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IMPLICATIONS OF FEMINIST CRITIQUES OF SCIENCE FOR THE TEACHING OF MATHEMATICS AND SCIENCE

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Within the last half of this century, challenges to science as the bastion of true and certain knowledge have been mounted on many fronts. The specifically feminist contribution to this discussion is in framing the analysis in terms of gender ideology. This article includes a summary of some of these feminist critiques of science, which leads to an investigation of the role that language plays within science. In addition I explore the ramifications of gendered discourse to the teaching of science and mathematics, and examine some of the ways in which nature and culture interact in the production and dissemination of scientific knowledge.

INTRODUCTION

There is a core of assumptions about science that set it apart from other knowledge systems and confer upon it a special status. This status is based on the alleged superiority of the two fundamental attributes of scientific knowledge: its rationality and its objectivity. The position of science is further enhanced by the firmly held belief that the principled application of pure logical reasoning to unbiased observations is itself assured by strict adherence to the rules of scientific method. For over three centuries the veracity and reliability of other knowledge systems have been judged by how closely they follow the scientific model. However, within the last half of this century, challenges to science as the bastion of true and certain knowledge of the world have been mounted on many fronts. Historians, philosophers, sociologists, literary critics, and feminists alike have sought to dethrone the scientific method as the reigning method of inquiry of choice, with uniquely privileged access to "truth" and "reality." The specifically feminist contribution to this discussion is in framing the analysis in terms of gender ideology, our culturally constructed beliefs about what constitutes male and female nature.

By now an impressive body of literature[1] has accumulated that documents and critiques the interpenetrations and linkages between traditional notions of objectivity and traditional notions of masculinity. One of the most lucid and insightful writers investigating these issues is Evelyn Fox Keller (1985, 1992a), who has now extended her critique from reflections on gender and science to thinking about language, gen-

This article profited from critical comments by Sharon Pedersen and Judith Isaacson. Special thanks go to Donald McCarthy for many stimulating discussions and his insightful reading of early drafts of this article.

[1]I will be citing some of this literature in this article, but I refer readers interested in the issues of feminism and science to the bibliography in Simons and Tuana (1988, pp. 145–155).

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der, and science. In considering what the consequences of a gendered discourse might be for science, she observes:

> It is easy enough to say, and to show, that the language of science is riddled with patriarchal imagery, but it is far more difficult to show—or even to think about—what effect a non-patriarchal discourse would have had or would now have (supposing that we could learn to ungender our discourse). In short, *what does language have to do with science*? This, I suggest, is the real task that faces not only feminist critiques of science, but all the history, philosophy and sociology of science (Keller, 1992b, p. 48).

Sandra Harding is another highly original intellect in this field. Harding's work has evolved from considering the science question in feminism to asking questions about whose science and whose knowledge we are studying (Harding, 1986, 1991). She admonishes feminist critics of science to refrain from essentialist formulations that ignore differences in class, race, and sexuality among women. Just as a gender analysis of a particular discipline often exposes other implicit cultural assumptions, questioning the exclusion of women's voices from science leads inevitably to examining the consequences of the exclusion of other minority perspectives.

In this article I summarize some of the feminist critiques of science and try to indicate the wide range of philosophical, social, historical, and psychological issues that are encompassed under the rubric of "gender and science." In addition, I investigate the role that language plays in reflecting as well as perpetuating underlying cultural assumptions about and within science. In particular, I examine some of the reasons mathematics has evolved as the chosen language of science. (This is a natural subject for me to study, as I began my adult life as a poet and became a mathematician in my middle years.) Next, I weave Keller's concerns into one other abiding passion in my life besides mathematics and language, namely, teaching. I explore some of the ramifications of gendered discourse to the *teaching* of science and mathematics (with the emphasis on mathematics). Since, as René Thom has pointed out, "all mathematical pedagogy . . . rests on a philosophy of mathematics" (Thom, 1972), it makes sense to take these feminist critiques (which examine the underlying presuppositions and philosophy of science and mathematics) into account when considering pedagogical issues. Finally, I address the relevance of this entire discussion to women and minorities in science and engineering. Creating more inclusive environments in classrooms and laboratories will certainly help increase the participation of members of previously underrepresented groups in these fields. But as the composition of the community itself changes, so too will the disciplines evolve. It is precisely this blurring of boundaries between "the Changer and the Changed"[2] that embodies the very essence and promise of a feminist science.

NATURE AND CULTURE

There are, in fact, not one but many feminist lenses through which the culture, content, and practice of science are refracted. In what is sometimes referred to as

[2]This is the title song of an album by Cris Williamson, a feminist singer/songwriter.

the liberal feminist critique, the focus is on affirmative action and equal access for women and other minorities to education and employment. Many argue that these critiques do not go far enough, that there can be no true equality of opportunity in fields whose concerns have been defined predominantly by the interests of white upper-class men. A more radical critique focuses on the choice of problems to be studied, and the design and interpretation of experiments, particularly in the life and social (the so-called softer) sciences. It is relatively straightforward to understand and convince others of the role that gender stereotypes play in the choice and formulation of research questions, maintaining elitist institutional structures, and methodological and explanatory preferences within the scientific establishment. This analysis, while successful in exposing biases in the setting of research agendas and the narratives that are constructed to make sense of the data and results, still does not address the question of what science *is*.

The most radical critique shakes the very foundations of science, questioning the assumptions of objectivity and rationalism that underlie the whole enterprise. These critics seek to reconceptualize objectivity as a *dialectical* process.[3] They distinguish the objective effort (an attempt to identify biases) from the objectivist illusion (ignoring the existence of self, and believing one's own perspective is objective and absolute). According to the modern Western tradition, scientific knowledge is achieved through rational, objective inquiry (attributes gendered as male), ensured by strict adherence to the rules of the scientific method. A postmodern relativist vision of reality denies the availability of a purely objective and direct experience of external events, and questions if indeed such an experience can be said to exist at all. "But," cries the working scientist, "science is not just a belief system! There is a Real World out there, and we can and do know something about it." How can one reconcile such differing perceptions of science, truth, and knowledge?

The problem is in insisting on a *single* view of reality. It is the privileging of the rational mode over, say, the empathetic mode of obtaining knowledge, and the power relations implied in the assumption of the superiority of reason (gendered as male) over feeling (gendered as female) that must be challenged. There is an underlying assumption in claiming that we can know the world through rational inquiry that is so "natural" that it goes unnoticed: that is, that the world we seek to know and understand is itself rational and orderly, and that human reason alone can discover principles and laws that govern the behavior of things. We forget that it takes a *leap of faith* to believe this. And we do not notice the role of language in perpetuating this belief, indeed masking the operation and very existence of an ideology at work.

> The particular conventions of language employed by a scientific community not only can permit a tacit incorporation of ideology into scientific theory but also can protect participants from recognition of such ideological influences and thus effectively secure the theoretical structure from substantive critical revision (Keller, 1992a, p. 142).

It is worth pondering and making explicit the underlying assumptions of the

[3]See, for instance, Harding (1991), who defines a "strong objectivity," and Haraway (1991), who discusses "socially situated knowledges."

world view implied when we say there are "laws" of nature that "govern" the behavior of inanimate objects in a gravitational field or animate biological organisms in an ecological system. Where did these laws come from?[4] Do the "rules" exist independently, apart from the reality they govern? Is this separation of nature into "the world" and "the laws" merely a cultural artifact (art + fact), a convenient artifice, artific-ial, one possible story about "the way things are" among many? Keller (1992a, p. 60) points out that most modern-day dichotomies were once seen as interlocking separations but grew into demarcations with rigid boundaries (God/Nature, Male/Female, Mind/Body, Nature/Culture, Animate/Inanimate, The World/ The Laws). From a separatist perspective, the laws of nature appear as eternal truths upon which the universe is built, the bedrock of reality. Alternatively, if one perceives nature and culture as an interacting complementarity, there is no one unique set of laws toward which scientific knowledge converges. Laws and theories cannot be separated from the circumstances in which they are formulated. It is the highly contested claim of many of the most radical critics that culture can define what scientific knowledge *is* (as well as *whose* it is). They ask how nature (gendered as female) and culture (gendered as male) *interact* in the production of scientific knowledge. It is the implications of this critique that I wish to examine.

As a poet, I am keenly aware of the power of metaphor to shape our understanding of the world around us. Each age tends to use its most impressive technology as a metaphor for the cosmos or God. Thus the Greeks spoke of the music of the spheres (God the Geometer)[5] and the Age of Reason presented us with the clockwork universe (God the Watchmaker), while today's computer technology gives us the image of the universe as an information-processing system (God the Programmer). In order to understand better the influence a prevailing metaphor can have on the acquisition and interpretation of "facts," and to make more plausible the interaction between nature and culture in the production of scientific knowledge, I will examine more closely the animate/inanimate duality.

One aspect of Aristotle's cosmology that seems quite alien to us is that, in spite of all he says about *mechanisms* to explain the motions of celestial objects, he believes that the heavenly bodies are *animate*. To paraphrase his view, "[e]verything in Nature has a purpose and is animated by a soul fitted to its purpose . . .," (Toulmin & Goodfield, 1961). Apparently the ancient Maya had a somewhat similar image of the cosmos. They believed that

> . . . the everyday human world was intimately related to the natural world and that these two worlds functioned in harmony. The universe was a distinct whole,

[4]In fact, the origin of the idea of a "law of nature" is intimately connected with the religion and politics of a particular era.

> Medieval Europe, subject on the one hand to the Christian doctrine of God's law manifested in nature, and on the other hand to a strongly enforced concept of civil law, provided a fertile milieu for the scientific idea of laws of nature to emerge (Davies, 1992, p. 76).

See also John Barrow (1991) for a fascinating study of the religious and cultural origins of the concept of physical laws.

[5]The discovery by Pythagoras (sixth century, B.C.) that numbers could describe music led to the belief that all phenomena could be described by relations between numbers. He and his followers associated geometric forms with certain numbers that they imbued with mystical significance. For example, a square was associated with the numbers 4, 9, and 16, and a triangle with the numbers 3, 6, and 10.

> with all parts intricately laced together, each aspect influencing the others. Nature and culture were one. . . . Their universe was animate—breathing, teeming, vibrant, and interactive (Aveni, 1993).

Anthony Aveni, a professor of both astronomy and anthropology, elaborates on the relationship between the Mayan world view and the kinds of knowledge they sought and glimpsed in the sky.

> The Maya were motivated not by a desire to express the workings of nature in terms of inert mathematical equations, but rather by the need to know how to mediate an alliance between the inherent power within the universe and their own direct physical well-being, between knowledge and human action. Today we might attribute a planet's change of color to an atmospheric effect, a shift in position to a dynamic effect, an alteration in brightness to a distance effect. The Maya would carefully watch the color, brightness, position, and movement of the planets because they believed all of these properties considered together were indices of the power of the gods, whom they hoped to influence through dialogue. Maya cosmic myths . . . may strike us as amusing stories, but behind the planetary, solar, and lunar alliances lie real people asking the kinds of questions we no longer ask of the sky: What is the origin of gender and sex? Where does fertility—or for that matter any power—come from? Where do we go when we die? How can we know the future? Answers to many of their inquiries were framed in the metaphor of visible planetary characteristics and changes: descent and resurrection (particularly for Mercury and Venus), dyadic and triadic bonds (sun, moon, and Venus) (Aveni, 1993).

This illustrates the important insights contributed by anthropologists (as well as sociologists, philosophers, historians, and feminists) in illuminating the connections between a particular culture (and the language in which it is embedded) and its representations and understanding of the world.[6]

MATHEMATICS AS THE LANGUAGE OF SCIENCE

Scientists like to explain things from "first principles," and some believe in the possibility of an "ultimate" level of explanation, perhaps even a "theory of everything."[7] They seek a logically coherent framework that can effectively predict a chain of causes and effects which account for and explain all observed phenomena. I can think of two ways that this project may fail. First, it may be that there are always certain starting assumptions (sometimes called "initial conditions") that must be built into any theory—God, logic, a set of laws—some foundation for existence from which all explanations can proceed. (Anyone who has ever been around [or simply

[6]The outlook of our modern Western cosmology is inherited not from the Greeks, but rather influenced by later Christian ideas. We draw a sharp distinction between animate and inanimate objects, sharper than either the Greeks or Mayas found natural. "Yet as the philosopher Whitehead has recently argued, there may be just as much virtue in thinking of the universe as a single grand organism as there is in thinking of it as an enormously complicated machine" (Toulmin & Goodfield, 1961).

[7]Note that not all scientists believe this is possible, nor is it only scientists who believe that science can explain everything.

remembers being] a two-year-old, knows the endless chain of why's—Why can't I stay up later? [Because you need your sleep.] Why do I need my sleep? [So your body can rest.] Why must my body rest?—which inevitably ends with some version of the fundamental statement, "Because I say so!") In mathematics, each subdiscipline has as its foundation a (small but necessary) list of undefined terms, concepts, or mathematical objects whose meaning and existence must be granted or "given" before the theory can be constructed. Perhaps any attempt at a comprehensive description of reality will confront the necessity of assuming some (arbitrary) starting conditions for the universe.

In any case, scientists must use language to represent what they learn about the world. And so there is a second, perhaps even more fundamental way in which the attempt to construct a theory of everything could fail: It may be that the very demands of the language in which science formulates its questions, a language of rationality and logic, impose restrictions on the sort of world we can know. Scientists value simplicity and analyzability. Thus legitimate questions are restricted to those capable of clear and unambiguous answers.

> The net effect is to exclude from the domain of theory those. . . phenomena that do not fit (or worse, threaten to undermine) the ideological commitments that are unspoken yet in language—built into science by the language we use in both constructing and applying our theories (Keller, 1992a, p. 143).

But what is the language of science? Mathematics. Why is this so? Well, one would like to assume that something is either true or not true, and this would certainly seem to be the case when one is proving mathematical theorems. Thus, early on, physical scientists, with the goal of achieving the absolute certainty accorded to logic and geometry, tried as much as possible to model their enterprise upon mathematics, as exemplified by Euclid. In the words of Ptolemy.[8]

> The systematic study of *mathematical* theory alone can yield its practitioners solid conclusions, free of doubt, since its demonstrations—whether arithmetical or geometrical—are carried out in a manner that admits of no dispute (Toulmin & Goodfield, 1961, p. 143).

And so the laws of nature were cast in mathematical form.[9]

The problem with the natural sciences is that they depend on observations, mediated by our senses or the instruments that extend them; and as any detective interviewing multiple witnesses to a single event soon realizes, the testimonies of our senses can be misleading. Furthermore, these observations must be classified and interpreted by human agents, and "[t]o identify the role of human agency in the making of an item of knowledge is to identify the possibility of it being otherwise" (Shapin & Schaffer, 1985, p. 23). Once we admit that we cannot trust our senses to provide absolute certainty about reality, we are inclined to agree with Ptolemy's claim that truth can be arrived at only through reasoned thinking. But we need some

[8]Claudius Ptolemy lived from about 85 to 165 A.D., and was a Greek astronomer in Alexandria.

[9]That this should be so effective a praxis is, in fact, a great mystery. See, for example, Eugene Wigner (1960).

common grounds for belief. In mathematics we formalize reason, hoping to assure certainty by adhering to unassailable rules of logical deduction. Thus in the quest for the purest, most "disinterested" language in which to describe scientific discoveries, it would seem that the mathematics is the holy grail.

Even dyed-in-the-wool feminist scholars seem willing to exempt mathematics (and the "hardest" of the sciences, physics) from the basic tenet of feminist scholarship, that no knowledge is value free.

> Physics and mathematics may be possible exceptions to this statement. In these fields, the constraints on both the questions that can be asked and on the possible results are so great that they appear to unfold in a deterministic way, unaffected of social factors (Lowe, 1993, p. 11).

Katherine Hayles, an interdisciplinary scholar in science and literature, has focused critical attention on these views. She notes that "[c]onvincing cases have been made for [cultural and gender encoding within] many of the biological sciences," but "[w]hen the theories are primarily mathematical rather than behavioral, the cases become more difficult to make. . . . For these reasons (among others), mathematical theories about nonliving physical systems remain largely an untouched preserve of masculinist science" (Hayles, 1992, p. 16).

If Keller's claim (1992a, p. 6) is true, that language mediates the course of science, that it guides (as well as reflects) the development of scientific models (and methods), how could cultural encoding possibly enter mathematics? In a provocative and ground-breaking article, Hayles demonstrates a connection between gender and certain cultural presuppositions made by the Greeks and encoded into mathematics early on, with far-reaching consequences.

> They can be stated as a pair of hierarchical dichotomies in which the first term is privileged at the expense of the second: continuity versus rupture, and conservation versus dissipation. The values implicit in these dichotomies mutated and took various forms . . . (Hayles, 1992, p. 22).

She makes strong arguments for "the power of the initial assumptions to influence the direction of subsequent theories," and challenges the state of "amnesia that made mathematical techniques seem natural solutions to obvious problems" (Hayles, 1992). On first reading, mathematicians often find Hayles's thesis challenging (at best), and even outrageous. Because Hayles herself is not trained as a mathematician, "insiders" find it easy to dismiss her critique as "uninformed." However, even when I may disagree on some of the technical details in her arguments, I take her challenges seriously and encourage others to examine them closely. Hayles is a pioneer and one of the few to attempt the difficult and necessary task of critiquing mathematics as a gendered discourse.

Clearly, much work remains to be done in uncovering the cultural assumptions encoded in and transmitted through mathematical language, and the ways in which this language mediates the course of science. One further point worth making is that feminists have also been arguing for at least two decades that "culture is classification" (Taylor, Kramarae, & Ebben, 1993). (And, as Marcia Ascher [1991, p. 8] points out, "how people categorize things is one of the major differences between one culture and another.") And mathematics is certainly, among other things, a system of classification. Thus choices are made in creating categories to include some things and exclude others (which then become "nonthings"), and I suggest that we seek out and study these choices to begin to uncover the imprint of culture within mathematics.

But here I want to address two related and perhaps somewhat easier questions. First I ask: What cultural values are encoded in the language of mathematics *education*? My second question arises from the observation made earlier that mathematics is perceived as totally depersonalized (i.e., objective, abstract, and rational). Paul Ernest, a mathematician in Great Britain, admits that "[t]he popular image of mathematics is that it is difficult, cold, abstract, ultra-rational, important and largely masculine" (Ernest, 1993, p. 53). Although most practicing mathematicians have a very different (insider's) view of their subject, it is this cold and heartless version that is promulgated by most textbooks and by our educational system in general. What is the relationship between this view of mathematics and the way it is taught? And most crucial for readers of this journal, I ask what impact might a shift from this view of mathematics as absolute and rigorous (as in rigor mortis?) have on pedagogy and accessibility to mathematics for women and minorities?

MATHEMATICS AND CULTURE

It is commonly assumed that the language of mathematics is culture fair because it is culture free. However, recent articles and books (see Ascher, 1991, and references therein) support the view that "culture and language influence mathematics itself and that different societies have different versions of mathematics" (Schurle, 1993, p. 12). Indeed most mathematics, as it is taught, is not context free. Word problems are notorious for instances of sexist, racist, and other, more subtle cultural biases. As a blatant example, I quote the following problem from a teacher's handbook printed in Nazi Germany:

> Problem 200. According to statements of the Draeger Works in Luebeck in the gassing of a city only 50 per cent of the evaporated poison gas is effective. The atmosphere must be poisoned up to a height of 20 metres in a concentration of 45 mg/m^3. How much phosgene is needed to poison a city of 50,000 inhabitants who live in an area of four square kilometers? (Cohen, 1988, p. 244)

But there are value systems hidden in even the most innocuous problems. Quantification, comparison, and measurement are in themselves cultural activities, whose assumed values are not universally shared. Consider the following example from research conducted by Kathryn Crawford with Australian Aboriginal children:

> . . . students from Pitjantjatjara communities live in a culture that has evolved to meet the needs of subsistence in a harsh and relatively stable environment. Property rights are not clearly defined. Material possessions are not the key determinant of status in these communities. Aboriginal people view their physical environment as an extension of themselves rather than as something to be con-

quered. Traditional cultural activities typically revolve around small numbers of specifically named natural objects. Quantity is not usually considered and this low priority is reflected in a vernacular with few words to denote number. So they ask:
"Why do you always own things?"
"Why do you always compare?"
"Why do you want to know how much?"
"Why do you measure?" (Crawford, 1989, p. 23)

Spatial conceptualization is culturally specific as well. Four faculty at the University of Alaska, with expertise in linguistics, mathematics, and education, studied language and its impact on mathematics learning among Native American and American Indian students in the interior of Alaska.

> Spatial conceptualization is an integral part of culture and world view and is expressed in the linguistic system. The manner in which a language encodes spatial relationships may affect the way a speaker acquires and understands concepts and principles of mathematics (Bradley, Basham, Axelrod, & Jones, 1990, p. 8).

The authors observed that "the Western world developed the notion of fractions and decimals out of a need to divide or segment a whole. The Navajo world view consistently appears not to segment the whole of an entity" (Bradley et al., 1990, p. 8). Among their conclusions are suggestions that "non-Euclidian geometry, motion theories, and/or fundamentals of calculus may be naturally compatible with Navajo spatial knowledge. Math classes should begin with these notions and continue deemphasizing the segmentation of notions into smaller parts" (Bradley et al., 1990, p. 8). In other words, for some students, it might be appropriate to teach calculus as elementary mathematics, and fractions in college!

Value conflicts occur even within our own culture. Martha Smith, a mathematician at the University of Texas at Austin, relates some anecdotes that helped her become aware of her "mathematically and scientifically related values and how they are often not shared by people outside these fields" (Smith, 1993, p. 1). For instance, one student "asked in his journal why we insist on proving things in mathematics. 'Why can't we just trust each other?' he asked. I had never realized until then that my value on proof might appear to conflict with a value on trust" (Smith, 1993, p. 1).

It has been argued by Chinese scholars that the Confucian virtues of loyalty, constancy, and gratitude precluded the development of the sort of questioning science that European and American culture has.[10] The differences in the development of science in the East and West have also been traced to theological differences in the two cultures. John Barrow claims that the Chinese lacked "the concept of a divine being who acted to legislate what went on in the natural world, whose decrees formed inviolate 'laws' of Nature, and who underwrote scientific enterprise" (Barrow, 1991, p. 35).

No doubt other factors are also responsible for the differential development of

[10]See "Isaac Newton Was Not Chinese," chap. 5 of Hsu (1992); and Joseph Needham (1969).

science in the two cultures, but the point needs to be made that the incompatibility of cultural values can also be a barrier in mathematics and science education. Comparing the Western "mathematico-technological" and the Islamic-Arab cultures, Murad Jurdak notes that the mathematical culture assumes that "values can be questioned and statements can be subjected to empirical test. In any religious culture, and certainly in the Islamo-Arabic culture, this assumption is not tenable because in such cultures there are some values which should not be questioned" (Jurdak, 1989, pp. 12–13).

A related issue that affects non-English-speaking and English-as-a-second-language (ESL) students is that since language is a cultural carrier, the language in which mathematics is taught affects the understanding and production of mathematical knowledge, as well as the ability to use it to cope with reality. There is even some evidence that formal deductive reasoning is language (and culture) specific (Jurdak, 1977, pp. 225–238). As teachers who value difference, we must give special attention to the conceptual understanding our students bring into the classroom, and build on what they know. We must not assume that (new) concepts are readily understood, simply because the words spoken by us are repeated back by the students. Further studies need to be done to compare the success in different types of problem solving among English-only speakers and ESL and non-English speakers, and the results of these investigations must be made available to teachers.

MATHEMATICS AND VALUES

At this point it occurs to me to ask why one should learn mathematics, or, alternatively, why we should teach mathematics? Perusing the literature, I have found five goals proposed in answer to this question, and remarkable agreement about the goals among mathematicians and mathematics educators alike. First, we must prepare citizens to be users of mathematics (a societal goal). Second, it is important to provide examples of the contributions of mathematics to culture at large (a cultural goal). Third, the mental discipline that the study of mathematics provides should be available as an educative force in everyone's life (a personal goal). Fourth, we must train the next generation of mathematicians and scientists (a technical goal). And last, there is the beauty of mathematics for its own sake (an esthetic goal).

In light of the discussion above, I would add that we have a responsibility to acknowledge that we are also teaching values when we teach mathematics. For instance, in presenting mathematics as part of culture, it is necessary to specify whose culture and whose mathematics. When we invite our students to appreciate the elegance of a proof, we should keep in mind that such esthetic judgments also vary across cultures and genders. I am a mathematical physicist who has been well educated and fairly successful in the traditional school of "pure and unsullied" mathematics. It took some time and steady encouragement from patient colleagues in women's studies departments for me to accept that gender and culture are indeed encoded in even mathematics and physics. I offer here some specific suggestions as to *how* one might begin to realize what values one is transmitting and teach the next generation to assimilate this radical perspective as plain common sense.

It is essential that we encourage our students to look for hidden assumptions and make them explicit. Most of them will have absorbed the underlying biases of our culture about objectivity, truth, the scientific enterprise, and the nature of mathematics. We can start by helping them make their own ideas (however inchoate or ill formed) explicit and learn to question them. We must teach them to *expect* a standpoint in any scientific statement and include it as part of their observations, as well as to look for it in others. In mathematics, we should include more open-ended problems that require one to make assumptions in order to solve them. In standard word problems, we can append questions that ask students to list what assumptions have been made. Finally, we need to emphasize that there are many valid alternative approaches to the same problem, and even more important, there is often more than one single correct solution. In fact, why must problems always be *solved* and made to give up their secrets? What if we also gave open-ended problems that invite students to imagine more of the story, in order to understand the situation? Philip Davis makes the point very well:

> [M]athematics is a kind of language, and this language creates a milieu for thought that is hard to escape . . .. The subconscious modalities of mathematics and of its applications must be made clear, must be taught, watched, argued. Since we are all consumers of mathematics, and since we are both beneficiaries as well as victims, all mathematizations ought to be opened up in the public forums where ideas are debated. These debates ought to begin in the secondary school[11] (Davis, 1988, p. 144).

It is also important that we do not present mathematics as a fixed body of knowledge—complete, certain, and absolute. In fact, scientists and mathematicians alike have a very different image of mathematics, and to some extent the public does too, thanks to popularized accounts of the work of Kurt Godel, Werner Heisenberg, and Albert Einstein (among others). "In the present century, absolutism has succumbed to Einsteinian relativity and Godel dislodged completeness. Proofs are now seen to be demonstrations which take place within fixed systems of propositions and are, consequently, relative to those systems" (Burton, 1989, p. 16). Morris Kline, a well-known historian of mathematics, has written quite poetically: "Mathematics is not a structure of steel resting on the bedrock of objective reality but gossamer floating with other speculations in the partially explored regions of the human mind" (Kline, 1972, p. 481).

We owe it to our students to present this other image of mathematics, and to provide them with experiences of the personal, intuitive, creative (and culturally dependent) process of *doing* mathematics, rather than merely reading the codified and axiomatic presentation that appears in most textbooks. It is not enough that women and minorities be granted entry into the heretofore exclusive club of mathematicians (and scientists and engineers) if membership requires that one subscribe to the same rules and speak the same language. Radical feminist critics insist that forcing everyone to fit the same mold is a bad idea. Rather, they claim, the solution is to expand the definition of scientist to incorporate others, and that science will in fact profit by doing so. We must, as Leone Burton so aptly puts it, "broaden not only physical access to mathematics, but more crucially psychological access" (Burton, 1989, p.

[11]I would add, perhaps even earlier.

17). A view of mathematics as based on incompleteness, conjecture, and relativity, and a shift of emphasis from final product to process, will appeal to the minds and hearts of many previously "math-anxious" students, and invigorate our often stale classrooms with a gust of fresh air.

Finally, just as Barbara McClintock developed a "feeling for the organism" by taking the time to look and having the patience to "hear what the material has to say to you" (Keller, 1983, pp. 198–199), we need to look at and listen to our *students*. As we learn from standpoint theory, outsiders can often see alternatives to the beliefs and practices of a culture that remain invisible to insiders. And there are risks involved in posing awkward questions about "what everybody knows." Thus if one is already a member of the club and tries to lift the veil from some taken-for-granted assumptions, one may be labeled a troublemaker (at best), or, if one persists, even expelled. But our students can effectively critique the content and methodologies of science with innocence and impunity, if we permit them—before they have been inculcated with the dominant paradigm. It is like the parable of the Emperor's new clothes: They can often see the naked truth underneath the layers of assumptions that most of us have been persuaded are the objective facts. (Recall Martha Smith's student, who asked "Why can't we just trust each other?")

Here is an example that illustrates the kind of teaching I am advocating. Anneli Lax, a mathematician and educator, presented the following word problem from the standardized New York Regents Competency Test to a group of students in a high school remedial English class. They were asked to evaluate the problem, which many of them had missed on the exam, from a linguistic point of view, rewrite it however they liked, and only then try to solve it. The problem read:

> Shirts cost $7, pants cost $12, and jackets cost $25. Fred has $100 to buy 1 jacket, 2 pairs of pants, and some shirts. What is the greatest number of shirts he can buy? (Duncan, 1989, p. 235)

She reports that "[a]s the students were working out their revisions of the clothing problem, a girl in the back of the room raised her hand rather urgently. 'This doesn't have to do with math,' she said. 'But tell me what kind of a jacket can he buy for twenty-five dollars?' " (Duncan, 1989, p. 237). We smile, but the question is important from the student's point of view. The problem has taken on a kind of realism that was missing before she tried to deal with it on her own terms. Indeed, by involving herself in the story, this student has revealed a real weakness of the problem: It is not very convincing. This is a weakness shared by most word problems involving a silly story constructed around a preconceived solution. It is difficult to take such problems seriously, yet they are presented as real-world applications of mathematics. When students are invited to critique a problem and rewrite it, they may not only come to understand it in their own terms, but can be empowered as they become authors and pose their *own* questions, questions whose answers would be meaningful to them.

We must look at our students as well as listen to them, where, as Lax puts it, "[b]y 'look at' I mean finding out who our students are, how they learn, and why" (Lax, 1989, p. 264). Then we must ask ourselves what kinds of training and habits of thought do we want to foster and nourish in them? Taking a cue from the critiques outlined above, these should include habits of clear thinking, insistence on critical self-reflection (on process as well as product), and the relentless pursuit and questioning of hidden assumptions.

CONCLUSION

Many feminists who have turned their attention toward science teaching have concluded, along with Irene Lanzinger, that "the forming of a different kind of science classroom requires a reconceptualization of the nature of scientific thought as well as a redefining of gender roles" (Lanzinger, 1993, p. 98). I have tried to indicate the ways in which various feminist critiques of science can inform our efforts to reform and re-vision both the structure and content of mathematics and science education. Most important, we must replace the Eurocentric masculinist caricature of science and scientists as

> . . . the strict separation of subject and object, the priority of the objective over the subjective, the depersonalized and seemingly disembodied discourse, the elevation of the abstract over the concrete, the asocial self-identity of the scientist, the total commitment to the calling, the fundamental incompatibility between scientific career and family life, and, of course, the alienation from and dread of women . . . (Noble, 1992, p. 281).

In its stead, we can offer a vision of science closer to that articulated by Stephen Jay Gould:

> Science . . . is a socially embedded activity. . . . Much of its change through time does not record a closer approach to absolute truth, but the alteration of cultural contexts that influence it so strongly. Facts are not pure and unsullied bits of information; culture also influences what we see and how we see it.[12] Theories, moreover, are not inexorable inductions from facts. The most creative theories are often imaginative visions imposed upon facts; the source of imagination is also strongly cultural (Gould, 1981, pp. 21–22).

It is essential that we start to view science and all knowledge claims through a multicultural prism.

> Otherwise, science will continue to produce skewed knowledge that . . . lessens the opportunities to reduce the distortion of scientific accounts that reflect the disproportionate influences of the dominant cultural group in science—white males (Frankel, 1993, p. 9).

One of the questions most frequently asked by feminist critics of science is "Is there a feminist science, and if so, what does it look like?" As we continue to seek the answers, we should keep in mind that we have much to learn from our students and be sure to enlist them in this project. After all, the dissemination and re-creation

[12]This reminds me of an aphorism from the Talmud: "We do not see things as they are—We see things as we are."

of knowledge is largely affected through the educational system. And I believe it is in our roles as teachers and mentors that we can have the greatest impact on the perspectives of the next generation. As one woman scientist put it:

> I believe that part of my role as a good scientist is training good students, because they are going to be telling my story long after I am gone. That's part of science.. . . That's not peripheral: Learning from others how best to get students excited about science, to teach and to communicate, is at the heart of science (Niewoehner, 1993, p. 14).

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