Doing Science

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Science as Practice

A new discipline called *science studies* entered the academic mainstream in the late 20th century. Science studies integrates elements from anthropology, history, philosophy, and sociology and aims, among other things, to understand science as an activity with social and political goals comparable to, say, religion or art. Admitting the human associations of science challenges the privileged status of scientific inquiry and the claim that science provides an objective description of reality. Where science studies intersects the postmodernist movement, scientific facts have been critiqued as culture-dependent, normative doctrines. If there is truth to be learned, then science provides only one of many possible means of access; truth-for-the-individual may be the most for which one can hope (see Pickering, 1992 for an overview of science studies.)

Not surprisingly, the postmodernist challenge to science has evoked a negative response from many within the scientific community who view such thinking as higher superstition and a flight from reason (Gross & Levitt, 1997). The polarized and sometimes amusing debate between the "anti" and "pro" science camps was named *science wars* (McMillen, 1996). Aside from the political rhetoric, however, there has been little attempt by experimental scientists to meet the postmodern critique on its own grounds through serious self-reflection on the everyday practice of science.

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As Sir Peter Medawar wrote: "(T)here is no such thing as a scientific mind; there is no such thing as the scientific method; [and] the idea of naïve or innocent observation is philosophers' make-believe." (Medawar, 1982, p.116). Indeed, it is only by describing the everyday practice of science that one can understand the scientific attitude towards experience and can learn what features distinguish science from other activities of everyday life (Grinnell, 1992).

The practice of baseball umpires helps define the issues. There are three types of umpires. The first type says: "I call balls and strikes as they are"; the second says: "I call them as I see them"; and the third says: "What I call them is what they become." The difference between these umpires is not the situation in which they find themselves but the attitudes that they bring to their project. As a result of their distinct attitudes, they practice umpiring differently. The first exemplifies truth; the second, perspective; and the third, power.

Philosophers might identify these different examples of the umpires as realist, contextualist, and social constructivist. The realist assumes a direct link observation and reality. The contextualist suggests that how one looks at things will determine what one sees. Finally, the social constructivist typifies the postmodern view that emphasizes a link between reality and power. (Tradition has it that the third umpire says "They ain't nothing until I call them." This version of the umpire reveals the human person as the location of knowledge but misses the importance of the umpire's power in determining its content.)

To see which of the umpires most accurately reflects what scientists do, consider the two central features of scientific practice: discovery and credibility. Through discovery an investigator learns new things about the world; through credibility the investigator tries to convince peers that the new findings are correct.

Discovery

In everyday practice, discovery begins in community. The researcher initiates his or her work in the midst of prevailing beliefs, using these beliefs as a starting context for action. At the same time, the goals of discovery assume that previous knowledge is incomplete or wrong. To be explicit, what I have in mind is discovery at the edge of knowledge, a place where no one has been before. At the edge, one encounters an ambiguous world demanding risky choices. What should be done first? What is the difference between data and noise? How does one recognize something without knowing in advance how it looks? And when experimental results do not meet one's expectations, is it because one's idea was wrong or because the methods used to test the idea were wrong? Hence the adage "don't give up a good idea just because the data don't fit."

This description of research contrasts sharply with the common image of science in which one proceeds from hypothesis to discovery in a linear fashion guided by method and logic. Of course, some science does

conform to the linear model such as a clinical drug trial approved by the Food and Drug Administration; researchers agree in advance on what will count for data, on how many patients will be necessary for the data to be meaningful, and on how a positive or negative outcome will be decided.

At the edge of knowledge, however, method and logic alone are insufficient. Intuition and creative insight become just as important. One responds to the situation out of an entire autobiographical context, not just scientific training. This is a key point, albeit with different nuances, of Fleck's *thought styles* (Fleck, 1979), Polanyi's *tacit dimension* (Polanyi, 1958), Kuhn's *paradigms* (Kuhn, 1962), and Holton's *thematic presuppositions* (Holton, 1973). Moreover, because experimental conditions cannot be controlled completely, unexpected and important results sometimes occur. Max Delbrück called this aspect of research the *principle of limited sloppiness* (Benzer, 1992). As a result, investigators frequently take unplanned journeys to unexpected places, places where what one has discovered only becomes evident retrospectively, a process that Charles Peirce called *abduction* (Delaney, 1993). Discovery is a real trip.

Credibility

Discovery is the first movement of science—at most protoscience. To become science, the researcher returns to the community, and the second movement begins. Now the goal is *credibility* – convincing peers that the new findings are correct. The work will be presented to the community in highly stylized research publications. Ambiguity and error disappear and the linear scientific method makes its appearance, now as the plot of the work. The publication becomes the discovery.

Medawar called the inductive framework of scientific papers a travesty of the nature of scientific thought (Medawar, 1963). Because the linear model is the primary way scientists communicate, the public has come to believe that science works in a linear fashion, a misunderstanding of the nature of science and a source of disappointment when the results of research do not meet expectations. When high school science teachers spend a summer working in my laboratory, they are amazed at how frequently experiments fail to work out as planned.

Professional scientists usually respond to new findings with a profound skepticism that goes beyond the specifics of the research findings themselves. When first confronted with new ideas, gatekeepers judge the work according to how well it fits prevailing beliefs. Therefore, the more novel and unexpected a discovery, the more likely that it will be rejected by the community precisely because it contradicts current understanding. Prospectively, N-rays, polywater, cold fusion, transposable genetic elements, ribozymes, and prions all looked like long shots.

Faced with rejection, the investigator experiences a deep sense of insecurity. Error often accompanies ambiguity and, in science, being wrong is just a short step away from being ignored—the very worst fate for a re-

searcher. On the other hand, another adage suggests, "don't give up a good idea just because the community doesn't understand." To succeed in science, researchers learn that they have to confront rejection by becoming advocates for their new findings and the implications of the work. Indeed, at every step of the process, investigators will continually shape and reshape their work to anticipate and respond to the criticisms that they might expect to receive from the community (Ziman, 1968).

Only when others validate the observations —often modifying them at the same time—will the new work become more widely accepted. Over time, individual subjectivity is replaced by intersubjective verification (Grinnell, 1992). Objectivity is the goal, not a condition, for doing science. Transposable genetic elements, ribozymes, and prions made it; N-rays, polywater, and cold fusion did not. Credibility happens to discovery. It becomes true, is made true by events—what William James described as pragmatism's conception of truth (James, 1975).

The Contextual Ledge

Returning to the baseball umpire analogy, it should now be clear that in everyday practice of science, individual researchers call things as they see them. Calling things as they are is reserved for the community, but even this calling is tentative. That is, with discovery oriented towards completion and correction, the scientific attitude defers truth to the future in favor of credibility in the present. Unchangeable truth cannot be part of science. The realism of science remains incipient and tightly linked to individual practice through technology. Last year's discoveries become this year's instruments of discovery. Moreover, the realistic view that emerges out of community occurs not through power, as supposed by postmodernists, but as the authentic example of Annette Baier's *commons of the mind*. "We reason together, challenge, revise, and complete each other's reasoning and each other's conceptions of reason" (Baier, 1997, p. 21). Everyday practice of science is neither realist nor social constructivist, but rather balanced on a contextual ledge in between.

As an aside, since scientific discovery remains open to new possibilities, future understanding of the world cannot be accorded certainty. Tension develops around this sense of uncertainty with those doing science typically optimistic about the future, and those watching from the sidelines often concerned about unanticipated consequences. History teaches us that we should not minimize such unanticipated consequences that can have a significant impact on society, as exemplified for instance, by the negative impacts of technology on the environment. The increasing power of science requires an increasing commitment to social responsibility.

Other Ways to Practice the World

What about the relationship between science and other social and po-

litical activities of everyday life. Yes, everyday practice of science is a most social and political activity (Hull, 1988). Does that mean that the boundaries between science and other activities have been blurred as suggested by the postmodernists?

Just as different attitudes result in different practices for baseball umpires, the scientific attitude is only one way to practice exploration of the world, and not everything that one finds during exploration can be accommodated by science (Grinnell, 1992). Besides mapping new territory, exploration offers individuals opportunities to learn how the world feels and what it appears to mean. These latter experiences resist intersubjective verification. They depend too much on unique features of existential encounter that are more difficult to incorporate into the commons of the mind. The credibility process in science attempts to extract from discovery just those aspects of the world that can be held in common, those aspects that come with the index: anyone, anywhere, anytime. From the point of view of the community, credible science is done by anonymous (albeit passionately self-interested) researchers. In contrast, unique existential encounter is central to religion and art.

Whereas the scientific attitude gives up the possibility of unchangeable truth for credibility, the religious attitude takes the opposite approach and gives up the possibility of scientific credibility for eternal truth. For religion, salvation may be in the future but the point of origin of truth resides in the past, for example, through revelation, prophecy, and enlightenment. Christianity cannot ignore Christ, or Judaism ignore Torah, or Buddhism ignore the teachings of Buddha, in the way that science can ignore the discoveries of Aristotle and other great figures in the history of science. Religious discovery is a different kind of re-search; religion evolves by rediscovery of the past in light of the present. Religious credibility plays an existential function through which one affirms allegiance to a particular source of truth and gains membership in the corresponding community by doing so. In those rare moments when religious experience reaches its greatest depths through an individual's spiritual encounter with the world, knowledge becomes absolute as personal boundaries disappear in ineffable union (James, 1961). Ineffable union, however, is a place where intersubjectivity cannot go.

In the artistic attitude, by contrast, the individual seeks neither science's version of credibility nor religion's version of truth. Instead, the individual offers through art his or her momentary vision of the world (Fineberg, 1995). The artist often tries to go where nobody has gone before but what she or he discovers there is an "inner truth." Intersubjective verification of the work through its revelatory impact on others or through critical acclaim is separate from the truth of the inner vision itself. Moreover, as the reflection of a particular historical moment, each artistic work has the potential to stand on its own, independent of past or future works.

In summary, a single individual can practice the world as science, religion, or art depending upon the attitude that he or she brings to the project, and each of these attitudes gives rise to a unique domain of experience.

For some, these different attitudes are viewed as exclusive, that is, there is only one truth. Others argue that different attitudes are relevant for different aspects of experience. A third approach attempts to understand these domains as convergent and argues that a signal truth can integrate them all (Barbour, 1997). Neils Bohr's principle of complementarity (Bohr, 1987), however, offers the most compelling account of the relationship between these practices. Rather than attempt in one fashion or another to isolate, choose, or erase the differences, complementarity accepts the different attitudes and domains and requires them all *as they are*, creating a state of holistic, dynamic tension.

If postmodernists think that the boundaries between science and these other practices have been blurred, it is because they are focused on power as the determining feature of social and political activities as exemplified by the third type of baseball umpire who says what he or she calls them is what they become. Eventually, however, technology will come to baseball. Instant replay will allow anyone who is interested to see in slow motion and from multiple angles the position of the baseball as it crosses the plate and to judge for herself the accuracy of the call. After that, all umpires will be calling them as they see them, and those who call them wrong too often will likely be looking for new work.

Education

Beyond the issue of boundaries, there is the question of the postmodern critique of scientific facts: are they reality or normative doctrine? From the point of view of everyday practice, scientific facts are neither reality nor normative doctrine. Instead, they have become credible through intersubjectivity and powerful through development into technology. Unfortunately, the origin of scientific facts in everyday practice is usually obscured by modern science education. We teach our students only the linear model of discovery, in which ambiguity disappears, along with intuition and creative insight, and in which research becomes equivalent to critical thinking, logic, and problem solving. We leave students with the expectation that the hypothesis must come first, never last. You lose points in science fairs by placing the hypothesis in the lower right-hand corner instead of the upper left.

Critical thinking, logic, and problem solving certainly are important for managing life in a complex world but what we give our students is an alienated view of science, with sterility and anonymity replacing adventure and excitement. Sir Peter Medawar believed that the scientific paper should include the *flights of imagination* that led investigators to their discoveries (Medawar, 1963). The same can be said of science education. An understanding of the everyday practice of science is just as important for science literacy as the mastery of scientific facts. We need to teach both.

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SCIENCE WARS

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