Inside Science
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It has become fashionable in recent times for scholars from the social sciences and other disciplines to visit the strange continent of Science and send back reports of their observations of the behavior and rituals of the natives. The resulting dialogue has not always been entirely amicable, and has in fact sometimes been referred to as "The Science Wars." We thought it might be useful in this context to send forth a description of the social organization of science as seen from the inside. We can hardly hope to bring the science wars to an end just when they are becoming amusing, but perhaps we can show that the way scientists run their business is in some ways remarkably similar to, and to be sure, in some ways different from other academic disciplines.

"In the cathedral of science," a famous scientist once said, "every brick is equally important." The remark evokes a vivid metaphor, of swarms of scientific workers erecting a grand monument to the scientific faith. The speaker was Max Delbrück, Nobel Prize winner, often called the father of molecular biology. The occasion was an idyllic Sunday afternoon in Pasadena, in Delbrück's backyard, where a group of players (including one of the authors) was enjoying an after-tennis drink. The remark captures with some precision the scientists' ambivalent view of their craft. Delbrück never for an instant thought the bricks he laid were no better than anyone else's. If anything, he regarded himself as the keeper of the blueprints, and he had the fame and prestige to prove it. But it was exactly his exalted position that made it obligatory that he make a ceremonial bow to the democratic ideal that most scientists espouse and few believe. In fact it is precisely the kind of recognition that Delbrück enjoyed that propels the scientific enterprise forward.

There are undoubtedly many reasons why people choose to become scientists. Simple greed, however, is not high on the list. The reason is that the rewards for success in science are not primarily monetary (although a certain degree of material well-being does often follow in their wake). If you are a scientist, each success is rewarded by the intoxicating glow that comes from knowing or believing that you have won at least one small round in the endless quest for knowledge. That glow fades quickly, however, unless it brings with it the admiration and esteem of your peers and colleagues (who are, after all, the only ones capable of understanding what you have done and, usually, the only ones who care). The various means by which scientists express their admiration and esteem for their colleagues are so subtle and complex that they beggar the etiquette of a medieval royal court. We will call them collectively the Reward System of science.

Closely linked to the Reward System, there is a second organization that we may call the Authority Structure. The Authority Structure guides and controls the Reward System. Moreover certain positions within the Authority Structure are among the most coveted fruits of the Reward System. Nevertheless the two are not identical. The pinnacle of the Reward System is scientific glory, fame and immortality. The goal of those in the Authority Structure is power and influence. Scientists distinguish sharply between the two. They will sit around the faculty lounge or the lunch table lamenting the fate of a distinguished colleague who has become the president of a famous university. "He was still capable of good work," they will say, sounding much like saddened warriors grieving the fate of a fallen comrade. The university president is a kingpin of the Authority Structure, but a dropout from the scientific Reward System.

The Reward System and the Authority Structure are both rooted in the institutions of science. The institutions of science vary somewhat from one discipline to another, and from one country to another, but the broad outlines will be recognizable to all. Our discussion is most influenced by the physical sciences as they are practiced in the United States.

Scientific research is performed in universities, and to a lesser extent, in colleges that do not grant Ph.D. degrees. It is also performed in national laboratories and in industrial laboratories. The universities and colleges may be public or private. The national laboratories may be run directly by government agencies or managed for the government by universities or consortia of universities. Industrial laboratories are usually, but not always, operated by a single company.

Scientific societies, such as the American Physical Society or the American Chemical Society have members from all the above types of scientific institutions. The societies organize national and regional scientific meetings, publish journals, and administer the awarding of certain prizes and honors. They are private organizations whose officers are elected by their members, and whose costs are paid by the dues of their members, and by other related sources of income. There are a few scientific societies (such as the American Association for the Advancement of Science) that are not tied to a particular scientific discipline, but still hold meetings and publish journals.

There are also purely honorary societies, typified by the National Academy of Sciences (NAS). The NAS holds meetings, publishes a journal and serves certain needs of the government through its research and consulting arm, the National Research Council. However, by far the most important thing the NAS does is to elect its own members. Election to the NAS is one of the highest rungs on the Reward System ladder.

The costs of performing scientific research are borne in large measure by agencies devoted to that purpose. Before the Second World War, those agencies were largely private (Rockefeller, Carnegie) but since WWII almost all funds for scientific research originate in the federal government. The most prominent supporters of basic research are the National Science Foundation (NSF), an independent agency and the National Institutes of Health (NIH), a part of the Public Health Service of the Department of Health and Human Services, but basic scientific research is also supported by arms of the Department of Defense, the Departments of Energy and Agriculture, NASA, and others. Many of these agencies have their own laboratories, and also award grants to researchers in universities.

These are the elements of the institutions of science. We have left out a few crucial items, such as the Scandinavian bureaucracy (the Swedish Royal Academy of Science and the Royal Caroline Institute) that awards Nobel prizes, and the mysterious college of historians and journalists that somehow decides which scientists shall become famous outside of science itself. However, even within the elements described, there are infinitely subtle layers of influence and prestige.

Among universities and colleges, behind a carefully cultivated veneer of cordiality, there is a fierce, endless struggle of legendary proportions for positions of honor in a peculiar contest, in which no one is quite sure who's keeping score, but everyone knows roughly what the score is. The contest ranks each university against others, each college against others, and within a single discipline, departments against one another. There are similar rivalries among national laboratories, and among industrial laboratories, and even among federal funding agencies.

To the aspiring academic scientist, the steps on the perilous ladder to fame and glory look something like this:

1. Be admitted to a prestigious undergraduate college or university (useful but not essential),

2. graduate with a B.S. degree (essential),

3. Be admitted to a prestigious graduate department (very important),

4. Graduate with a Ph.D. (essential),

5. Get a postdoctoral appointment or fellowship at another prestigious university (almost always lower in the invisible rankings than the university you were graduated from--that's why item 3 is so important).

6. Get a position as Assistant Professor. The ranking of the university and department is crucial, since you are unlikely ever to move up from there in the invisible rankings. National and industrial laboratories have positions analogous to Assistant Professor. Some people prefer the risky course of starting in an industrial lab with the hope of being successful enough to be called to a university later.

7. Bring in external research support (mostly from those federal agencies), attract graduate students of your own, get papers published in the best journals (that usually means the ones published by the professional societies--but there are exceptions such as Nature, which is privately published), get invited to speak at national or (even better) international meetings sponsored by professional societies, and generally become visible among active scientists in your own field outside your own institution. Doing all of the above will generally entail making some genuine scientific progress, which will, fortunately, afford some personal psychic rewards to help keep you going. It is useful, but not essential at this stage of your career, to teach well and to participate in academic committees and the like.

8. Get tenure (as a result of doing number 7 very well).

9. Get promoted to Full Professor.

10. Your colleagues darkly suspect that you will now rest on your laurels, and you must prove them wrong. Get more funding, expand the size of your research group (graduate students, postdocs, technicians, etc.). Get yourself appointed to national boards, panels and committees, invited to speak at more meetings, and so on. If at all possible, get something named after yourself. This is the most effective way of

getting noticed, but tricky since someone else must do it for you, and then it has to catch on among workers in the field.

11. The following are now available if you work hard enough to get them and manage to have a little luck in your research:

Awards and prizes from your professional society,

A chaired professorship,

Membership in the National Academy,

International prizes up to the Nobel itself, and

Immortality.

At each of these various steps, you have faced Gatekeepers from the Authority Structure of science. They are generally people who have scaled that rung and a few others, but then stepped out of the competition at some higher point (remember the university president mentioned earlier). For example, the faculty of an undergraduate college (where you may choose to attempt steps 1 and 2) will generally have reached step 4 (a Ph.D.), and perhaps 5 (a postdoc), but opted out of the research competition at step 6 (by taking a position in a college rather than a research university). They may very well never have intended to climb any higher than necessary to reach their positions as college faculty, but it would have been unwise for them to admit as much while they were climbing. Each of the Gatekeepers they faced probably had to be convinced they were aspiring to the very pinnacle. These are the people who will now decide on your fate. They are most likely to be impressed if they believe you are aspiring to that same pinnacle.

At the graduate school level, your Ph.D. thesis advisor, a very important person in your life, will probably (had better be) still climbing, and may very well be quite high already, but decisions about you will be made also by department chairs, deans and others who have traded their places on the ladder for positions in the Authority Structure of science.

Once you pass the Ph.D., the rules for scaling successive steps become increasingly less well defined. The rules are often unwritten, and the people you must impress are further afield. Each promotion will require confidential letters of recommendation from people outside your own institution, solicited not by you but by the chair of a committee. You will thus be expected to be known by people you have not met, merely because of your growing scientific reputation. Your reputation will be based on published papers whose fate will be in the hands of journal editors and anonymous referees chosen by them. The research reported in those papers will be possible only if you can win financial support on the basis of research proposals submitted to the granting agencies. Your proposals will be handled by project officers (either permanent or temporary refugees from the race up the research ladder) and judged once again by anonymous referees, or a panel of active scientists. Finally, even if you manage to finance and publish your work, it will be little noticed unless you manage to get invited to speak at national meetings organized by your professional society. The staff of the society will generally have dropped out of the race, but decisions about who speaks will most likely be made by committees of active scientists. Notice that at each point of decision, there tends to be two kinds of Gatekeepers. One kind is an administrator (department chair or dean, journal editor, project officer, professional society staff) and the other kind an active scientist (writers of letters of recommendation, anonymous referees, members of panels and committees). The first kind has often stepped out of the race (the position itself is generally the reward for having reached a certain level) and the other is still very much in the race. The people in this latter group are not only your judges, they are also your competition. Furthermore, you have become one of them. People in the other group, if they are no longer in competition with you, have often forgotten the fierce struggle you face and, moreover, they tend to have the curious view that you are working for them.

It should be clear from this discussion that scientific scorekeeping is no simple matter. The issue of who will emerge as famous and successful in science depends in large measure on who has the best ideas and who works the hardest. In that sense science is a true meritocracy. However, there are very clearly other elements at play here. One of the most important is being in the right place at the right time. For example, the discovery of quantum mechanics early in this century swept a whole generation of theoretical physicists to fame and glory. The very best made truly fundamental contributions, but even those of more modest talent found untouched problems ready to be solved with the new theory. Another example is the wartime projects, the Manhattan Project and the Radiation Lab, that swept yet another generation of physicists to power and influence.

In addition to those factors there are others that have been observed and documented, that arise out of the behavior and customs of scientists as a group. Robert K. Merton has called one of them the Matthew Effect, after the Gospel According to St. Matthew:

"For unto every one that hath shall be given, and he shall

have abundance; but from him that hath not shall be taken
away even that which he hath."

The Matthew Effect in science is the observation that credit tends to go to those who are already famous, at the expense of those who are not. For example, if a paper is written by a group of authors, only one of whom is well known in the field, readers will automatically assume that person is responsible. A paper signed by Nobody, Nobody, and Somebody will be casually referred to as "work done in Somebody's lab," and even sometimes cited (incorrectly) in the literature as due to "Somebody, et al."

Another important piece of scientific folklore is referred to as the Ortega Hypothesis, after Jose Ortega y Gasset, who wrote in his classic 1932 book, The Revolt of the Masses,

"For it is necessary to insist upon this extraordinary
but undeniable fact: experimental science has progressed
thanks in great part to the work of men astoundingly
Mediocre. That is to say, modern science, the root and
symbol of our actual civilization, finds a place for the
intellectually common place man and allows him to work
therein with success. In this way the majority of
scientists help the general advance of science while shut up
in the narrow cell of their laboratory like the bee in the
cell of its hive, or the turnspit of its wheel."

The Ortega Hypothesis is thus the view expressed by Delbrück at the outset of this article, but with slightly different metaphors. This widely held view is probably based on the empirical observation that there are indeed, in each field of science, many ordinary scientists doing more or less routine work, publishing papers, getting promotions, and generally playing the Reward System game, albeit in the minor leagues of science. It is also supported by the theoretical view that knowledge of the universe is a kind of limitless wilderness to be conquered by relentless hacking away of underbrush by many hands. An idea that is supported by both theory and observation always has a very firm standing in science.

The Ortega Hypothesis was named that by Jonathan and Steven Cole when they set out to demolish it, a job they accomplished by tracing citations in physics journals. The Ortega Hypothesis is incorrect, they conclude, adding,

"It seems, rather, that a relatively small number of
physicists produce work that becomes the base for
future discoveries in physics. We have found that
even papers of relatively minor significance have
used to a disproportionate degree the work of the
eminent scientists..."

In other words, a small number of elite scientists produce the vast majority of scientific progress. Seen in this light, the Reward System is a mechanism evolved for the purpose of identifying, promoting and rewarding the star performers who will propel science forward. On the other hand, for those who still believe in the Ortega Hypothesis, the Reward System is merely a capricious lottery, with the Matthew Effect, the Old Boy Network, and other similar iniquities helping to distribute credit unfairly.

The beginnings of the Reward System and the Authority Structure can be discerned in the 17th century, very close to the birth of modern science itself. It is probably fair to say that experimental physics was invented by Galileo Galilei (1564-1642). Galileo discovered (or perhaps just found supporting evidence for) the Law of Falling Bodies and the Law of Inertia by means of experiments using ingeniously crafted instruments. The scientific research laboratory was first created not much later by English chemist Robert Boyle, who set up a team of assistants, specialists, technicians and apprentices to carry out systematic chemical investigations. Both Galileo and Boyle helped found scientific societies that still exist (L'Accademia dei Lincei and The Royal Society). Boyle supported his research by means of his own wealth, but Galileo spent much of his time and energy seeking government and private sponsorship (it is not for nothing that Galileo named the moons of Jupiter the Sidera Medicea -- the Medician stars. Sponsorship by the Medicis no longer being what it once was, they are today more commonly called the Galilean Satellites). Both Galileo and Boyle engaged in fierce struggles over priority for scientific discoveries. In other words, the basic outlines of the social organization of science emerged almost as soon as science did, and it was firmly in place by the time Isaac Newton (who became a Chaired Professor and President of the Royal Society) wrote his Principia. It is difficult to avoid the conclusion that science cannot exist -- certainly not flourish -- without the Reward System and the Authority Structure.

Of course, professional societies, prizes and awards, to say nothing of department chairs and deans are by no means limited to the sciences. One can detect the basic elements of the Reward System and the Authority Structure in virtually all academic disciplines. Nevertheless, it seems better developed, more highly organized in the sciences than elsewhere. The reason is undoubtably to be found both in the nature of science, and in human nature, since it is we humans who must pursue science. Science is basically a collaborative enterprise to discover important truths about the world, carried out by individuals who are generally more strongly motivated by their own interests than by the collective good. The Reward System and the Authority Structure serve to regulate and channel this collaboration-cum-competition to produce useful results. So long as it succeeds in doing so, this system of ours seems likely to remain firmly in place.

And, oh yes. Science costs a lot of money. That may have something to do with it, too.