, and the other giving students basic information and directing them toward answers. The teacher effect was large, and the technology itself did not determine a style or purpose of use.

In the Collaborative Visualization project (CoVis), researchers initially intended to provide Internet-based tools that could be used in authentic scientific investigations of data. Over the years of the project, classroom implementation studies indicated the need to expand materials to included curriculum materials (e.g., suggestions for unit and lesson plans), teacher development materials, and eventually, CD-Rom data sets with which CoVis could be used entirely off line. This transition from an Internet information use project to a highly developed curriculum project was driven by the needs of classroom teachers (Edelson et al. 1999).

These and other technology projects that have provided materials and tools to classrooms have found enormous variety in what teachers and students do with a given technology (Dwyer 1994; Fisher et al. 1996; Mandinach and Cline 1994; Ruopp et al. 1993). In most cases, the intervening variables of teacher beliefs and existing practices greatly influence the ways in which teachers use these technologies and the information they provide.

In the end, research on teachers as users of classroom materials offers a paradoxical picture of similarity and variation. On the one hand, teachers use and rely on textbooks as a fundamental ingredient in their teaching, a fact that seems to have changed little over the last few decades. On the other hand, how teachers use textbooks may vary widely from teacher to teacher and across subjects. Teachers make numerous decisions about their use of textbooks, selecting topics and activities, modifying and supplementing what is provided. Still, they rely on textbooks for many supports they provide, including content, organization, and ease of use.

At the same time, although textbook use has been the norm for many years, there is very little evidence about what teachers do when they are not using textbooks. As recently as 1986, science teachers, especially in high school, regularly used laboratory work, the library, and some multimedia materials (primarily filmstrips at that time) but there is little evidence about how they
chose these resources, or what they did with them in interaction with students (Weiss 1987). Recent data suggests that computers are widely and frequently used, but we have little knowledge of how they are used. Even with strong evidence that most teachers use textbooks most of the time, and that they use them primarily as a source of information to be transmitted to students, there is much room to investigate what goes on in the margins, and a great need to do so if we are to understand the possibilities for new information resources.

**Discussion and Conclusions**

There are three questions that need to be addressed to make sense of the data presented above. First, what is the teacher's role in turning information into opportunities for students to learn? Second, what are the affordances materials offer to the teacher in accomplishing this task? And finally, how does the Internet fit into this picture?

First, the teacher's role in turning information into opportunities for students to learn. Some researchers argue that the job of teaching is creating curriculum, the two are inseparable ingredients in the enactment of instruction (Ben-Peretz 1990; Clandinin and Connelly 1992; Hawthorne 1992). Schwab describes curriculum as follows:

> Curriculum is brought to bear, not on ideal or abstract representations, but on the real thing, on the concrete case, in all its completeness and with all its differences from other concrete cases, on a body of fact concerning which the theoretic abstraction is silent. The materials of a concrete curriculum will not consist merely of portions of 'science,' of 'literature,' of 'process.' On the contrary, their constituents will be particular assertions about selected matters couched in a particular vocabulary, syntax and rhetoric. They will be particular novels, short stories, or lyric poems, each, for better or for worse, with its own flavor. They will be particular acts upon particular matters in a given sequence. They will be perceptions conditioned by particular past conditionings of particular things and events. The curriculum constructed of these particulars will be brought to bear, not in some archetypical classroom, but in a particular locus in time and space with smells, shadows, seats, and conditions outside its walls which may have much to do with what is achieved inside. Above all, the supposed beneficiary is not the generic child, not even a class or kind of child out of the psychological or sociological literature pertaining to the child. The beneficiary will consist of very local kinds of children and, within the local kinds, individual children. (Schwab 1978a, pp. 309-310)

In a later essay he introduces the concept of the “curriculum potential” of “scholarly materials”:

> The methods by which scholarly materials are translated into defensible curriculum are not mere transformations of one kind or style of material into another. They are methods for assessing privations, perversities, errors, and misdevelopments in those who are to be recipients of the putative benefits of curriculum; then, methods for discovering in scholarly materials curricular potentials which serve the purposes which have been envisaged in the light of detected student needs; then, assessment of the probable advantages of one
potential against others as a means toward educational benefits. (Schwab 1978b, p. 380)

Building on theoretical work of Schwab (Schwab 1978b; Schwab 1978c), Ben-Peretz refers to teaching as curriculum-making. She defines curriculum as constituted not by materials and guidelines provided to the teacher, but by the actual experience of students and teacher together in the classroom as they use resources and engage in the activities of teaching and learning. She further argues that curriculum materials provide possibilities or potential for what happens in classrooms, but they cannot determine what the classroom experience will be. Whatever the intentions of curriculum developers, they cannot fully anticipate how materials will be used because use is dependent on the particulars of the situation: the knowledge, beliefs, and ideas of students and teacher as well as the unique setting of a given day, time, and place (Ben-Peretz 1990). Ben-Peretz writes,

[C]urriculum materials are richer in educational potential than any predetermined set of intended learning themes and activities stated by the developers. The issue becomes one of the interpretative skills needed for a ‘reading’ of curriculum materials which goes beyond their obvious and explicit meaning. (p. 8)

In a study of teachers’ understanding and expectations of curriculum materials, Ben-Peretz found that teachers are most concerned with how the materials present subject matter, and especially, how they reflect “the principles and concepts of the discipline.” She goes on to suggest that the knowledge which enables a teacher to ‘read’ the potential of curriculum materials and develop that potential into classroom experience is what distinguishes expert from novice teachers (p. 84).

Clandinin and Connelly, in a review of literature on teachers’ role as curriculum maker, assert, “that the teacher is an integral part of the curriculum constructed and enacted in classroom,” (Clandinin and Connelly 1992). They see teachers’ stories as a primary source for understanding the teacher as curriculum maker, and they retell stories from Robert Coles and Vivian Paley as examples of curriculum making and as sites for learning about curriculum. The other body of literature which considers the teacher’s role in creating curriculum, they write, is literature of school reform, “in which the teacher generally figures in the discrepancy between intended and achieved ends; curriculum is seen as an instrument of reform, and teachers are regarded as mediators between the curriculum and intended outcomes,” (p. 392).

What are the affordances of materials in classrooms? What can they provide to teachers to make more manageable this job of turning materials into curriculum. In previous research, I proposed the following affordances as critical to the work of teachers, and present in greater or lesser degrees in prescribed curriculum materials and in computer-based resources (Wallace 2000). Each affordance functions not as a feature of the material, but rather as a possibility, something the material may offer to the teacher if the teacher chooses to use it (Gibson 1977). These affordances are not absolutes, either available or not. Instead they can be thought of as a spectrum of possibilities.
Boundaries (intellectual, physical)

Authority (source, relevance)

Stability (origin, frequency of change)

Contextual support (history of work, common artifacts of work)

Disciplinary support (topics, coherence, connections)

Table 4: Affordances of Materials

1. **Boundaries.** Classroom materials can give teachers boundaries around the subject matter they are expected to teach. They can bound the subject not only intellectually, providing a collection of disciplinary content on which the teacher may focus, but also physically, providing a location for studying that content.

2. **Authority.** Classroom materials can be a source of authority for subject matter. Teachers can rely on materials for a canonical account of the discipline, and for including relevant content.

3. **Stability.** They can provide teachers with a stable way to develop a base of experience on which to build. Some kinds of materials – e.g., textbooks – change very slowly, if at all, from year to year. Using the same materials over and over, teachers can develop a repertoire of expectations and understandings about how students will respond and what ideas need more or less time and attention.

4. **Contextual Support.** Classroom materials can provide sites for student work and common artifacts for use in the classroom. The materials can be sites for communication and collaboration, and they can give a context for teaching and learning. With some materials, teachers can see at a glance where students are in the materials and, in some cases, what they are doing.

5. **Disciplinary Support.** Classroom materials can give a sequence of topics and sometimes specific activities that the teacher can follow and use to give coherence to subject matter and to assess student progress. They can support a teacher's ability to know what students have done both as a group and individually, and what they need to do next.

The Internet as a classroom resource is low on each of the five affordances. Teachers have a lot of work to do to make the Internet into the kind of resource they know how to use. One default use observed research by this author is to use the Internet for students to "do research." (Wallace et al. 2000). It is a default in the sense that it takes little preparation or know-how to let students use the Internet for research. Although it may not be an effective way to teach science, it satisfies several goals science teachers may have. In particular, it allows them to have students using the Internet. This is similar in many respects to the ways that teachers have used the library over the century during which we have had school libraries. Both function as a black box for student research: the student has a topic, goes off to do the research, and comes
back with a report or product. Teachers often do not focus on what happens inside the library, or between the student and the Internet (Kuhlthau 1993).

Another possibility is for teachers to design Internet uses that mimic their use of textbooks. In some cases, teachers create worksheets, specify Web sites, and use the Internet as the source for information. The teacher thus establishes boundaries and authority, and creates both a pedagogical and disciplinary context for student work. If it differs from doing the same thing with printed text or a CD ROM, it differs because of the content that can be reached through the Internet. This can be an important difference, but points toward a very controlled, bounded, activity familiar to the teacher.

Can teachers effectively leave more of these affordances open, allowing for exploration and inquiry? This is an unanswered question, but one that many research projects are working on. CoVis and its later offspring at the Center for Innovative Learning Technologies, Kids as Global Scientists, the Middle Years Digital Library project, and others are still working toward developing tools and resources that provide support for teachers yet still leave room for student exploration and inquiry. However, none of these projects is based on a model of flooding science classrooms with information and leaving it to the teacher to find ways to make sense of it.

This analysis of information resources in the classroom points toward the conclusion that information resources, to be useful and usable in science classrooms, must take into account the affordances teachers rely on to be able to teach. The volumes of information that are available in classrooms, on the Internet and in the massive textbooks now used to teach science, cannot possibly be managed by classroom teachers in ways that promote inquiry and deep consideration of complex ideas.

ENDNOTES

1 For some divergent views, see, for example, (Healy 1998; Oppenheimer; Owston 1997; Papert 1993).

2 For descriptions of classroom information resources before the Internet, see (Boyer 1983; Cronbach 1955; Cuban 1984; 1986; Elliott and Woodward 1990; Stake and Easley 1978)

3 An exception is television, which might broadcast current information in multiple representations. However, broadcast television is still rare in classrooms and is not included as a usual resource in either the traditional or the connected classroom.

4 There has been much speculation about the impact of the Internet on classrooms, including the characteristics of the information made available through the Web. (See, for example, Harasim et al. 1995; Honey et al. 1998; Marchionini and Maurer 1995; Owston 1997; Pea et al. 1995; Wallace et al. 1996; Williams et al. 1998; Windschitl 1998)
BIBLIOGRAPHICAL NOTE

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