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The Practice of Science at the Edge of Knowledge

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In recent decades, postmodernists and sociologists of science have argued that science is just one of many human activities with social and political aims -- comparable to, say, religion or art. They have questioned the objectivity of science, and whether it has any unique ability to find the truth. Not surprisingly, such claims have evoked a negative response from proponents of the traditional view of science; the debate between the two sides has been called the science wars. In the debate, scientists have made few attempts to meet the postmodern critique on its own grounds, through serious reflection on the everyday practice of science. Yet that is the only way to understand the nature of science and the features that distinguish science from other activities.

The behavior 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."

What distinguishes the types of umpires is not the situations in which they find themselves, but the attitudes that they bring to their work. As a result of those attitudes, they practice umpiring differently. The first type claims truth; the second, perspective; and the third, power.

Philosophers might identify the umpires' different claims as realism, contextualism, and social constructivism. Realism corresponds to the traditional view of science that links reality directly to observation. Contextualism suggests that how one looks at things will determine, to some extent, what one sees. Social constructivism corresponds to the postmodern view, linking reality with power. To determine which view most accurately reflects what scientists do, let us consider the two central features of scientific practice: discovery and credibility.

Discovery begins within the context of prevailing scientific beliefs. At the same time, the goals of discovery assume that previous knowledge is incomplete or wrong. Discovery takes place at the edge of knowledge, an ambiguous place where no one has been before. At the edge, one must make risky choices and address hard questions: What should be done first? How does one recognize data, especially when one is searching for something never seen before? And when experimental results do not meet one's expectations, is it because one's original idea was wrong, or because the methods used to test the idea were wrong? Scientists have a saying: Don't give up a good idea just because the data don't fit.

That description of research contrasts sharply with the traditional idea that in science, one proceeds from hypothesis to discovery in a linear fashion, guided by method and logic. Of course, some science does conform to that traditional model. An example would be a clinical drug trial approved by the Food and Drug Administration, in which researchers agree in advance on what will count as data, how many patients will be necessary for the data to be meaningful, and what will constitute a positive or negative outcome.

At the edge of knowledge, however, method and logic are insufficient. Intuition and creative insight become just as important. Moreover, researchers frequently find themselves taking unplanned journeys to unexpected places, realizing only later just what it is that they have discovered. Because experimental conditions cannot be controlled completely, unexpected and important results sometimes occur, an aspect of research that Max Delbruck often called the principle of limited sloppiness.

Discovery begins as protoscience. For it to become science, the researcher must focus next on credibility -- convincing his or her peers that the new findings are correct. The researcher presents the work in highly stylized research publications. In those scientific short stories, which use the linear scientific method as plot, ambiguity and error disappear. The publication becomes the discovery. Because the linear model is the primary way in which 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. When first confronted with new work, gatekeepers judge it according to how well it fits with prevailing beliefs. Therefore, the more novel and unexpected a discovery, the more likely that other scientists will reject it -- precisely because it contradicts current understanding. When they were initially proposed, ribozymes, prions, and cold fusion all looked like long shots.

Faced with rejection, the researcher experiences a deep sense of insecurity. Error often accompanies the ambiguity of discovery, and in science, being wrong is almost as bad as being ignored. On the other hand, as another saying puts it: Don't give up a good idea just because others don't understand it. To succeed in science, researchers have to confront rejection by becoming advocates for their new findings.

Indeed, at every step of the process, researchers continually reshape their work to anticipate and respond to the criticisms that they expect to receive from their peers. Only when others validate the observations -- often modifying them at the same time -- will the new work become widely accepted. Objectivity is embedded in the group, not the individual. Ribozymes and prions made it; cold fusion did not.

Returning to the analogy of the baseball umpire, it should now be clear that in the everyday practice of science, individual researchers call things as they see them. Calling things as they are is reserved for scientists acting collectively, and even those calls are tentative. That is, scientists are satisfied with credibility in the present, deferring truth to the future. In fact, unchangeable truth cannot be part of science. Last year's discoveries become this year's instruments of discovery. Moreover, the emergence of truth occurs not through power, as postmodernists assume, but as what the philosopher Annette Baier refers to as the commons of the mind, in her book of that name: "We reason together, challenge, revise, and complete each other's reasoning and each other's conceptions of reason."

The everyday practice of science is neither realism nor social constructivism, but rather balances on a contextual ledge in between.

As an aside, science obviously involves uncertainty, as it remains open to new possibilities. That uncertainty typically produces optimism in scientists about the future, while those watching from the sidelines often are concerned about unanticipated consequences of discoveries. History teaches us that we should not minimize such unanticipated consequences, which can have a significant impact on society. An example would be the negative effects of technology on the environment. The increasing

power of science requires an increasing commitment to social responsibility.

Postmodernists are right that the everyday practice of science is a social and political activity. But that does not mean that science is indistinguishable from other social and political activities. 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.

Besides mapping new territory, exploration offers us opportunities to learn how the world feels, and what it appears to mean. But those latter experiences typically depend too much on the individual's unique background and beliefs for others to verify them. Establishing credibility in science means trying to extract from experience just those aspects of the world that are common to other people, in other places and at other times. In an ideal world, credible science would be done by anonymous researchers.

In contrast, the individual is central in religion and art. In the religious attitude, knowledge of the world becomes absolute as the content of an individual's experience disappears in pure encounter -- ineffable spiritual union. Rather than looking for truth in the future, religion is oriented toward the past, where the sources of unchanging truth typically are located: revelation, prophecy, enlightenment. As a result, the aim is rediscovery rather than discovery. In corresponding fashion, credibility functions as a means of reaffirming the past and as a criterion for membership.

In the artistic attitude, on the other hand, knowledge of the world becomes personal through an individual's momentary vision. As in science, the artist tries to go where nobody has gone before, but what the artist discovers is an inner truth. That truth may have revelatory impact on others, and the quality of the artistic expression will always be open to critical evaluation, but those features are separate from the truth of the vision. 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 short, we can practice the world as science, religion, or art, depending upon the attitude that we bring to the project. If postmodernists think that the boundaries between science and those other practices have been blurred, it is because they focus on power, or the view of the third type of baseball umpire: "What I call them is what they become."

Eventually, however, technology will come to baseball. Instant replays 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 the accuracy of the call. Then all umpires will be calling them as they see them, and those who call them wrong too often will be looking for new work.

Some postmodernists also critique scientific facts as mere social constructs, instead of reality. From the point of view of everyday practice, scientific facts are neither. Instead, they have become credible through verification by others, 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.

Critical thinking, logic, and problem solving are certainly 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 used to criticize the traditional scientific paper because it omitted the "flights of imagination" that led researchers to their discoveries. 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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