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Educating for social responsibility: changing the syllabus of developmental biology

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ABSTRACT Developmental biology is deeply embedded in the social issues of our times. Such topics as cloning, stems cells, reproductive technologies, sex selection, environmental hormone mimics and gene therapy all converge on developmental biology. It is therefore critical that developmental biologists learn about the possible social consequences of their work and of the possible molding of their discipline by social forces. We present two models for integrating social issues into the developmental biology curriculum. One model seeks to place discussions of social issues into the laboratory portion of the curriculum; the other model seeks to restructure the course, such that developmental biology and its social contexts are synthesized directly.

KEY WORDS: *education in context, developmental biology, syllabus, teaching, ethics*

Background Information

Scholarly Interests of the Authors

Scott Gilbert is interested in the morphogenesis of evolutionarily novel structures and in the morphogenesis of the discipline of developmental biology. His current research explores the developmental genetic mechanisms by which the turtle forms its shell. As the author of the textbook, *Developmental Biology* (presently in its sixth edition), he is interested in new pedagogical methods, and in 1994, this book became the first biology text to have a website wherein readers could post additions and corrections.

Professor Fausto-Sterling conducts research in the fields of developmental genetics and developmental ecology. Her most recent laboratory research has focused on the evolution of regeneration and sexual reproduction in a group of flatworms known as *Planaria*, while her earlier work was in the field of *Drosophila* developmental genetics. In addition she has written several papers and books which critically analyze the role of preconceptions about gender in structuring theories of development.

Representative Publications

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Introduction

Reproductive cloning, stem cell differentiation, abortion, genetic enhancement, gene therapy, environmental estrogens, sex selection, and teratogenesis all converge on developmental biology. Developmental biology is not only a scientific discipline. It is also a social discourse that is deeply embedded in cultural concerns. Developmental biology tells us how we were created, how we are born, and how we become sexed. Developmental biology is therefore the focus of reproductive technologies that permit many in our society to conceive and that enable physicians to monitor and sometimes treat the outcomes of conception. Developmental biology is also becoming the concern of genetic technologies that may enable us to alter the outcomes of development. It even serves as a source of information concerning species preservation. DDT has been outlawed for its effect on avian embryos, conservation biologists raise turtle embryos at different temperatures to generate both sexes, and every time we drink an alcoholic beverage in America, we are reminded by the label that such beverages may damage our fetuses.

It is imperative that developmental biologists learn of the possible social consequences of their work and of the possible molding of their discipline by social forces. For today's biology students may be given more physical and social power than any group of people before them. Biologists will soon be able to alter the course of evolution, cure or cause epidemic disease, and create new forms of life. Moreover, it is developmental biology that is going to be at the center of these matters. In addition to the specific concerns mentioned above (cloning, stem cells, sex selection, etc.), developmental biology plays a critical role in our self-definition. Joseph Needham (1959) recognized that embryology is not merely a provider of information, and that a theory about human development is never culturally neutral. This assessment has been confirmed many times (see Bleier, 1985; Laqueur, 1990; Martin, 1992; Fausto-Sterling, 1992, 2000; Haraway, 1997). As Abraham Joshua Heschel (1965, p. 7) noted, "Thus the truth of a theory about man is either creative or irrelevant. It is never merely descriptive." A theory about the formation of stars never becomes part of the being of the stars, while a theory about human formation enters into our consciousness of who we are. Developmental biologists are quickly moving to the interface of science and the larger society. This means that we are probably going to have more social responsibility than we have ever wanted. Developmental biologists need to know about ethics, social issues, and their relationships to our science. Thus, it is crucial that biologists, especially developmental biologists, be educated for social responsibility. How are we going to teach such issues (and learn about them ourselves)?

In this essay, two curricular models are presented, each of which integrates developmental biology and social concerns. In the first model, social concerns are integrated into the context of developmental biology. Here, a traditional course has been "retrofitted" to include ethical issues. In the second model, developmental biology is integrated into its social context, and the entire course syllabus has been radically restructured. Neither model is presented as "the answer," and each model depends on its respective professor's context within his or her department. (For instance, some people might not wish to expand their courses in these directions until after receiving tenure.) In neither model is developmental biology seen as being a mere relativistic construct, totally dependent on societal perspectives. A danger of relativism is inactivity, and the default state of inactivity leaves decisions on ethics and science to the market (Paul, 1998).

We must remember that few of the people in our courses will be so fortunate as to become developmental biologists. In the context of education in the United States, our courses in developmental biology are taken not only by future scientists, but also by future physicians, lawyers, and politicians, to name but a few of the careers pursued by liberal arts students at a four-year American undergraduate college. By addressing the social implications of our science in such courses, therefore, we participate in the essential education of our most active citizens. There are two reasons why such education is imperative. First, out of pure self-interest, it is important for our future voting and law-making citizens to understand biology as an area that can provide important conclusions and medical technologies and also has practitioners who are committed to the socially responsible application of ideas they develop and teach. Such understanding should lead to well-measured public support of research efforts. Second, we want all active members of a democracy to make intelligent decisions about scientific questions that affect their daily lives. In England, these goals have been expressed in a program to teach citizenship in science classes (Adam, 2002). We offer two examples of teaching science citizenship in developmental biology courses.

Model 1: Inclusion of Ethics and Social Issues into a Traditional Developmental Biology Course (Scott Gilbert)

My approach comes from the perspective of a liberal arts college wherein the faculty member teaches both the developmental biology course and its laboratory. Moreover, at liberal arts colleges, material from one subject is expected to be integrated with other areas of knowledge, and it is not unusual for many students to come into my developmental biology course with substantial backgrounds in philosophy and public policy.

The major change that I have made to my developmental biology course has been the inclusion of these ethical and social issues into its laboratory sections. There are several reasons to bring these discussions into the laboratory rather than into the classroom (Gilbert, 2000). First, the students are brought together in a more informal setting than during lecture time. Second, there is a lot of "downtime" in developmental biology laboratories. Third, the laboratory studies themselves often open directly to discussion of these ethical issues. (So we discuss feminist critiques of fertilization narratives or the ethics of sex selection after just having seen fertilization taking place in sea urchins and are waiting 90 minutes for the first cell division to occur.) Fourth, since their laboratory grades depend on their notebooks and projects, students can discuss these issues without fear of being graded on their views.

Sometimes I have assigned the students to read certain articles, and we have discussion immediately; other times, I have lectured to them about the articles, and then we discuss them. In no cases were the students tested on this material. I feel that it is important to introduce social issues to the class so that the students will be challenged to look at their assumptions and the assumptions of the literature. I do not ask for their agreement with my views.

Current Ethical Concerns

Cloning and Stem Cells. The material in these sessions differs from year to year. In some instances, the discussion session is initiated by a newspaper article or a particular issue of student concern. This was the case when mammalian cloning was first accomplished in 1997. Since then, we discuss cloning both in the classroom (where we discuss the mechanisms by which mammals *have been* cloned) and in the laboratory, where we discuss whether humans *should* be cloned. The class is assigned to read certain material on the web, and this is supplemented by articles that I have put on reserve. Some of these articles have included the statement on cloning by the Society for Developmental Biology (http://sdb.bio.purdue.edu/AboutThisSite/From_the_SDB_Office/position_statements.html) as well as material I have collected. The Society for Developmental Biology also updates a web site on stem cells (http://sdb.bio.purdue.edu/publications/focus/index.html) that has been a good starting point.

When does Life Begin? Another topic that was initiated by student concerns involves when does human life begin. This discussion was occasioned by a bulletin board set up by a religious action group at our college. The board claimed that while philosophy and religion may have different opinions concerning when human life begins, science has no such problems. Students were told that biologists were unanimous in agreeing that life starts at fertilization, and that there was no dispute in the scientific literature. Besides being a parody of science (*i.e.*, that scientific facts are the objective truth and that all scientists agree about what these facts mean), there is actually a wide range of scientific positions on when life begins. I have assigned students to read an introductory statement on this topic (http://www.devbio.com/chap02/link0202a.shtml) and to come to the laboratory prepared to defend one or more points of view.

Sex Selection. Recently, our class has discussed issues involving the selection of sex in human embryos. In 2002, sex selection made news headlines when the American Society for Reproductive Medicine claimed that sex selection was ethical, despite the denial of this view by the Society for Assisted Reproductive Technology. The students searched the web and the library for material on this topic. Interestingly, some of the students were appalled that their searches (such as searching for "sex selection" on Google) brought down two commercial sex selection organizations as the first hits. Indeed, this Google site is a "sponsored link" whose cosponsors are MicroSort Gender Selection and the Los Angeles Fertility Center ("IVF, surrogates, 100% sex selection. Click here for low prices, high success"). This brought us into a discussion of the commercialization of developmental biology and how the market can have a dramatic effect on science. This is also good for nascent developmental biologists to consider. Indeed, it may be immoral to train 21st-century developmental biologists who have *not* considered what their science may be doing to the larger society and what the larger society may be doing to their science.

We have never been at a loss for ethical items to bring up in the laboratory discussions. The freedom the students have in their laboratory sessions to discuss without fear of grading helps makes these discussions provocative, and the fact that they are assigned to read material and learn the necessary scientific principles makes these discussions more than mere arguments between opinions. Such discussions also allow the students to bring material in from other classes (philosophy, religion, sociology, anthropology, history) and to see the relevance of both these other classes and developmental biology.

Criticizing the Language of Developmental Biology

Developmental Biology is a field that involves describing how fertilization occurs, how sex is created in the embryo, and how the brain is formed—issues that have been considered central to defining one's humanness, maleness, or femaleness. Because of the importance of developmental biology to one's self-definition and to the problems of reproductive technology, several individuals and groups have scrutinized this area and have written excellent critiques of its language, its narratives, and its interactions with society (*e.g.*, Hubbard, 1982; Schatten and Schatten, 1983; Bleier, 1985; Fausto-Sterling, 1985; Eicher and Washburn, 1986; The Biology and Gender Study Group, 1988; Martin, 1992; Keller, 1995).

Most of the above-mentioned people are developmental biologists. Thus, developmental biology has seen a remarkable reform-from-within. The scientific data themselves have not been questioned so much as the types of questions thought important and the interpretations drawn from experiments and observations. In most all these instances, these critiques have been used to make the science "better" in the normative sense. These critiques were used as a control. Just as a good scientist would control for temperature, pressure, and solvent effects, so the scientist should also control for social biases and cultural assumptions.

Fertilization Stories. I usually assign two articles, "The Importance of Feminist Critique for Contemporary Cell Biology" (Biology and Gender Study Group, 1988) and "Sperm Wars" (Small, 1991), before the laboratory period. The laboratory period begins with a discussion of the importance of narrative and metaphors in science. I often start with the following quotation, reading directly from its source:

> *In all systems that we have considered, maleness means mastery, the Y-chromosome over the X, the medulla over the cortex, androgen over estrogen. So physiologically speaking, there is no justification for believing in the equality of the sexes.*

This evidence for social biases in developmental biology comes from a textbook published in 1972—when I was a postdoctoral fellow (Short, 1972; see Spanier, 1984; this paragraph and others like it are not to be found in the 1982 revision of this book). If nothing else, this type of quotation shocks the students, jarring them with the possibility that social critique may have something to say to them. After a general discussion of metaphors, we discuss how we represent the sperm and the egg. (They are, after all, *gametes*, *i.e.* marriage partners; from the Greek, *gamos*, marriage). The BGSG paper looks specifically at the analogy sperm:man = egg:woman, and it is an obvious analogy for all the students to see. They instantly bring up the *Look Who's Talking* movies with the anthropomorphized sperm, and they begin to question the images that they have held as true.

The BGSG paper has documented an evolution of sperm and egg stories that parallels the roles expected of men and women in society. In the 1800s, the sperm was the egg's suitor. Later, the sperm and the egg are depicted as characters in a self-congratulatory hero myth. The "Sleeping Beauty" version of the egg is also

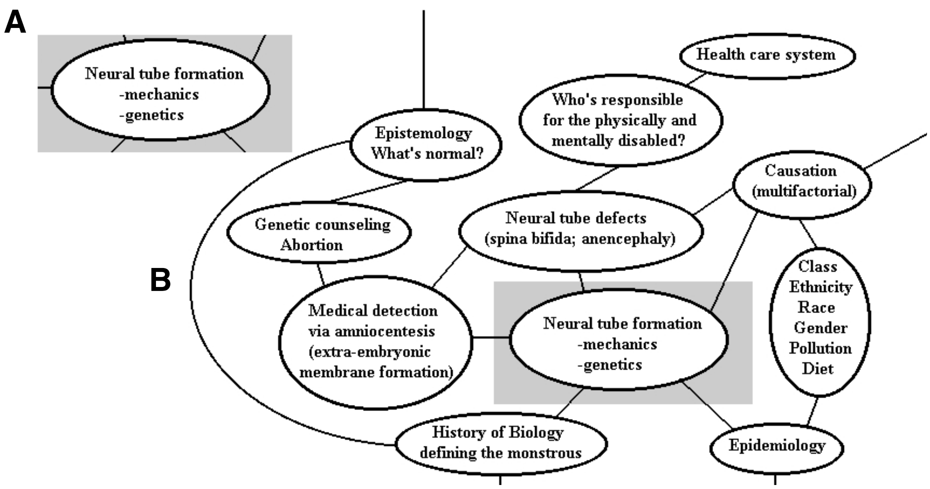

Fig. 1. Approaches to teaching neural tube formation. (A) *Traditional approach.* **(B)** *Neural tube formation embedded in a broader web of knowledge.*

discussed, as is the "rape" of the egg by sperm. To make certain that the students do not think that such metaphors are a thing of the past, the "Sperm Wars" paper depicts sperm as the ultimate warriors in the never-ending battle against the egg, other sperm, and, ultimately, against female promiscuity. Sperm are described as "tactically smart," "well-armed," and as "a formidable .00024-inch weapon, tipped with a chemical warhead"! We discuss the narrative structure of the article as well as the complex of metaphors it privileges. In the end, though, the students have become aware of the storytelling component of developmental biology texts and their responsibility in telling appropriate stories[1]. By the end of the laboratory period, the students are often talking amongst themselves (while they do their experiments) about metaphors they have encountered in the press, in textbooks, and in laboratories in which they have worked.

I believe that such training is necessary for those students who become scientists to be aware of their metaphors and what stories they are telling. Perhaps more importantly, such training allows those members of the class who are not going to become biologists to read the popular literature with more scrutiny.

New Modes of Education

The inclusion of social concerns into a normative developmental biology course can be done without sacrificing the scientific material one wishes to teach. It enriches and enlivens the class, and it brings a social dimension to the learning, which is crucial in our present time. However, it is not easy. Having obtained a master's degree in the history of science, I have access to some teaching tools in this area, and our college's library budget is able to pay for the reference works that are needed. It is also difficult to have discussions when much of one's available laboratory time is spent introducing the laboratory material to the class. To facilitate the integration of social material into the developmental biology laboratories, we are putting a series of essays on the public website (devbio.com) affiliated with our textbook. These essays include material on cloning, stem cells, sex selection, genetic reductionism, and the concept of what is "normal".

Model 2: Embryology in Social Context (ESC): New Philosophies and Pedagogy (Anne Fausto-Sterling)

The Way it Used to Be

Like Scott Gilbert, I teach at a four-year undergraduate college in the United States. Thirty years ago, a colleague and I developed a course entitled "Comparative Vertebrate Embryology." Our target audience included first- and second-year college students, most of whom would go on to become physicians (including medical researchers) and a smaller number of whom would become developmental biology researchers. A significant minority would enter fields such as law, elementary and secondary school teaching, and a variety of nonscience oriented professions. When we first developed comparative embryology, it was a traditional course. The first third of the course contained lectures on fertilization and early development, with special emphasis on the vertebrate body plan and comparative extra-embryonic membranes. We devoted the remaining two-thirds of the lectures to the development of specific organ systems—circulatory, heart, sense organs, nervous system, skeletal and muscle, and digestive systems. We made extensive use of the many excellent films available to animate various developmental systems, and we integrated our lectures with a laboratory component. In the lab, students studied serial sections of slides of amphioxus, amphibian, chick, and pig embryos at various stages of development, learning to recognize and identify significant anatomical markers as they changed during development.

Exams were traditional—essays and short answers from material presented in lecture, and identification of body parts on slides for the lab exams. The primary mode of learning in this introductory course was memorization and development of skills enabling students to envision the changing developmental anatomy in the four dimensions of space and time. In our broader biology curriculum, we taught the application of molecular and genetic approaches to experimental analysis of development in a more advanced course, which students took in their third or fourth years, after they had acquired additional background in biology. Students evaluated comparative vertebrate embryology positively and the course had a solid enrollment. I participated in it for about the first 15 years of its existence. By the mid-1980s, however, I had developed a second set of academic interests in the history and philosophy of biology—paying special attention to the interplay between social concepts of gender and the construction of biological knowledge. (Fausto-Sterling, 1985, 1987, 2000) I therefore entered a hiatus during which I taught rather different types of biology courses (Fausto-Sterling, 1982; Fausto-Sterling and English, 1986).

A New Approach: Overview of Themes and Pedagogy

From the mid-1980s to the present, my understanding of what science is and how it is practiced changed enormously. Thus, when my department asked me a few years ago to participate once more in teaching Comparative Vertebrate Embryology, I faced a significant

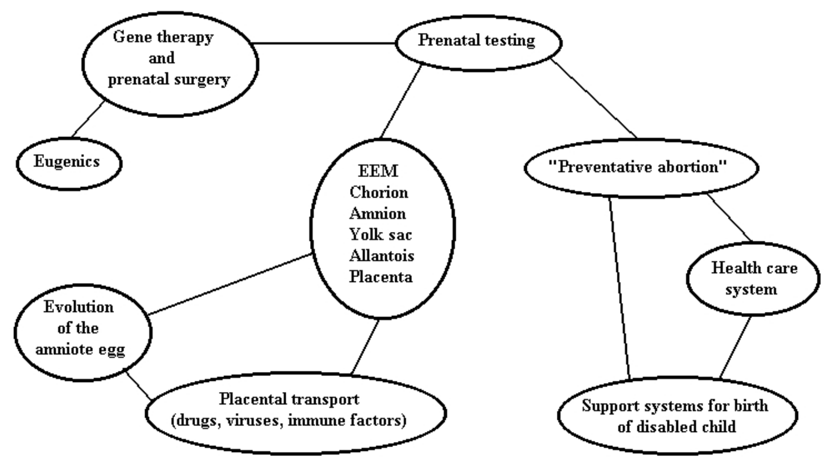

Fig. 2. Knowledge web for discussion of extraembryonic membranes.

dilemma. My philosophical and moral awareness of my own beloved field had changed so much that I could no longer teach the course as it had originally been designed. (For a discussion of these personal, philosophical changes and the resultant conflicts that arose with my colleagues, see Fausto-Sterling, 2003). Furthermore, I found myself profoundly disaffected from the traditional pedagogy–lectures, labs, and exams that ask students to recite the lecture and lab material—with little opportunity for discussion or reflection. If I were to function successfully in this course again, I needed to change it.

Thirty years ago, when I first began to teach, embryology seemed straightforward. A lecture on 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 doing it using the standard model—my discussion of induction would include an account of events both more complex and more subtle than those known 30 years ago, including an introductory level account of key genes involved in neural tube formation (Fig. 1A). But when I returned to neural tube formation after my sojourn in feminist theory and science studies, a vastly expanded image sprung to mind (Fig. 1B). The neural tube appeared to me embedded in a matrix of epidemiological, medical, historical, and social questions. I no longer felt morally comfortable talking about neural tube development without also mentioning neural tube defects. This, in turn, led to discussions of the epidemiology of birth malformations. The fact that, in the United States, there is a direct correlation between the number of prenatal doctor's visits and the frequency of birth defects led in turn to a discussion of a system that does not provide basic health care to all, regardless of income. Discussion of neural tube defects also led to the discussion of prenatal diagnosis and selective abortion.

Every topic I now lecture on appears in my mind's eye embedded in a web of broader questions. I resolved to teach these knowledge webs as an integral and required part of a revised course which I entitled "Embryology in Social Context" (ESC). Figures 1B, 2, 3 and 4 show examples of webs that my students and I developed for several traditional topics in embryology. Before delving into the specifics of these webs, let me make some other comments about the structure of "Embryology in Social Context." Many traditional development courses devote the final one or two lectures to a discussion of teratology (as had we in our original course). As part of my insistence on webs of knowledge, I integrated relevant teratology into every topic. Even though I developed the knowledge webs in lectures, I significantly reduced the amount of time devoted to traditional lecture (Table 1). In its place I instituted regularly scheduled discussions based on readings which explicated some of the topics alluded to in the knowledge webs. I also included news packets that contained a mix of short, recent articles, culled from the pages of major newspapers and magazines as well as the news sections of *Science* and *Nature*. Many of the historical readings—including both primary and secondary texts—came from the enormously helpful web sites developed by Scott Gilbert and referenced earlier in this paper. The availability of web sites and interactive CD-ROMs[2] that permit students to study much of the basic developmental anatomy on their own (see for example: http://www.med.unc.edu/embryo_images/unit-welcome/welcome_htms/contents.htm) meant that I could require the students to become active learners. We could spend more classroom time devoted to understanding the historical origins and current ramifications of developmental knowledge without sacrificing the learning of the basic developmental anatomy. (For the specific mix of lecture, lab, and discussion, see our course web site)[3].

My goal in changing the course's pedagogy was to produce a more active form of learning, one in which students took responsibility for finding things out for themselves, for seeing and pursuing both scientific and social connections. The more traditional classroom, in my opinion, promotes a passivity in which students accept whatever the professor tells them, learn it dutifully, and repeat it on the test. While I believe that students must learn "facts" which represent the current state of knowledge in a field, I also know that such "facts" change rapidly. As an educator, I want to produce future citizens who know how to follow knowledge as it changes and who can search out

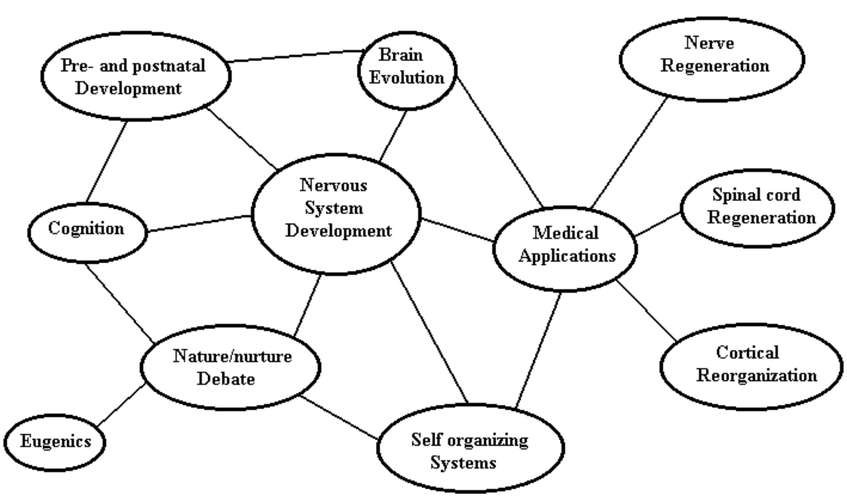

Fig. 3. Knowledge web for discussion of organogenesis of the nervous system.

and think intelligently about the many social and political ramifications of the particular science in which they are engaged.

I emphasized the importance of the discussion material by asking questions on the readings and on all of the lecture material—including the historical and philosophical analyses—on the exams. At the same time, I changed the weight of the exams so that they counted for only 60% of the final grade. I then introduced a new assignment, which I called a web expansion unit[4]. Groups of three or four students worked on these units (also forecasting for students the collaborative nature of scientific work), and the groups produced two units during the semester. The general assignment was for the group to expand on an idea or topic related to some aspect of the course and to design a short, informative web site on the topic. I graded the site and then linked it to the relevant topic on the syllabus displayed on the course web site. In this manner, the network of knowledge in which developmental biology is embedded became literally manifest as a hyperlink on a web site. The students had to include an accurate account of the basic science of the topic they had chosen as well as historical, ethical, and philosophical issues connected to their topic. For example, a web expansion unit on conjoined twins considered etiology, classification, and technical aspects of surgical separation as well as historical responses to conjoined twins, highlighting some famous 19th-century twins. The web unit addressed ethical issues concerning surgical separation, including discussions of the ethics of abortion of conjoined twins and the ethical dilemmas of killing one twin in order to save the other. I placed a hyperlink to this web unit on the class syllabus opposite lectures and labs on the cleavage stage of early development.

Given all the changes I introduced in Embryology in Social Context (ESC), how was it possible to limit the topics addressed to something manageable within a single semester? 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 easy answers. We have to limit the subject matter to make it manageable, but the arbitrary nature of the limits, and what subject matter lies beyond that chosen for a semester's study, should be made visible to the students.

In ESC, 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 organogenesis of the gut tube, reasoning that the principles of development (*e.g.*, morphogenetic movements, differential gene activity, epithelial mesenchymal interactions) that I had laid out for other organ systems contained the most essential knowledge. Furthermore, the textbook and some of the web sites we used contained details of gut tube development should a particular student wish to learn more. Similarly, I eliminated the tradition of asking students to memorize all 12 cranial nerves, assuming that those students who became neurosurgeons would have to return to a careful study of these nerves, but that others could learn important principles of nerve anatomy from a more limited sampling. Trimming of this sort did not, in my opinion, detract from learning of biological principles, but it did make space for the additional readings, discussions, and web projects.

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 knowledge webs and give students time and intellectual space to explore and question. 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 but in the theory and practice I was taught and even more in the sense of wonder and curiosity my college biology courses engendered. Today we have different theories and different practices that we can teach effectively without covering every subtopic of every field. I list the topics covered in ESC in Table 2.

TABLE 1

CHANGED BALANCE OF LECTURE, LAB AND DISCUSSION

	Percent time devoted to:	
	Comparative Vertebrate Embryology	**Embryology in Social Context**
Lecture	49	30
Laboratory	49	40
Discussion of readings and social context, including work on group projects	2	30

Reading Assignments and Discussions of Sample Knowledge Webs

Before concluding this article, I thought it might be helpful to discuss a few of the embryology knowledge webs in more detail. Consider the web surrounding neural tube formation featured in Fig. 1B. The mechanics and genetics of neural tube formation center my narrative, but I connect these basic mechanisms to their failure by discussing topics such as spina bifida and anencephaly. The required text for the class, Carlson's *Human Embryology* (Carlson, 1999) also integrates relevant teratology into each of its chapters. Spina bifida and anencephaly rates differ wildly in different regions of the world and even within a single, geographically small country. This geographic variation results partly from genetic variability but also from occupational health hazards, nutritional deficiencies, and contaminated drinking water. Race, class, and gender bias (most studies focus on maternal rather than paternal exposures or behaviors) all play their part. As part of this course segment, students read scientific journal articles which discuss the multifactorial nature of neural tube defects (Brender and Suarez, 1990; Botto *et al.*, 1999). In discussion, they struggle with the tentative nature of such knowledge and our current inability to produce a mechanism that translates the multiple contributors to neural tube malformation into the basic biology of neural tube formation. In these discussions, the students come to appreciate the imperfection of scientific knowledge; but I also invite them, as the next generation of knowledge producers, to fill in the missing pieces of the puzzle.

Another important set of questions that I place in 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

TABLE 2

TOPICS COVERED IN EMBRYOLOGY IN SOCIAL CONTEXT

Class	Topic or Activity
1	Introduction to course structure and content overview
2	Fertilization and social issues;
3	Cleavage
4	Germ layer formation: meanings and mechanisms
5	**No lecture**: Lab and project organization:
6	Neurulation and axis formation
7	Asymmetry
8	EEM formation in chick
9	Placentation and EEM formation in mammals
10	**Lab and Lecture Exam**
11	Brain development and evolution; neurogenesis
12	Brain and behavior: nature/nurture vs developmental systems;
13	Eye development:
14	Evolution of the eye;
15	Branchial and pharyngeal development;
16	Branchial and pharyngeal regions—evolution
17	History of embryology and evolution
18	**Lecture and Lab/discussion Exam**
19	Recapitulation: an idea's pervasive influence
20	Heart development
21	Circulatory system
22	Uro-
23	-genital
24	Intersexuality
25	Class meets to discuss and demonstrate projects
26	Class meets to discuss and demonstrate projects
27	**3rd exam on remaining (not yet tested) material**

Each class session ran for 3 hours and was divided between lecture (1 hour) and lab and discussion (2 hours)

a social as it is a scientific decision. In class, 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 or ultrasound (see also Fig. 2). This fact leads directly to questions about genetic counseling and abortion (Rapp, 1997, 1999). One of the interesting things about using amniocentesis to detect a defect such as spina bifida is that 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 cannot offer certain answers. Parents can have a child who may turn out to be fairly able-bodied or who might be profoundly disabled. If, instead, they choose to abort, 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. Born without a cerebrum, such babies often die within a week. At the time of birth, their healthy organs could be used for transplants that could save the life of a child who might then live a long and productive life. By the time anencephalic babies die naturally, however, their organs have deteriorated. Hence the question: should one save other lives by taking organs from anencephalic babies while they are still healthy, in essence killing a baby prematurely, even though he or she is certainly going to die soon? (American Academy of Pediatrics, 1992).

And one could go on. Rapp (1999), for example, 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 in the United States there are not good social support and networks to take proper care of disabled people, individual families—usually, individual women—bear a terrible burden of fighting for their children and fighting for the disabled, if they choose not to abort. Here too we discuss readings that address these issues (Landsman, 1998). The knowledge webs presented in Figs. 2 and 3 present similar opportunities for discussing both the science of embryology and its ramifications in a manner much expanded from a traditional embryology course. The readings assigned for each of the course segments as well as additional knowledge webs devised for each course topic can be found on our course web site (see note 3).

Concluding Comments

Teaching science embedded in its social and historical context not only reaches out to nonscience 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 United States National Institutes of Health (NIH) already mandate 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 argues in his new book *Science, Truth and Democracy* (Kitcher, 2002), 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 we propose would acquaint students with the methods, processes, history, and societal, and ethical contexts of biology. 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 such complexity, we will reinvigorate science education. In the process many students - women, minorities, socially concerned students from a variety of backgrounds - will come to view the science classroom as a compelling place to be.

Footnotes

[1]And this is when I get to ask the question: "What story am I telling in my textbook?" It takes them a while, but the students usually come to the conclusion that I am telling a story about the interaction of equals. The sperm and the egg mutually activate one another, and by a series of these activations, the drama of fertilization is completed. This model is based on compelling biochemical data involving signal transduction pathways. And then I can ask the most important question: "Is my story any less socially constructed than the others we've discussed? Perhaps I'm just modeling my sperm and egg after what I think a marriage should be. After all, I went to college in the '60s, and my wife has her own name and her own career." Yes, what's in their textbook may be a story, too. I believe it to be an accurate account of fertilization, a better, more biochemical, and more balanced story than what I had learned as a student. For more about teaching philosophies at liberal arts colleges, see http://www.teratology.org/jfs/Gilbert.html

[2]*e.g.*, Jay Lash's "Interactive Embryology: The Human Embryo Program (Sinauer Associates) or a CD-ROM entitled "The Microscopy Tutor." These programs were made available on computers in the laboratory so that students did not have added purchase expenses. I did not lecture on microscope parts and use as I had in the past but required students to do the CD-ROM tutorial, from which I took questions for the exam.

[3]The web address is: http://www.brown.edu/Courses/BI0032-Fausto-Sterling/course/. Although the site is password protected (because of copyright considerations), I am happy to give the password to anyone who requests it. Just e-mail me at Anne_Fausto-Sterling@brown.edu.

[4]The details of this assignment may be found on the ESC web site.

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