Science Matters, Culture Matters

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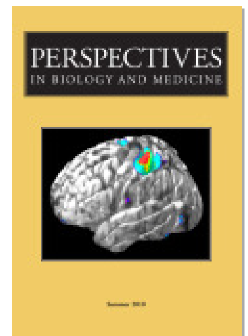

Science Matters, Culture Matters

Anne Fausto-Sterling

My father and mother believed in science as a source of rational truth. Science was trustworthy and exportable to the many corners of human activity. Medicine, engineering, weather prediction, and even social planning could be approached scientifically. All one needed to do was isolate a problem, analyze it carefully, and design appropriate solutions. Politics were a separate matter. One could (and certainly did) argue about whether it was moral or immoral to drop the atomic bomb, or whether Lysenko had any right to stick his nose into the development of Soviet genetics. But although both science and politics were important for producing human progress, scientific knowledge and social belief were different beasts.

Understandings of how the world works change with time, and my current world is not my father's world of science. In the course of almost 40 years of practicing biology and thinking about how it works, I have come to believe in my deepest core that scientific knowledge is a particular form of social knowledge—that the scientific and the cultural are inseparable. Recently I have gained insight into my journey from my parents' science to my vision (shared, as the reader will see, with many other students of scientific knowledge) by thinking about a painful conflict I had with my department over an embryology course. One lesson from this journey is that how you teach science depends on what you think about the nature of scientific knowledge. I argue that we still teach science as if the world worked as it did in the first half of the 20th century, and that teaching this way is not a good thing.

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Comparing Embryos

About 30 years ago, a colleague and I designed a course entitled "Comparative Vertebrate Embryology." It was a meat-and-potatoes course aimed at first- and second-year biology majors. In it we introduced the concept of morphogenesis (how groups of embryonic cells take on the three-dimensional shapes we come to recognize as fetuses, babies, and adults). Because the course compared embryonic development in different back-boned organisms, we discussed enough vertebrate evolution to make sense of the different developmental patterns we studied.

We integrated lecture material with the laboratory study of embryonic anatomy; students used the microscope to study serial sections that ran from the head to the rear of frog, chick, and pig embryos that had been prepared at different times after fertilization. In order to "get it," to picture what goes on during embryonic development, students had, in their mind's eye, to reconstruct a whole embryo from the microscopic slices. (This is rather like envisioning a whole loaf of bread—including the precise location of the air bubbles, raisins, and sunflower seeds—from a careful study of each slice in the loaf.) But to make matters even more difficult, they had to envision the embryo and all of its developing organ systems, not once, but at several discrete stages of development. To keep the bread metaphor going, they would need to reassemble not only the slices from the finished loaf, but also from the dough when it was first placed in the pan, and thereafter at various points in the baking process. We asked our students to understand developmental processes and to commit to memory the names and relationships of structures, so that during exams they could identify the structures on their slides and write descriptively about the processes by which they formed.

Over the years the course maintained a high enrollment and was well reviewed. Because of its success, Comparative Vertebrate Embryology also established for itself a permanent place in our departmental curriculum. For about the first 15 years, I taught the course more-or-less every other year, often jointly with the same colleague with whom I had initially designed the class. Eventually, though, I found myself more compelled by the work I was doing on gender and the nature of scientific knowledge (Fausto-Sterling 1987, 1989, 1992a, 1992b, 1993a, 1993b, 1995, 2000), and I stopped teaching Comparative Vertebrate Embryology altogether.

About 10 years ago, however, my colleagues asked that I rotate back into the course. Their request seemed perfectly reasonable; as a good departmental citizen one should do one's bit, even if it involves teaching a course that is no longer one's perfectly prepared cup of tea. But as it turned out, moving back into the course initiated an interval of painful conflict between me and some of my long-time colleagues. Eventually, the troubles were resolved, and what has emerged is a new model for teaching science, a model I call "science in social context." In the pages that follow I discuss new theories of scientific knowledge which enabled me to understand how my own visions of science have slowly changed. Understanding my own theoretical shifts made it possible for me to better understand my differences with colleagues and, eventually, to work my way out of a bitter impasse. The new course, "Comparative Vertebrate Embryology in Social Context," embodies, I believe, a theory and practice applicable to any arena of science teaching.

THE CONFLICT

When I reentered the course after years of learning to think in new ways about science, I found it difficult to communicate my new perspectives to either my colleagues or students. For the first time in my life I got terrible student evaluations. Students accused me of not preparing my classes, of not caring—things which, for a teacher who does indeed care about both the subject matter and the students, were extremely painful to hear. And I fought with my colleagues. I can't say how it looked to them, but from my perspective they seemed mysteriously resistant to my new viewpoints, and—rightly or not—I felt constantly undermined in the classroom. Of course both the students and my teaching colleagues were on to something: I felt unable to continue teaching this course without changing it dramatically, because I no longer saw science the same way. Continuing to teach in the old format violated something that had in the intervening years become a core part of myself.

In the good old days (when I was young and just beginning), embryology seemed straightforward. A lecture on the development of the central nervous system, for example, included a description of the morphogenetic events leading to its formation and a discussion of embryonic induction. Today—if I were teaching in the standard model—I would certainly include a discussion of key genes expressed in the embryonic nervous system (Figure 1A). But when I returned to the neural tube after my sojourn in feminist theories and science studies, a vastly expanded image sprung to mind (Figure 1B). The neural tube appeared to me embedded in a matrix of epidemiological, medical, historical, and social questions. I could no longer talk about neural tube development without also mentioning neural tube defects that included fairly common problems, such as spina bifida, and somewhat rarer defects, such as anencephaly. Once these were on the docket, I could not avoid examining the epidemiology of birth defects. And this, in turn, raised questions about who gets what kind of health care in the United States, the ethics of selective abortion, etc., etc. The problem did not begin or end with the lecture on the neural tube. The embedded nature of every topic in the course leapt out at me.

I found it impossible to continue to teach Comparative Vertebrate Embryology without discussing embryos as embedded in a larger knowledge network, and I tried to articulate my dissatisfaction with the old course to my colleagues.

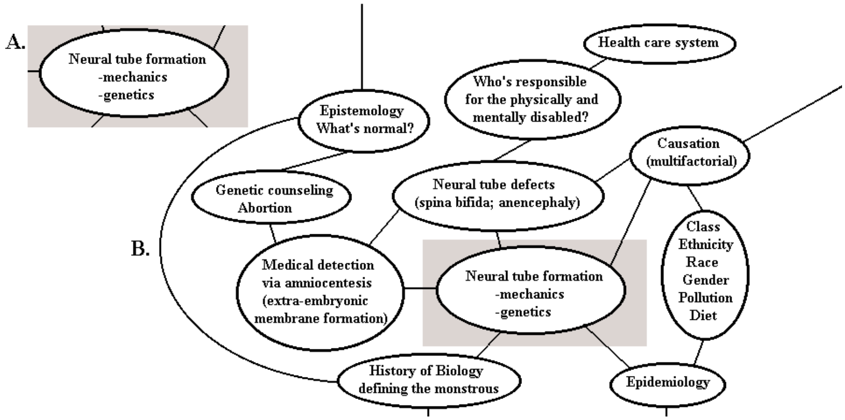

Figure 1

A. *Teaching about neural tube formation the "old" way.*
B. *A new vision of neural tube formation.*

But everyone—even those who knew that I subscribe to and read a good half-dozen biology journals, who know that I love developmental biology—had a uniform response when I expressed my discomfort. They said, "It's fine if you teach about the social impact of embryology, as long as you still teach the anatomy." The first time I heard this, I tried to reassure them: "Of course I'll teach the anatomy—what else would I do?" The second time, I tried again to reassure them. But by the fifth time yet another person said that exact same phrase to me, I got mad. How could these long-time colleagues of mine imagine that in a course on developmental anatomy I *wouldn't* teach the anatomy? Why was it that my attempts to articulate my need to transform this course always evoked the same suspicious response?

The Theory

In struggling with this conflict, I found that some of the recent writings of Bruno Latour and Emily Martin helped me to make sense of what had happened. In the first few pages of *We Have Never Been Modern*, Bruno Latour (1993) sketches out the conceptual problem. He starts out by referring to the daily papers. Everywhere one looks in the papers one sees hybrids mixing ingredients of science, power, and knowledge; economics, sex, and war; complex stories about our daily lives:

> I learned that the Paris AIDS virus contaminated culture xxx in Professor Gallo's laboratory; that Mr. Chirac and Mr. Reagan, however, solemnly swore not to go back over the history of that discovery; that the chemical industry is not moving fast enough to market medications, which patient organizations are vocally demanding; that the epidemic is spreading in sub-Saharan Africa. Heads of state,

> chemists, biologists, desperate patients, and industrialists find themselves caught up in a single uncertain story mixing biology and society. (Latour 1993, pp. 1–2)

In fact, Latour claims that the daily papers churn up all of nature, and all of culture, and spit them out in odd and confusing mixtures, all the while insisting that nothing odd is going on. The newspapers use headings such as Economy, Politics, Science, Books, etc., as if the articles they publish neatly fit into these categories. Latour continues:

> The smallest AIDS virus takes you from sex to the unconscious, then to Africa, tissue cultures, DNA, and San Francisco, but the analysts, journalists, and decision-makers will slice the delicate network traced by the wires into tidy compartments where you will only find science, only economy, only social phenomena, only sentiment, only sex. (p. 2)

Science and journalists slice these hybrid networks into distinct, separate disciplines, and then contend that we must not mix together knowledge, interest, justice, and power. Latour concludes:

> Let us not mix up heaven and earth, the global stage and the local scene, the human and the non-human. But, you argue, these imbroglios do the mixing. They weave our world together. And the response comes: *Act as if they didn't exist*. (p. 3, emphasis added)

My problem, I realized when I read Latour, is that 20 or 25 years ago, at least when I was teaching science, I was able to act as though these networks didn't exist. I could, therefore, work within the ontological framework of what Latour calls "the modern constitution." Latour suggests that in premodern Europe there was not a clean separation between the idea of *culture* and the idea of *nature*. People saw both nature and culture as part of a universe that was put on earth by God. The serfs and the monarchs each held a natural spot in the world; God spoke at times through signs of nature; and social bodies used natural signs to guide their behavior. In Latour's view, modernism represented a new era. On the one hand, humans attempted to understand and control nature. On the other hand, they set God on the sidelines and tried to establish new human relationships, in which larger numbers of people could, through varieties of democratic and economic means, take control of their own destinies.

This modernist move contained a double commitment to the domination of nature and the emancipation of humans. Accomplishing such ends, Latour suggested, required a clean dichotomy. In order to dominate nature, you had to at least pretend that it was something fully external to humans. At the same time, a new domain of pure human politics and culture emerged. This became the appropriate terrain on which to secure concepts of human democracy and human rights. Thus the move to keep nature separate from culture was both part of the development of modern science and also part of the development of the Enlightenment concepts of democracy and freedom. This was, indeed, my parents' view of the word.

Latour argues that from the beginning, the claim that science and culture were separate was false. He and others (Potter 2001; Shapin and Shaffer 1985) examined some of the key experiments performed by Robert Boyle, designed to demonstrate the existence of a vacuum. Demonstrations of the production of a vacuum could be observed on the main floor of a neutral setting such as the British Royal Academy. But the observations only counted when made by appropriate "modest witnesses"—gentlemen of a certain class and standing. Meanwhile, below ground, in the basement, working men labored to operate the air pump, and keep it functioning—always an uncertain business. Women could not be modest witnesses and the laborers were hidden in the basement. Thus the relationships of gender, class, work, and instrument design became invisible to the modest witness. More importantly, in order for the experiment to count as science, the messiness involved in producing it *had* to be invisible (Shapin 1999). In the case of the air pump, Enlightenment thinkers literally forced the hybrid networks linking nature and culture underground. They made the hybrids disappear.

In addition to drawing a line separating the non-human world and the human, cultural world, Enlightenment scholars separated those who studied human culture from those who studied non-human nature. In order to be a successful scientist or to successfully represent science to others, one had to develop a way of being, a way of viewing the world, that made hybrids connecting nature and culture disappear. For a scientist, work had to be an out-of-body experience. Indeed, this is how we have traditionally taught both science and anything that we would call cultural. We make sure that there is nothing about non-human nature in our English courses, and nothing about human culture in our science courses.

Although a strategy of ignoring hybrids worked in the beginning, it embodied a paradox. The better it worked, the more unacknowledged hybrids developed. The more we dominated nature, the more the proof of our domination poured into culture; the more culture dominated nature, and the more we created objects that were neither truly natural nor truly cultural. And so we now face a new kind of crisis, a crisis quite evident in our educational system. The clean borders are blurred, and the discipline-based academy struggles to figure out how to accommodate new configurations of knowledge.

Emily Martin (1998) thinks about this problem a little differently. She uses two metaphors: the citadel and the rhizome. The citadel is a walled city in which the scientists live, and there are various communities and hamlets—culture—outside that walled city. The rhizome is an underground root that can take a variety of odd shapes and forms. Sometimes it is just below the surface, and sometimes it is right at the surface. Rhizomes are unruly. You can link them in networks or break them apart. But broken pieces can generate new racemes that in turn produce new roots and new plants. Rhizomes can and do also burrow right under the walls of the citadel, bringing ideas born in culture into the realm of scientific theory.

Martin suggests that the field of science and technology studies began by exploding the idea that there is no culture within the citadel of science. For this claim she points to scholars such Sharon Traweek (1988). Traweek examined the social world of high-energy physicists, a world she dubbed "a culture of no culture" (p. 162). For Traweek, this memorable phrase describes life in the citadel—a culture of relationships between working scientists and their students. Inside the citadel, life operates on the premise that there is pure, objective science. Outside, culture lies in wait. Traweek's work stimulated a revolution in thinking about the workings of science. Even though scientists strive for a culture-free production of scientific knowledge, Traweek and others (e.g., Latour 1987; Latour and Woolgar 1986) have shown that there is a culture inside the citadel.

In her anthropological study of scientific and popular knowledge of the immune system, Martin (1994) found that most biological researchers operate with a very mechanistic view of the body. The body seems to be divided into compartments called organs, the organs have a hierarchical relationship, and in Euro-American culture the brain rules that hierarchy. Like the citadel, the body is self-contained, cleanly separated from the outside environment. But when Martin spoke with non-scientists about how they viewed the body, she heard quite a different account. Her informants spoke at length about the intimate way in which the environment molds the body, and vice versa. Moving "rhizomically" back into the citadel, Martin encountered a group of scientists who also claimed that the body is made up of complex nonlinear systems inseparable from their environment (Martin 1998, pp. 34–35).

Suppose this currently minority view within the citadel eventually triumphs and becomes the majority opinion, which will then be called "the facts" about the body. Martin hopes that we will remember, when this happens, that this view was held first *outside* the citadel, at large in the general population. Only later did it become the view that was held inside the citadel and defended in the variety of ways that scientists defend and argue for their particular viewpoints.[1]

[1]There are many other studies that illustrate Martin's point. For example, anthropologist Deborah Heath has examined the production of scientific knowledge about Marfan's syndrome. She particularly emphasizes the sometimes conflict-laden interactions between working scientists who study Marfan's syndrome and interested lay people, including patients with this syndrome. Like Martin, Heath emphasizes the ways in which these interactions shape emerging knowledge about a genetic syndrome (Heath 1997, 1998).

Would I Still Teach Anatomy? The Gender Connection

When I first read Latour (1987), a light bulb clicked on in my mind. I suddenly understood why I couldn't communicate with my colleagues about a basic course in developmental biology. When I began teaching and doing research, I was, as Latour would say, thoroughly modern. I taught and did science with great devotion. I was equally devoted to various political activities, of which in the early 1970s there were no lack. But I viewed my political activities and my science as separate. Women's studies began to infiltrate the academy in this period. At first the field asked a basic question of a large variety of disciplines: Where are the women? Later, other questions—the gender questions—emerged. What is the gender of the unnamed point of view in the novel, and does it matter? What work is gender doing in this poem? What happens to history as a discipline if you start to tell the stories of the mass of women working in the home and fields rather than just recounting great military battles, kings, and presidents?

While the "where" questions are an important first step, over the past two decades the gender questions have generated profound changes in the epistemology of many of the disciplines in the humanities and social sciences. But for feminist scientists the process has worked somewhat differently. At first nobody asked the gender questions. To do so seemed terribly inappropriate, because gender involved culture and science did not. By the 1980s, however, feminist science studies began to emerge. I, for one, was completely drawn in by the work of writers such as Ruth Bleier (1984), Ruth Hubbard (1990), Evelyn Fox Keller (1985), and Carolyn Merchant (1980). Not too long after these first forays into examining gender and science, I began to add my own work (Fausto-Sterling 1987, 1992b). Soon there was a multifaceted conversation, which included feminist scholars from the fields of philosophy, literature, and history (Haraway 1989; Harding 1986; Longino 1990; Schiebinger 1989, 1993, 1999). Today a second generation of feminist science studies has begun to emerge, along with ever more sophisticated analyses (Haraway 1997; Mayberry, Subramaniam, and Weasel 2001).

For me to ask the gender questions in science, I needed to understand more about how science works. How is scientific knowledge produced? Are there cultural fingerprints on scientific knowledge? What does that mean? Combining feminism with science, and bringing the work of Latour and many other science studies scholars into my worldview has changed my vision of science. In 1970, I couldn't see the hybrids. Now I can't make them disappear (see also Fausto-Sterling 2000). In contrast, my departmental colleagues are still very modern, in Latour's sense of the word. They can't see the hybrids, or at least they feel compelled to banish such monstrous formations to the sidelines.

Here, finally, we arrive at the heart of the problem. My colleagues feel compelled to ask "But will you still teach the anatomy?" because they can only imagine, when I begin to talk about bringing scitech-cultural hybrids into the room, that I have switched from being a person who wants to teach about nature to one who wants to teach about society. The modern view that science and culture are separate and that hybrids do not exist lies at the heart of our communication problem.

TEACHING EMBRYOLOGY THE NON-MODERN WAY

Once I understood the problem, I had no difficulty asking my chair to let me develop my own course. Here I could demonstrate how I might teach comparative embryology by studying the hybrids themselves. In my non-modern approach to embryology I begin each new topic by presenting (or having the students construct) a knowledge web. Let me return to Figure 1A—the development of the neural tube. When I lectured on neural tube formation in 1970, I talked about how the cells in the neural plate change shape and how the neural plate rolls up to become the neural tube. Today's modernist would add in a lot of fascinating information about the genetics and molecular biology of the cells in the neural plate, the underlying notochord, and the developing neural tube (Gilbert 1997).

In my non-modern embryology course (Figure 1B), I still locate the mechanics and genetics of neural tube formation in the center of the picture. (In a course on epidemiology these items would be found on the periphery.) Now, however, I routinely connect basic mechanisms to their failures, e.g., neural tube defects such as spina bifida and anencephaly. In contrast, in a modern course, birth anomalies are banished to one or two lectures attached at the very end of the course. Spina bifida and anencephaly exemplify birth anomalies produced by a variety of contributing factors. For example, certain geographical or regional areas of the world have very high frequencies of neural tube defects. The patchy geographic distribution is due in part to genetic factors, but also to occupational exposures, nutritional problems, and contaminated drinking water. Race, class, and gender bias (most studies focus on maternal rather than paternal exposures or behaviors) all play their part (Botto et al. 1999; Brender and Suarez 1990). In Embryology in Social Context, students read journal articles that discuss the multifactorial nature of neural tube defects. They find themselves struggling with the tentative nature of such knowledge, as well as with our current inability to produce a mechanism that translates the multiple contributors to neural tube defects into the basic biology of neural tube formation. The imperfection of scientific knowledge is a big take-home lesson, but also an invitation to students, as the next generation of knowledge producers, to fill in the many missing pieces of the puzzle.

Another important set of questions that radiate out from the neural tube knowledge web concerns definitions of the monstrous. How do we discuss malformations? How do we decide what is normal and what is abnormal? There are wonderful writings from historians of biology on this topic (Daston and Park

1998), and I point out to students that any time we talk about a birth defect, we set up a divide between something we call normal and something we call abnormal. How and where we construct that divide is as much a social as it is a scientific decision. Students read and discuss articles on the formation of conjoined twins to address the social nature of definitions of normality (Dreger 1998).

Some neural tube defects can be detected by amniocentesis (also discussed as part of the knowledge web for extraembryonic membrane formation) or ultrasound. This fact leads us directly to questions about genetic counseling and abortion (Rapp 1997, 1999). When spina bifida is detected by amniocentesis, one cannot tell if the problem will turn out to be mild and easily reparable, or so severe as to cause permanent and profound disability. Under such circumstances, genetic counseling is a kind of crapshoot. Parents can have a child who may turn out to be fairly able-bodied or who might be profoundly disabled. Or they can have an abortion, in which case they may lose a child they could have managed and cared for, or the abortion may have saved them a lifetime of distress. Again, students discuss and face up to the uncertain nature of knowledge, a fact that strengthens their abilities to confront and understand complex scientific information.

Different ethical questions surround the birth of anencephalic children. These babies are born without a cerebrum and often die within a week. But when they are first born, their healthy organs are usable for transplants that could save the life of a child that has the potential to survive and thrive. If you let anencephalic babies die naturally, their organs deteriorate. Hence the question: should one save other lives by taking organs from anencephalic infants while they are still healthy, in essence killing a baby prematurely even though he or she is certainly going to die in short order (AAP 1992)?

And one could go one. Other questions related to genetic counseling have been very nicely discussed by Rayna Rapp (1999). Rapp asks who is responsible for the physically and mentally disabled and what does it mean to an individual family to choose not to abort? Because there aren't good social supports and social networks to take good care of disabled people, individual families—usually, individual women—bear a terrible burden of fighting for their kids, fighting for the disabled, doing all sorts of things, if they choose not to abort. These are not questions for which I propose answers, but we do discuss readings that address these issues (Landsman 1998). Sometimes I merely point out how they are connected to the discussion of neural tube formation and suggest, for example, that a bioethics course, history of biology course, or an epidemiology course could provide students with skills needed to truly dissect the neural tube knowledge web.

I am not alone in such approaches. Donna Haraway (1997), for example, dissects a basic high-school text called *Advances in Genetic Technology*. She shows how it might be possible to use a non-modern approach to the book to provide students with a better grasp of an integrated science/culture. Haraway asks what would happen if a textbook such as:

> *Advances in Genetic Technology* were read in a high school English class to illustrate the structure of foundation narratives as well as in a science class to illustrate the structure of the natural-technical world? And what if the biology text were read in lab classes as itself a moral discourse and not just a science book that has a wannabe chapter on the techniques of moral reasoning? What if the study and crafting of fiction and fact happened *explicitly*, instead of covertly, in the same room, and in all rooms? Would the graduates of that pedagogy have a keener grasp of what it might take to build a practice of situated knowledges or strong objectivity, where the simultaneously engaging and endangering stories never slipped from the loving grasp within the daily toolkit of on-the-ground techno-scientific practice? (p. 110)

Michael Flower (2000) also uses the Latourian framework to think about scientific literacy and the transformation of undergraduate science education, while Susan Squier (1999) suggests how to use Latour to integrate the study of science and literature.

Opening up a science course in the manner just described raises an important pedagogical problem: how to limit the topics addressed to something manageable within a single semester. This can be looked at from two angles. On the one hand, webs of knowledge reach without limit into a broader world. How does an individual teacher decide what is so far beyond his or her individual expertise as to be inappropriate subject matter for the course at hand? And, at the same time, how does one make space for expanded coverage without losing the essentials of the scientific subject matter around which the course is designed in the first place?

There are no pat answers. We have to fence in the subject matter to make it manageable, but the fences should be picket or lattice—something the students can see through to the landscape beyond. In my anatomy course, for example, students spent much more time studying the neural tube than they did the health care system. Nevertheless, I did eliminate some traditional subject matter. For example, I did not discuss the development of the digestive system, reasoning that the principles of development I had laid out for other organ systems contained the most essential knowledge, and that the textbook contained details should a particular student wish to learn more. In similar manner, I eliminated the tradition of asking students to memorize all 12 cranial nerves, pointing out that if any of them became neurosurgeons they would have to go back and learn these. Instead, I chose a few of the nerves to illustrate important concepts of nerve origin and structure. Trimming of this sort did not, in my opinion, harm their learning of biological principles, but it did make space for the additional readings and knowledge web discussions.

We all have emotional attachments to subject matter that comprises a field we love so deeply that we have chosen to devote our entire lives to it. This emotion makes it hard to decide which "facts" might be cut in order to teach about sci-tech hybrids. But there is little that I learned when I studied biology in college that I would teach the same way today. The field has changed enormously in this time period. The value of what I learned lay not in the specific set of facts I was taught, but in the theory and practice. Today we have different theories and different practices, and we can teach these well without covering every subtopic of every field—something we all know is impossible anyway.

In addition to changing the subject matter, I introduced a new set of assignments—collaborative projects that I called "web expansion units." During the semester, groups of students had to design units in which they expanded on topics that intersected in some fashion with the main subject matter of the course. Students chose topics such as in vitro fertilization, cloning, conjoined twins, stem cells, and anencephaly. They designed web sites that address the history, the science, and the ethics and social context of their topics. Eventually, I linked their units to the course syllabus.[2]

Student reviews were positive. I personally received strong ratings, suggesting that, in responding to my new philosophical views with new pedagogy, I did a better job with the students. The course itself received strong ratings. Most students liked the breadth of coverage, although a few wished I had covered "more science and less social stuff"; many were very excited to have learned how to design a web site. My colleagues, I think, were both reassured that I still deserved to be called a biology teacher and impressed by the quality of the web projects. Questions remain, however. How easily can my vision of teaching science in social context be taken up by others? Should it be brought to all levels of teaching, from high school to graduate school? Why should we go to a lot of bother to change our current approaches?

Expanding the Vision

I am personally happy with teaching biology embedded in its larger web of knowledge, but I would like to see the concepts and teaching methods I have developed extended to other courses. Science colleagues, especially those with active research labs, find my ideas exciting but personally daunting, while humanities and social science colleagues often don't know how the science fits in. Not everyone will, can, or should become the interdisciplinary scholar I have become. But there is more than one way to skin this cat. One possibility is to use *course linkage*. One could, for example develop new courses specifically designed to coordinate with existing introductory and intermediate level biology courses. Or (and) one might identify already existing courses that could profit from linkage, and work with the relevant faculty to guide and encourage such coordination.

[2] To look at the course syllabus, including other examples of knowledge webs in embryology, the web assignments and their execution by student groups, contact the author via email. The syllabus is password protected for copyright reasons.

In using a course linkage model, one ought to keep several goals in mind. *Co-enrollment of non-science students in a science and related non-science course* would enable non-science students to study science in a context that makes sense to them. Goals for this set of students would include: (1) that they learn the specific science in the course in which they are enrolled; (2) that a positive experience aided by the linked courses lead them to take other science courses; and (3) that this result in a lifelong interest in following and thinking about science, no matter what part of the working world they end up in. *Co-enrollment for science majors in a related non-science course* would help these students understand more about how the science they study is linked to the rest of their lives and to the lives of others. Before they graduate, I would like to see these students enroll in more social science and humanities courses in order to obtain skills, such as communication, writing, and social reasoning, that they often don't acquire when they major in science. In short, I would like to produce science majors who not only can *do* science, but who can also think about how science works.

Linked courses would also increase faculty awareness of the myriad linkages between the sciences, social sciences, and humanities, an awareness that would in turn lead to more new pedagogy for science study. The linked courses would move away from the lecture format and instead employ a variety of approaches to active student learning. These would include the Socratic Seminar (Johnson and Sizer 1996), collaborative student projects, and student engagement with course progress and subject matter. Discussions and demonstrations of new pedagogy can expose the faculty of already existing courses to these newer approaches to science education and encourage them to experiment in their more pedagogically traditional courses.

Many schools have linked courses (AAC&U 2001). The University of Texas at El Paso, for example, has designed a Learning Community aimed especially at entering students of Hispanic origin. These students take a block of three clustered courses, including a seminar with a science or engineering theme (Rothman and Narum 1999). Carleton College has a similar first-year program entitled "Science as One of the Liberal Arts: Linking Introductory Courses for Science Literacy."[3] A third example comes from SUNY Stony Brook's Learning Communities, also designed for first-year students.

A non-modern approach to teaching science is consistent with current ideas on teaching promoted in a report to the National Science Foundation Advisory Committee on Undergraduate Education (George et al. 1996). This report exhorts science teachers at all levels to serve all students, not just science majors. The report also argues that we should speak to students of varying abilities and levels—that is, we should get rid of the idea that science courses are filters. A

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[3]The college programs mentioned in this paragraph may be examined at the following web sites: http://www.acad.carleton.edu/curricular/BIOL/faculty/ssinger/lab/educational%20activities/triad.html and http://naples.cc.sunysb.edu/Prov/lcp.nsf.

non-modern approach to science teaching can accomplish such goals. We can start from some place familiar to students—the newspaper, the television, the hospital—and teach the science that is "out there" in their lives. This science is just one thread in a hybrid network, and as the students follow that thread, they will, willy-nilly, end up in the laboratory, where they will learn modern biology, albeit from a new perspective.

The non-modern approach not only reaches out to non-science majors, it improves the education of future scientists and science professionals. I see no reason why such approaches could not be adapted to professional training even at the graduate level. Indeed, the NIH already mandates that graduate programs receiving NIH support must develop courses in research ethics for trainees. Similarly, it should be possible to make positive changes in secondary science education, especially if we begin to train a cadre of students who have a more integrated, situated understanding of science and daily life. Philosopher Philip Kitcher (2001) argues that it is time to provide the philosophy and the practice of science with an ethical dimension it still mostly lacks. The changes in science education that I propose would acquaint students with the methods, processes, history, and societal and ethical contexts of science, math, engineering, and technology. We can pursue Kitcher's goal by using the very well-developed science studies and gender studies literature in our science classes. By redesigning our science courses to let the cultural complexities of scientific knowledge become visible in the classroom, and by permitting our students to grapple with these hybrids, we will re-invigorate science education. In the process, many students—women, minorities, socially concerned students from a variety of backgrounds—will suddenly view the science classroom as a compelling place to be.

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