Chapter 9: The Scientist's World

Them/us – one of the simplest and potentially most devastating human classifications – is the topic of this chapter. Here we examine our relationships as scientists to various other groups, within and outside science.

Scientist and Lay Person

In what way -- if any -- are scientists unique? In the following passages, the difference between scientists and other people is described by Herbert Spencer, Annie Dillard, and William Shakespeare (though scientists were not the subject of Shakespeare's thoughts). Yet Spencer's perspective is laced with arrogance, Dillard's with apparent envy, and Shakespeare's with joy.

> "Is it not, indeed, an absurd and almost a sacrilegious belief that the more a man studies Nature the less he reveres it? Think you that a drop of water, which to the vulgar eye is but a drop of water, loses anything in the eye of the physicist who knows that its elements are held together by a force which, if suddenly liberated, would produce a flash of lightning? . . . Think you that the rounded rock marked with parallel scratches calls up as much poetry in an ignorant mind as in the mind of a geologist, who knows that over this rock a glacier slid a million years ago? The truth is, that those who have never entered upon scientific pursuits know not a tithe of the poetry by which they are surrounded. Whoever has not in youth collected plants and insects, knows not half the halo of interest which lanes and hedgerows can assume. Whoever has not sought for fossils, has little idea of the poetical associations that surround the places where imbedded treasures were found. Whoever at the seaside has not had a microscope and aquarium, has yet to learn what the highest pleasures of the seaside are. Sad, indeed, is it to see how men occupy themselves with trivialities, and are indifferent to the grandest phenomena -- care not to understand the architecture of the Heavens, but are deeply interested in some contemptible controversy about the intrigues of Mary Queen of Scots!" [Spencer, 1883]

> "I cherish mental images I have of three perfectly happy people. One collects stones. Another -- an Englishman, say -- watches clouds. The third lives on a coast and collects drops of seawater which he examines microscopically and mounts. But I don't see what the specialist sees, and so I cut myself off, not only from the total picture, but from the various forms of happiness." [Dillard, 1974]

> "And this our life exempt from public haunt
> Finds tongues in trees, books in the running brooks,
> Sermons in stones and good in every thing.
> I would not change it."
> [Shakespeare, 1600]

Many lay people hold a stereotypical view of scientists. We are perceived to be:

- very intelligent;
- myopic in interest, focusing on precise measurements of a tiny subject;
- objective in both measurements and interpretations;
- conservative, accepting no interpretation or conclusion unless it has been proved beyond doubt;

- oblivious of the possibly harmful applications of our research results; and
- above all, completely rational and unemotional.

These perceptions are, in part, responsible for the authority of science. Like all stereotypes, however, they depersonalize. Scientists are above average in intelligence, and I have known individual scientists who were myopic, precise, conservative, or oblivious. I have seen scanty evidence, however, that scientists in general fulfill the stereotypes above. Only our publications are completely rational and unemotional; their authors, in contrast, are passionate.

Scientists do tend to differ from most lay people in their techniques, particularly in their embracing of the scientific methods. But of course every kind of specialist differs from lay people in embracing certain techniques and achieving professionalism in exercising those techniques. Like many other specialists, scientists inadvertently build a barrier of jargon. The jargon permits efficient, exact communication among specialists but seems to the outsider to be deliberately exclusive and abstruse. The motivations of scientists -- to the extent that one can generalize -- resemble those of artists; they differ only in degree from most other people.

We are craftsmen, not geniuses.

* * *

Science and Society

> On seeing the culmination of the Manhattan Project (the first detonation of a nuclear bomb) J. Robert Oppenheimer [1945] quoted from the Bhagavad Gita: "I am become Death, the shatterer of worlds."

Some species are solitary and some are social. People try to gain the advantages of both strategies, living together in an interdependent society but encouraging individuality. Inevitably conflict erupts between individual and societal needs. This balancing act is acutely felt by scientists, who accept support but not control from society. The scientist listens to cultural guidelines but personally selects values and priorities [Campbell, 1988b]. The "age-old conflict between intellectual [or moral] leadership and civil authority" [Bronowski, 1973] was fought by Socrates, Jesus, Galileo, Darwin, and Gandhi, as well as by scientists whose names are forgotten. Einstein [1879-1955] may have underestimated the strength of the opposition in his 1953 comment:

> "In the realm of the seekers after truth there is no human authority. Whoever attempts to play the magistrate there founders on the laughter of the Gods."

Scientific responsibility is personal:

> In 1933 Leo Szilard was stopped at a red light while walking to work, when suddenly he realized that neutron bombardment could potentially initiate an explosive chain reaction. He faced the choice of keeping his discovery secret or publishing it, of delaying its use or allowing its abuse. Seeking secrecy, he took out a patent and assigned it to the British admiralty [Bronowski, 1973], but of course development of the atomic bomb would not be slowed by a patent. In 1939 he ghost-wrote a letter, signed by Einstein, which warned President Roosevelt of the danger of nuclear weapons.

Szilard would have empathized with the anonymous statement [cited by Matthiessen, 1978]: "God offers man the choice between repose and truth: he cannot have both." Then, as now, applied science was not confined to discovering what technologies are possible; it also predicted consequences and side effects of those technologies.

About 4% of the U.S. population has a degree in science or engineering. For most of the others, exposure to science is generally indirect: basic science ⇒ applied science ⇒ engineering ⇒ technology [Derry, 1999]. Technology is the tangible result of combining applied science with engineering and business skills.

Popular opinion of science and scientists waxes and wanes with attitudes toward technology. After the technological enthusiasm and optimism of the sixties, the rock group Jefferson Starship [1970] sang: "Do you know we could go, we are free. Anyplace you can think of, we could be." A decade later, however, a society that seldom can think more than four years ahead encountered the consequences of past technological decisions and found that the technological 'gift' of comfort actually has a price. "Comfort, that invader that enters as a visitor, stays as a guest, and becomes master" (Sufi saying). Someone must be blamed, and a musician said to my wife: "Oh, you're a physicist. I suppose you build bombs." Mea culpa, mea maxima culpa. In the nineties, technological development led to improved standards of living and an exuberant tech bubble. Ethical concerns and fears about technological developments have shifted from atomic weapons to genetic engineering.

> "To every man is given the key to the gates of heaven; the same key opens the gates of hell." [Buddhist proverb, cited by Feynman, 1988]

> "We fear the cold and the things we do not understand. But most of all we fear the doings of the heedless ones among ourselves." [a shaman of the Arctic Inuit, cited by Calvin, 1986]

The beneficiaries of technology have the opportunity to see its shortcomings. In contrast, people whom I have met in underdeveloped countries simply hunger for its rewards and for its escape from boring drudgery. Few of the critics of science accuse it of being evil, but many accuse it of being amoral. One can counter such arguments by asking whether the professions of farming and carpentry are also guilty of amorality. Or one can recall that science's highest value is truth (Bronowski, 1978), and that we judge truth from criteria of beauty, simplicity and elegance; is this amorality? But such arguments miss the point. Some people simply are becoming disillusioned with technology, and they are replacing the illusion of technology as magic bullet with one of technology as evil destroyer.

> "Daedalus, who can be thought of as the master technician of most ancient Greece, put the wings he had made on his son Icarus, so that he might fly out of and escape from the Cretan labyrinth which he himself had invented. . . He watched his son become ecstatic and fly too high. The wax melted, and the boy fell into the sea. For some reason, people talk more about Icarus than about Daedalus, as though the wings themselves had been responsible for the young astronaut's fall. But that is no case against industry and science. Poor Icarus fell into the water -- but Daedalus, who flew the middle way, succeeded in getting to the other shore." [Campbell, 1988b]

* * *

The relationship between science and society is changing, in response not only to evolving perceptions by society, but also to other evolutionary pressures. Both the tasks and needs for science are adapting accordingly.

Science has transformed the highly generalized and adaptable human species into the most adaptable species that the earth has ever seen (Bronowski, 1978). Yet arguably we have increased our need for adaptability at an even faster pace, because each technological change can have unforeseen interactions, either with the environment or with other technological changes. In response, many scientists are becoming environmental and technological troubleshooters.

Biological evolution demonstrates that specialization only survives in a static environment. Society's needs concerning specialization versus adaptability are changing: the pace of technological change is increasing, professions are waxing and waning, and therefore our society needs individuals with the ability to move into newly emerging careers. We also need individuals comfortable in interdisciplinary teams.

Scientific education is evolving in response to these changes. For graduate study, the change is less than one might expect: graduate programs entail specialized research, but the competencies learned actually increase the student's adaptability. The old notion of an early academic education followed by a lifetime profession may be obsolete; it is certainly incomplete. The rapid pace of scientific and technological change means that knowledge is not static and education is never really finished. Increasingly, the educational system is being used for retooling and redirection. Students are teaching the professors by communicating the perspectives and needs of industry. Conversely, the students are taking practical applications of their course work to the work-place *immediately*, not years later.

* * *

Major changes of any kind are stressful -- to individuals, groups, and society. The redirection of scientific efforts and education, in response to societal needs, is non-trivial, emotionally taxing, but essential.

The public and politician, having grown up with textbook-science facts, expect certainty from scientists. We, in contrast, savor the uncertainty implicit in forefront science, where ideas are explored, modified, and usually discarded. We offer the authority of science with humility. More than once in the history of science, scientists have had to fight for the privilege of questioning authority. This popular expectation of scientific certainty creates roadblocks, when the implications of scientific research are that society needs to take expensive action. Scientific debate provides a political excuse for societal inaction, even if the key issues are agreed upon among scientists.

> An example is the greenhouse effect, concisely summarized by Stevens [1992a]. Researchers agree that: (1) atmospheric carbon dioxide is rising due to burning fossil fuels and clearing rainforests, (2) atmospheric carbon dioxide will have doubled within the next 60 years, (3) increased carbon dioxide warms the earth through the greenhouse effect, and (4) as a consequence, the earth will warm up during the coming decades.
>
> Some issues are still being debated: How much greenhouse warming has already occurred? How fast and how much warming will the doubling of carbon dioxide induce? What will the local climate effects be? Uncertainty over these questions obscures consensus on the former concerns. We postpone remediation; 'wait-and-see' is cheaper.

Technological innovations are the most frequent and obvious contributions of science to society, but occasionally science has a more fundamental impact: it can change humanity's self-image [Derry, 1999], by generating "the light which has served to illuminate man's place in the universe" [J.F. Kennedy, 1963]. The determinism of Newton's mechanics and the indeterminacy of quantum mechanics challenge our assumption of free will, but this assumption is rooted too firmly to be damaged. The Copernican revolution did not merely overthrow the concept of Earth as center of the rotating universe; it dislodged humanity also from that position. Darwin's theory of biological evolution by natural selection forced another radical revision of self-image: not people as the designated masters of animals, but people as distant relatives of all other animals. The Copernican revolution was resisted and the Darwinian revolution is still resisted because of unwillingness to relinquish self-importance.

> "Most laymen, when they contemplate the effect physics may have had upon their lives, think of technology, war, automation. What they usually do not consider is the effect of science upon their way of reasoning." [Baker, 1970]

* * *

Science and the Arts

As scientists reach out to society, attempting to dispel misconceptions of science, shall we consider the arts as allies or opponents? Are there two cultures, scientific and literary, separated by a gulf of misunderstanding and conflicting values? C. P. Snow [1964] argued persuasively that there are. Most of us have met both scientists and artists whose scorn for the other culture is vast:

> "It may be important to great thinkers to examine the world, to explain and despise it. But I think it is only important to love the world, not to despise it, . . . to regard the world and ourselves and all beings with love, admiration and respect." [Hesse, 1923]

> "In fact, pure science . . . is at once a substitute for logic as a discipline for the mind and an expression of an insatiable desire for the conquest of all knowledge, for an intellectual mastery of the universe." [Burns, 1963]

> "The highest Art of every kind is based upon Science – that without Science there can be neither perfect production nor full appreciation." [Spencer, 1883]

Such individuals separate themselves from a potentially enriching aspect of life by a barrier built at least partially upon misconceptions. The barrier is permeable: many scientists, particularly physicists, are also amateur musicians. A few remarkable individuals, such as Leonardo da Vinci and Benjamin Franklin, excelled in both cultures. I suspect that today's cultural separation is largely a failure to communicate.

Science and art share some key features. Creativity is the source of vitality in both. Science has no monopoly on subjecting that creativity to a rigorous, critical attitude, as any art critic would point out. Virtuosity of both design and technical performance is a hallmark of the best in science and the arts. Both science and poetry are "acts of imagination grounded in reality. . . These two great ways of seeing lie on the same imaginative continuum." [Timpane, 1991].

The craftsmen differ more in their tools than in their skills.

* * *

Science and Pseudoscience

In examining links between science and society, or between science and art, we assume agreement at least on what science is and is not. But how does one distinguish science from pseudoscience? Most scientists do so on a case-by-case basis, with a demarcation that is subjective and value-dependent.

The prevailing discriminator is use of the ‘scientific method’: sciences all use the scientific method, and pseudosciences either do not use it, misapply it, or minimize a crucial portion of it. The problem with this criterion, however, is its invalid premise -- that a single scientific method is used by all sciences. This book is based on a different premise: the sciences share a suite of scientific methods, but the emphasis on individual techniques varies among and within sciences.

This revised discriminator -- use of the suite of scientific methods -- is employed by scientists with reasonable success. Astrology, UFO’s, and psychic healing are considered by many to be pseudosciences, because they lack a well-controlled observation base. Parapsychology, in contrast, is very rigorous experimentally, yet most scientists reject it because of inadequate replicatability and because its results challenge their key assumptions (e.g., can the outcome of an experiment be affected by the experimenter’s wishes?). Immanuel Velikovsky’s [1967, 1977] ideas about colliding planets are rejected in spite of his volumes of supporting evidence, because of his complete absence of objectivity in evidence evaluation.

Are political science and sociology really sciences? For many scientists, the answer to that question depends less on each field’s methods than on respect for their results. That decision should be based on reading the original literature or at least textbooks, rather than on such ‘data’ as newspaper editorials.

* * *

The challenge of separating science from pseudoscience has intrigued many philosophers of science. This goal inspired the birth of falsificationism, Karl Popper’s philosophy that science should concentrate on trying to falsify hypotheses (Chapter 7). Popper was uncomfortable with the ‘scientific’ theories of Marx, Freud, and Adler, particularly in the way these theories seemed to account for *any* observation:

> “What, I asked myself, did it confirm? No more than that a case could be interpreted in the light of the theory. But this meant very little, I reflected, since every conceivable case could be interpreted in the light of Adler’s theory, or equally of Freud’s. . . It was precisely this fact -- that they always fitted, that they were always confirmed -- which in the eyes of their admirers constituted the strongest argument in favor of these theories. It began to dawn on me that this apparent strength was in fact their weakness.” [Popper, 1963]

The line that Popper found to separate science from pseudoscience was the criterion of falsifiability: “statements or systems of statements, in order to be ranked as scientific, must be capable of conflicting with possible, or conceivable, observations.” Hypothesis testing certainly is an integral component of all sciences.

Thomas Kuhn used a quite different discriminator: every science has a ruling paradigm that explains a wide variety of observations and guides research, whereas fields that lack such a paradigm are in the ‘pre-science’ stage. Kuhn’s discrimination of pre-paradigm and paradigm-guided research is useful (Chapter 7), but it does not follow that pre-paradigm fields are pre-science or pseudoscience. For example, sociology and parts of psychology lack consensus on a unifying paradigm, but that lack does not constitute grounds for rejecting their findings.

* * *

Why have scientists largely ignored the efforts to identify a science/pseudoscience demarcation? They reject the premise of this quest: “I define the criterion that determines whether you are a scientist or pseudoscientist.” The label of ‘pseudoscience’ accomplishes more harm than good.

This pejorative term substitutes for a rational discussion of the scientific strengths and weaknesses of fields. The result is ostracism rather than inducement for a field to respond constructively to outside criticism.

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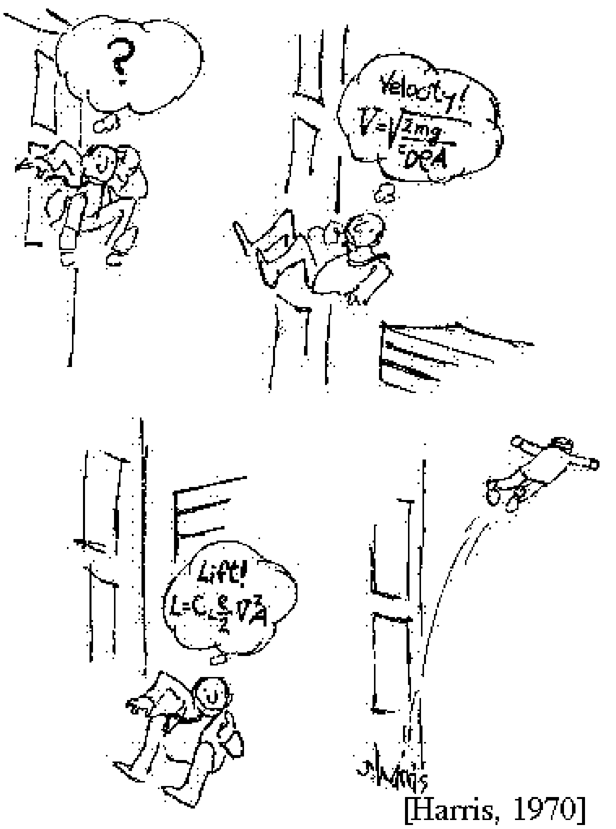
Applied and Basic Research

The bridge between science and society is the teamwork of basic and applied research. Yet sometimes it seems that the distance across that bridge is too great for clear perception.



[Harris, 1970]

Conflict: Applied vs. Basic Research

That some non-scientists hold distorted views of science and technology is not surprising. Even scientists sometimes succumb to stereotypes concerning science, particularly regarding applied vs. basic research.

The choice between applied and basic research is a watershed career decision. Perhaps it is to be expected that the individual will reinforce that choice, by emphasizing the perceived disadvantages of the rejected option.

My own perspective of the dichotomy between basic and applied research is from the physical sciences. The boundary is fuzzier and perhaps the prejudices are fewer in the social sciences, because study of behavior is implicitly alert to human applications. I have worked primarily in basic research, and I have often heard the academics' stereotypes about industry scientists ('materialistic', 'less intelligent', 'less creative'). This prejudice is particularly obvious in the academic's use of the term 'pure research' to describe basic research, as if applied research is somehow impure. Yet I also worked for several years in industry, where I saw corresponding stereotypes by industry researchers toward academics ('ivory tower', 'dilettantes and dabblers', 'groundless pomposity'). Both sets of stereotypes had more to do with personal ego massage than with real differences. Some generalizations are possible, if we are mindful of frequent exceptions.

The methods of basic research and applied research are the same.

Basic research seeks knowledge of any kind. Applied research is alert to and partially directed by potential practical applications. This distinction is not absolute, however. Branches of basic research with obvious implications for society are more fundable than other basic research. An applied researcher may devote prolonged effort to basic issues if they have been inadequately developed by academics. Indeed, some industrial analysts attribute Japanese technological success partly to the willingness of Japanese industry to establish a firm theoretical foundation. Thus applied research does not merely follow up on basic research; the converse can be true.

Some basic researchers claim that they are free to explore the implications of unexpected results, whereas applied researchers are compelled to focus on a known objective. Yet both pursue applications of their discoveries, whether industrial or scientific, and both allow potentially fruitful surprises to refocus their research direction.

Successful industrial competition means not only getting ahead in some areas, but also keeping up in others. Often, it is more efficient for a company to introduce and apply published work by others than to initiate experiments. Applied researchers may experience conflict between their scientific value of open communication and the business need for confidentiality. Applied researchers tend to be more alert than basic researchers to potential applications for their research of discoveries in a different field. Applied research is generally more mindful of economic factors, more cognizant that an approach may be theoretically viable yet financially or otherwise impractical.

Usually the academic researcher can maintain the illusion of having no boss, whereas the chain of command in industry is obvious. It may be easier to start a pilot project in industry. Go/no-go decisions are more frequent too; continuation of the project must be defended at every step.

Some applied researchers [e.g., Killeffer, 1969] see academic research as a ‘stroll through the park,’ with no pressure to produce or to work efficiently. Job security in either type of research affects productivity pressure; probably the most pressured are researchers on ‘soft money’ -- dependent on funding their own proposals. Self-motivation drives the most productive researchers in both applied and basic research; burn-outs are present in both.

Applied researchers have the satisfaction of knowing that their research has a concrete benefit for humanity. Basic researchers know that their research may have highly leveraged downstream applications, and that knowledge is an intrinsically worthwhile aspect of culture. What is the value of culture?

> “To assess basic research by its application value would be awful. It would be like assessing the value of the works of Mozart by the sum they bring in each year to the Salzburg Festival.” [Lorenz, 1962]

* * *

Every scientist, basic or applied, has an implicit contract with society. Most scientists are paid by either industry or (perhaps indirectly) by state or federal government in the expectation that we will provide rewarding results. Technology is one such result; another is teaching that is enhanced by active participation in science. Basic researchers are in a unique position to recognize ways that their research might be of practical value. For a basic researcher to take salary and support services from the public, while neglecting possible usefulness of that research to society, is fraudulent.

The synergy between academic research and the local economy has not been quantified, but clues can be found in a detailed survey of the economic relationship between Stanford University and Silicon Valley technology. Most notable was the direct personnel influence: one third of the 3000 small companies in Silicon Valley were created by people who were or had been associated with Stanford. Direct technology transfer, though important, was much more modest: only 5% of the technology employed by these companies came directly from Stanford research [Lubkin et al., 1995].

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Changing Goals for Applied and Basic Research

Attitudes toward applied and basic research are not just a concern for individuals; they also affect national policy. When resources are tight, for example, how can a nation set priorities for funding of basic and applied science? How can funding agencies choose among such diverse research areas as subatomic particles and the human genome? One approach is to define the goals of science, from a national perspective [Gomory, 1993]. Setting goals is a powerful basis for decision-making. Unfortunately, the choice of goals for basic and applied research is hotly debated.

The goal of basic research is reliable knowledge of nature, and the goal of applied science is useful knowledge of nature. These objectives are, perhaps, too sweeping to guide science funding. Until recently, U.S. research funding has been guided by the rationale laid out by Vannevar Bush [1945] half a century ago: both basic and applied research inevitably serve the mission of strengthening national security, mainly by promoting national defense but also by increasing self-sufficiency and standard of living. Bush's vision catalyzed the subsequent growth of U.S. research funding and the breadth of supported disciplines. Priorities have gradually shifted toward greater emphasis on health and medicine, but the framework has remained intact until the last decade.

Some recent attempts to redefine U.S. scientific goals [Gomory, 1993; COSEPUP, 1993] appear to me to be based on the following flawed assumption: a nation or company does not need to make the discoveries; it just needs to be poised to use the discoveries of others. Gomory [1993] and numerous government officials extend this idea even farther, arguing that the purpose of science is industrial competitiveness. If so, perhaps basic science can be reduced to a support service for applied science. A minority [e.g., Jarrard, 1994; Cohen and Noll, 1994] respond that it would be a mistake to redefine the goal of science as industrial competitiveness.

Industrial competitiveness is essential to the economic welfare of the U.S., it is a high national priority, and it is a modern mantra. It is not -- and has never been -- the primary objective of scientific research. Making industrial competitiveness the purpose of applied research defines resulting industrial improvements in other countries as liabilities, not assets. Both individual companies and individual countries benefit from total technological growth, even without competitive advantage.

Pragmatism, not naïveté, suggests the following criterion for national science funding: return on investment, not relative advantage. How much money should a nation invest in basic and applied science? As with all potential investments, the first step is to evaluate return on investment:

> "Science is an endless and sustainable resource with extraordinary dividends." [Executive Office of the President, 1994]
>
> "Basic research . . . has been an astounding success, whether measured in terms of understanding natural phenomena or improving material wealth and living standards of the world." [Gomory, 1993]
>
> Many economic studies have investigated the relationship of R&D to productivity, and "the main conclusions from their work are that more than half the historical growth in per capita income in the U.S. is attributable to advances in technology and that the total economic return on investment in R&D is several times as high as that for other forms of investment." [Cohen and Noll, 1994]

With confidence in return on investment, one then invests as much as one can afford. More funded research will lead inevitably to more discoveries, increased productivity, and a higher standard of living.

* * *

Resolution: Bridging the Gap

The changing national priorities for basic and applied research affect research in many ways. The long-term cost-effectiveness of research remains unchallenged. The current focus of concern is, instead, on maximizing the efficacy and speed with which basic-research findings are transferred to the marketplace. One resulting trend is a reallocation of resources, with a higher proportion going to applied research. Today about half of the Ph.D.'s in science and engineering are employed outside the academic environment -- a substantial increase since the 1970's [National Science Foundation, 1994]. Another response is simply a more conscientious linkage between basic research and its potential applications to quality of life (e.g., in industry, professions, and health).

Research funding is changing. The proportion of projects funded entirely by a single grant from a federal agency is dropping. Increasingly, funding agencies are requiring cost sharing and collaboration with private industry. Joint projects between academic researchers and businesses are sprouting at an unprecedented rate, as both groups discover that carefully framed collaborative projects permit individuals to maintain their own objectives and benefit from broader expertise. For example, companies are recognizing the R&D leverage inherent in using faculty expertise and faculty-generated government cost sharing.

Universities are implementing mechanisms for assuring technology transfer and cooperative research among faculty, students, and local business. Some examples are student internships, graduate-student summer jobs in local industry, undergraduate research opportunity programs, university research parks, technology transfer offices, and seed money for research oriented toward technology development.

> "To feed applied science by starving basic science is like economising on the foundations of a building so that it may be built higher." [Porter, 1986]

How far will the pendulum of transformation in research funding swing? The rift between applied and basic research is decreasing, but is there still too much emphasis on basic research? At state and national levels, some are asking whether we really need and can afford the research universities.

Both research and graduate-level teaching make the same major demand on an individual's time: to be up-to-the-minute in a specialized and rapidly growing field. Whereas textbooks are fine for the undergraduate level where well-established 'facts' are taught, graduate-level teaching and research must be at the cutting edge where new ideas are being proposed, evaluated, and rejected. Active researchers are the best guides in this frontier, where the graduate student must learn to travel.

Graduate study is an apprenticeship. Like undergraduate education, it includes some texts and lectures. Unlike undergraduate education and trade schools, most graduate and professional programs require an individually tailored interplay of supervised yet independent study, a learning-by-doing that develops both specialized knowledge and a combination of competencies and work attitudes. Effective graduate-level apprenticeship requires a mentor, research facilities, identification of feasible and decisive research topics, and usually research funding. The research component of a research university is designed to provide exactly these requirements.

These two aspects of graduate study, apprenticeship and evaluation of new ideas, make graduate study less amenable to distance learning and electronic teaching than is undergraduate study. The combination of personal attention and electronic technology is, in contrast, at the heart of graduate education in a research university.

* * *

Big Science versus Little Science

As the geometric growth in number of scientists collides with the linear growth in available science funding, debate is inevitable about where the scarce resources should go. Much of this debate has centered on the issue of big versus little science. More accurately, since there is a continuum between the two, the question is: what are the optimum proportions between large and small projects within a discipline, in order to maximize the scientific payoff per dollar expended?

Big science can be in the form of a single multi-investigator project or research thrust, or a large facility that is used by many researchers for their individual small-science projects. Multibillion dollar examples of the former are the Human Genome Project, (cancelled) supercollider, and space station, though even within these projects there are many moderate-scale subprojects. Examples of large facilities for small-scale projects are telescopes, oceanographic ships, supercomputers, and Antarctic research stations.

Proponents of small science point out that most major discoveries have been a product of small research groups working with modest funding. Such projects are very cost-effective, because most of the money goes to scientists rather than to the equipment and technicians that generally consume most big-science dollars. Advocates of large science accept these arguments, but they claim that the waves of small science have merely washed around some key problems that were too expensive to tackle. Now these problems are the most critical issues remaining to be solved; they can no longer be bypassed.

Most scientists do small science. If science were democratic, many of the big science projects could not fly. Thus the proponents of the largest projects seek a different constituency; they also solicit line-item funding that does not obviously reduce small-science funding. Successful proponents of big science tend to be well known senior scientists who already head large groups and who are on committees charged with outlining new directions for a field. Younger and less famous scientists feel left out.

> This week my closest colleague at Columbia University won the largest grant that Columbia had ever received. Yet most of my friends there are less successful 'soft-money' researchers, who doubt that they will be able to write enough successful proposals to provide their own salaries next year. Also this week, cosmologists are ecstatic over the results of the big-science COBE satellite: the big bang theory has received remarkably strong confirmation, through a mapping of the original subtle heterogeneity of its radiation. Is there a more fundamental scientific question that the origin of the universe, the mother of all singularities?

> Debate over the Human Genome Project was often personal. James Wyngaarden, who was head of the National Institutes for Health when NIH started funding of the project, said "Most knowledgeable people and most eminent scientists are solidly behind [the project]. The ones who are critical are journeymen biochemists who may be having a hard time competing themselves." James Watson, Nobel laureate and previous head of the program at NIH, said, "It's essentially immoral not to get it done as fast as possible." [Angier, 1992]

Polarization and alienation are hazards of the battle. The big-science projects generate another hazard: grand expectations. Virtually all funded proposals make confident predictions of valuable results; optimism and a modest amount of oversell are almost prerequisites for funding. Most of these projects will be somewhat fruitful, partly because the investigators are free to react and refocus their research to avoid obstacles and exploit discoveries, but most projects will also deliver less than the proposals promised. Small-science projects can get away with this because there is safety in numbers: a few projects will be stunningly rewarding, and the combination of these breakthroughs and many smaller successes creates rapid small-science progress.

Big science, however, lacks this safety in numbers. If a single big-science project fails, public reaction to the 'wasted taxpayers' money' can hurt all scientists' reputations and funding prospects. Such was the initial impact of the Hubble space telescope. Fortunately, NASA corrected its deficiencies, and recent Hubble results have been breathtaking.

* * *

Ego and the Scientific Pecking Order

> "Go, wondrous creature! mount where Science guides,
> Go, measure earth, weigh air, and state the tides;
> Instruct the planets in what orbs to run,
> Correct old Time, and regulate the Sun.
> . . . Go, teach Eternal Wisdom how to rule --
> Then drop into thyself, and be a fool!" [Pope, 1733]

The scientific pecking order is another manifestation of the attitude of "me, in competition with them; me, better than them; me, rather than them." Like chickens, some scientists seem to be obsessed with climbing an imagined pecking order. Those 'below' such a scientist see a scornful user of their efforts; those 'above' such a scientist see a productive team player.

Beyond the local interpersonal pecking order is a broader pecking order of professions that is remarkably fluid in its ability to place one's personal field at the apex. One common pecking order of scientific superiority is *'hard' sciences (i.e., physical sciences)* **>** *social sciences*. Within the physical sciences *physics* **<>***mathematics* (of course depending on whether one is a physicist or mathematician), and *physics & math* **>** *astronomy* **>>** *other physical sciences*. For example, the following provocative 'joke' by Rutherford [Blackett, 1962] makes a non-physicist's blood boil: "All science is either physics or stamp collecting." *Academics* **>** *applied scientists* of industry, because of the hasty generalization that the latter are materialists first and scientists only second. *Applied scientists* **>** *academics*, because of the hasty generalization that the latter are marginally useful ivory-tower dabblers. For example, the applied scientist Werner von Braun said [Weber, 1973], "Basic research is what I'm doing when I don't know what I am doing."

Theoreticians **>** *experimentalists*, because the latter are less intelligent grunt workers. *Experimentalists* **>** *theoreticians*, because the latter are out of touch with reality and think that 'data are confirmed by the model.' Oliver [1991], for example, claims that theories are useless except as an "organization of observations" and that "observation is the ultimate truth of science." *Full-time researchers* ('full-time scientists') **>** *college teachers* ('part-time scientists') **>** *high school teachers*, though in reality the latter may have the most highly leveraged impact on science and the least glory. *Professor* **>** *assistant professor* **>** *lecturer* **>** *student*, because seniority is more important than originality. *Ph.D. researchers* **>** *technicians* > *scientific administrators*, because the latter are not 'true scientists', though they may be just as essential for science.

All of these hierarchies are counterproductive and hypocritical. They are counterproductive because the pecking instinct allows only one at the top of each of the many hierarchies; we all must be both pecked and peckers. This defensive ego building is successful in creating a feeling of superiority only by careful editing of perceptions to focus downward. It is also counterproductive because time and energy are wasted worrying about where one is. The scientific pecking order is hypocritical because it is an *ex post facto* justification. Almost no one picks their scientific specialty based on the above considerations (a possible exception is the choice between applied and basic research). Fortunately, we pick a field instead because it fascinates us most, and we pick a job within that field because it somehow suits us most. We might almost say that the scientific field chose us, and we obeyed in spite of rational reasons to the contrary.

For the explorers of nature, there are no box seats, no upper-balcony seats. Remember Dedekind's postulate: every segment of a numeric series, however small, is itself infinite. Similarly, within every scientific field are infinities to be explored.

> "And there is no trade or employment but the young man following it may become a hero,
>
> And there is no object so soft but it makes a hub for the wheeled universe." [Whitman, 1892]

How much of our pecking is, like chickens, a reaction to being pecked? How much is ego massage? How much is our need to have a status commensurate with our years of effort? How much is the desire to give a rational explanation for an emotionally inspired career choice?

The scientist's banes are egoism and egotism. The scientific pecking order is one manifestation of egoism, the self-centered practice of valuing everything only in proportion to one's own interest. Egotism, pride, and self-conceit are enhanced by a combination of peer recognition, the value placed by society on intelligence and technology, and one's own false sense of the importance of their contributions to science.

Egotism is not in proportion to peer recognition. Peer recognition and fame can aggravate egotism, but it need not do so. For example, on receiving the 1925 Gold Medal from the Royal Astronomical Society of London, Albert Einstein's response was:

> "He who finds a thought that lets us penetrate even a little deeper into the eternal mystery of nature has been granted great grace. He who, in addition, experiences the recognition, sympathy, and help of the best minds of his time, has been given almost more happiness than a man can bear." [Einstein, 1879-1955]

Too often, "he who finds a thought that lets us penetrate even a little deeper into the eternal mystery of nature" thinks that he is hot shit. Perhaps this is the egotistical trap: we fool ourselves into thinking that we are wresting the secrets away from Nature or God and therefore we must be godlike. Campanella, a 17th century Italian philosopher, described man as:

> "a second god, the first God's own miracle, for man commands the depths, mounts to heaven without wings, counts its moving bodies and measures their nature. . . He knows the nature of the stars. . . and determines their laws, like a god. He has given to paper the art of speech, and to brass he has given a tongue to tell time." [cited by Smith, 1930]

How much of the pride and ego of modern science is a cultural phenomenon? For example, the boasting about mental powers and control stems partly from the Renaissance feeling that humans are master of the earth. Contrast the ancient Greek perspective that wonder is more appropriate than self-conceit, because people can never achieve the ideals revealed by science. Empedocles [5th century B.C.] said:

> "And having seen [only] a small portion of life in their experience, they soar and fly off like smoke, swift to their dooms, each one convinced of only that very thing

> which he has chanced to meet, as they are driven in all directions. But each boasts of having seen the whole."

If scientists allow themselves to be seen as Prometheus giving the power of fire to humanity, then they may start thinking of themselves as demigods. J. Campbell [1988b] reminds us that "Man did not weave the web of life, he is merely a strand in it." Bronowski [1973] speaks feelingly and eloquently of the danger of this scientific egotism:

> "[Mathematician] Johnny von Neumann was in love with the aristocracy of intellect. And that is a belief which can only destroy the civilisation that we know. If we are anything, we must be a democracy of the intellect. We must not perish by the distance between people and government, between people and power, by which Babylon and Egypt and Rome failed. And that distance can only be conflated, can only be closed, if knowledge sits in the homes and heads of people with no ambition to control others, and not up in the isolated seats of power."

The luster of an individual's contributions to science is tarnished by the near certainty that some other scientist would have made the same contribution sooner or later. One can help erect the scaffolding of the scientific cathedral, but the scaffolding later will be torn down and forgotten. One can cling to the comfortable fantasy of scientific immortality, but today's scientific breakthrough will be tomorrow's naïveté.

> "Voltaire, when complemented by someone on the work he had done for posterity, replied, 'Yes, I have planted four thousand trees'. . . Nearly a score of centuries ago, Marcus Aurelius reminded us that, 'Short-lived are both the praiser and the praised, the rememberer and the remembered.'" [Teale, 1959]

> "I returned, and saw under the sun, that the race is not to the swift, nor the battle to the strong, neither yet bread to the wise, nor yet riches to men of understanding, nor yet favour to men of skill; but time and chance happeneth to them all." [Solomon, ~1000 B.C., Ecclesiastes 10:11]

[Watterson, 1993]