Where Science is Headed—Sixteen Trends / Joseph Coates

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While the scope of science is boundless, the contents massive, and the impact universal, it is still practical to see trends which mark the path of science into the future. Sixteen trends noted here are durable and likely to shape the overall scientific enterprise in the next decade or two. Trends within specific sciences are not covered.

1. There is a continuing blurring of the distinction between science and technology. This is most clearly seen in hi-tech areas such as the production of computer chips, where basic science is increasingly called upon for help and new capabilities are rapidly employed. More generally, science is called upon where the identifiable limitations of current technologies demand a fresh basic look to find radically new avenues of improvement. The classic example of this is the telephone industry's needs for relief from unrealistic future demands on equipment and on its workforce, which led to the invention of the transistor.

2. The distinction between basic and applied science also continues to blur. This is extremely significant because it implies the break up of the self-serving conceptual distinction made by academics. Obviously, academics prefer to see themselves as involved in basic scientific research, best characterized as self-initiated, with those in applied research assigned to a secondary and less prestigious status. In spite of all sorts of efforts to sustain the distinction, the differences between the two are fading quickly, in much the same way that the distinction between science and technology is fading. Practical needs and goals of the funders of research eventually shape, if not fully determine, the nature of the research enterprise. For example, Federal funders are increasingly requiring a statement of the potential future benefits of proposed research.

In many advanced projects, best illustrated by the space program or by military technology, the need to achieve some objective such as "a man on the moon by the year X" implies that plans specify large numbers of developments that are not possible at the time the plan is written. This situation frequently leads to "research basic to..." This again is an illustration of the crack in the academic monopoly on basic research since many of these basic research projects end up in the hands not of universities but of non-profit and government laboratories and private contractors.

The two trends above link to a third trend in an important way because they show the shortcomings of the academic distinctions that are so important to maintaining the disciplinary categories at the university, and the associated performance necessary to progress up an academic ladder.

3. Interdisciplinarity is increasingly important in research while largely ignored by academics and their universities. Almost all of the new leading edge fields in science-genetics, brain research, and nanotechnology, as well as materials science, robotics and automation-require interdisciplinary R&D. The university is by and large not comfortable in accommodating this intrinsic demand of contemporary research. As a partial mechanism for dealing with the need for interdisciplinarity they often set up "institutes," which are more often than not only loosely linked to the basic science departments' teaching and curricula.

There clearly are exceptions to this common behavior. One can see, for example, several programs at Harvard, MIT and other distinguished universities getting into interdisciplinarity especially in their graduate schools. But as a rule the bulk of American universities' interdisciplinarity can be seen as aspiration or as empty claims rather than as reality. Far too often, academic programs attempt to achieve interdisciplinarity by the stapler rather than by the true conceptual integration of research programs and the production of something truly interdisciplinary.

Again, interdisciplinarity in science is more and more being captured by federal laboratories, by federal contractors, and by large non-profits such as SRI International. This is a pity, because first, it shortchanges the employers of the scientific workforce by training students too narrowly, in disciplines, while the action today is at the interface of disciplines. Second, it does the university a disservice by making it less viable as the primary or secondary place one wishes to go to in order to move into the most intellectually exciting research areas.

4. Credentialing in science is rapidly changing, expanding, and diversifying. This is a challenge to the traditional certifying by the university and is a response to the university's indifference and sluggishness in responding to new needs. The scientific enterprise is changing. Learning that is *ad hoc,* through free-standing courses or electronically-based colleges, certifications by professional societies, and various other kinds of teaching and learning through the media, the Internet, and cassettes mark these forces for change. There is now also the credentialing beginning at high school that allows college credit for an expanding range of courses. There is the credentialing going on within corporations through in-house or contracted education and training programs for their own employees or contractors.

5. Globalization of both basic and applied research is rapidly progressing. This goes well beyond the two hundred-plus year globalization of science embodied in open literature exchange and international meetings. The current level of globalization involves the integration of research on global sites by research sponsors. Corporations such as Siemens or governmental agencies, looking for the highest degree of talent at the best possible cost, will buy that talent wherever it is.

Globalization has been facilitated by the end of the Cold War, which generated a super-abundance of cheap, highly skilled labor in the Iron Curtain countries, and by the more recent emergence of highly skilled labor in China, India, and to a lesser extent in other countries. The quality of that foreign talent is an attractive complement to the U.S. base, in being stronger in theory but perhaps marginal in goals and commitment to practical applications.

Aside from the low cost and high volume of talent available, information technology is the single most important facilitator of globalized research. It can, for example, give the research organization a 16- or even a 24-hour day in R&D, as research activity passes through time zone after time zone to make a global circuit. Round the clock research accelerates the productive outcomes of a project and thereby offers the sponsor a potential advantage in meeting competitive goals.

In addition, information technology allows extremely effective management by more or less wiping out distance as a temporal factor. With a little experience or training, both R&D mangers and staff learn to communicate effectively and economically through the use of groupware and broadband communications to exchange and discuss real-time details-whether graphic, tabular, or simply verbal.

6. Outsourcing is increasingly commonplace. It is virtually universal in some sectors of research and development, production, test and evaluation. Field work is frequently outsourced. These tendencies are especially strong in the chemical sector and in information technology. In sectors with already extensive experience in outsourcing manufacturing, such as automotives, it is an easy and comfortable extension into outsourcing R&D. The key advantage is that it allows one to draw upon best available talent, while the cost is often lower and the flexibility much higher than if the work were conducted internal to the organization.

7. English is now the universal language in science. Scientists outside of the English speaking world strive to be published in English language journals. Young scientists-those under 40-are fully literate in English. The professional universality of English facilitates the globalization in outsourcing noted above. Possibly an exception to the universality is Japan. Technical and scientific results are often reported in both English and Japanese. But the difficulty of the Japanese language affords some advantage in which Japan can claim openness-and at the same time be relatively closed. This is accomplished by publishing many things, particularly in science policy, only in Japanese-and only much later, if at all in English. It is not clear the extent to which China is engaged in similar publication policies in the planned globalization of its own R&D.

8. In the United States, basic and applied science is increasingly falling into the hands of foreign born scientists, in training in American universities and among those already established in their field. This has to be good for the global community of science, for foreign countries, and for businesses outside of the United States, since we are the outstanding training ground for scientists in almost every field. The policy issue needing to be examined is whether this growing dependency on foreign-born talent is good for the future of the U. S. R&D establishment and for our general competitive position in the world. Heartfelt beliefs are no substitute for the absent research on this issue.

Recently a new issue has arisen that has not been adequately documented in terms of scope and significance. It appears to be quite common that a hi-tech firm, usually an information technology firm, will fire high priced native-born scientists and then make a plea to import foreign scientists at a substantially lower pay rate to fit a gap in its work force. While that is the overall pattern, the details by which one can accomplish this are complex. This illustrates a side effect of globalization of talent, and it creates a domestic issue. What are the effects on the economic health and well-being of individual American scientists, engineers, and technologists, and on their families? Should companies be allowed openly or by subterfuge to replace a citizen by a foreigner merely to enhance the corporate bottom line?

9. Physical science is still king of the hill, although biological sciences are fast coming to share that primacy, especially through genetics research, medical research, and brain research. The area where the most definitive research is conducted and hence the largest economic value continues to lie is in physical science and its derivative applications My criterion for the status of the sciences is their ability to make definitive, unequivocal, highly reliable, and precise responses to current needs and questions through practical applications. There is no doubt that almost any questions of a mechanical, engineering, material or electronic sort can be answered definitely so that one can confidently make institutional, operational, planning and personal decisions.

The social sciences are still at the pre-definitive stage; that is, both theory and research often-if not usually-fall short of definite conclusions to shape policy, planning, and actions. They however should not be dismissed in public organizational decision making. They are able to inject an awareness of incompleteness, uncertainty, and openness into plans, programs, and projects that scientists, engineers, business people, and politicians may be too aggressively promoting. On the other hand, the social sciences, because they are still at a pre-definitive stage, too often have a strong ideological orientation and a less-than-even-handed approach to social, economic and political issues. Regrettably, the social sciences in their relentless move toward more and more quantitative methods (apparently in some mimicry of physical sciences) have all too often given theory short shrift.

10. Physical and biological sciences are undergoing increasingly important changes because of effects of information technology, particularly computers and telecommunications. Devices, equipment, tests, and analyses are moving to smaller and smaller scale, with the consequence that often incredibly large numbers of analyses and vast amounts of data are produced rapidly. Particularly in pharmacology, chemistry, and genetics, thousands of tests can routinely be conducted simultaneously on small scale arrays. An interesting example of the practical effects is in forensic science, where incredibly small amounts of DNA evidence can provide definitive identification in a criminal situation.

Secondly-apparently at odds with the above-is that low cost tools, equipment, and techniques now offer much broader opportunities for field work. For example, low cost sensors and reporting devices can be put out in large numbers to collect a volume of information that was unthinkably difficult to gather twenty years ago. Sensors are now often in practice and surely in principle able to detect anything that one would want to detect. One sees this, for example, in the development of artificial noses to detect contraband material. Any physical phenomenon or biological material or other signal such as precursors to earthquakes can now be sensed or measured and hence contribute to the overall competence of the sciences in practical affairs and theoretical understanding.

Thirdly, simulation has become a tool in virtually every scientific area. Soon nothing will be constructed until it has been planned, designed, tested, evaluated, and modified in cyberspace.

11. Ecology is the logical scientific base for all environmentalism and for the environmental movement. But regrettably progress is slow, under-funded, and without a sound theoretical base. One only has very general semi-quantitative and qualitative notions, such as "everything goes somewhere" serving as weak theory Without an adequate scientific base we still see a tremendous amount of gratuitous conflict and disagreement with regard to environmental management and the future.

12. The scientific knowledge held by the public is pitiably thin and unreliable. Recurrent surveys sponsored by the National Science Foundation show the ubiquity of ignorance about science. The government is the primary potential source of remedy for this deficiency. But both the executive and legislative branches more or less sit on their hands. The National Science Foundation had its political misadventure decades ago in producing text book material and has been gun shy ever since. The most conservative inhabitants of Capitol Hill are ever ready to block educational, medical, or other information they find ideologically obscene, and to punish the perpetrators by budgetary cuts or constrictive legislation. The President's education program promises "no student left behind" but at least as far as science goes, it is a joke.

The primary consequence of this regrettable state of public ignorance is that as more and more often scientific matters become public policy issues, the population is left open to extremist, erroneous or fantastic claims, unsound policy solutions, and a general intellectual mess of conflicting and faulty recommendations and ultimately bad laws, regulations and policies.

13. Industrial sponsored basic research has more or less tanked. It is difficult to see much basic research with a truly long term perspective, or beyond their immediate business interests in the 25 or so top firms in terms of R&D investment. The amount of money industry spends on research is not strongly correlated with its basic nature. General Motors and Ford are among the nation's, and therefore the world's, largest funders of R&D. They have been right up there for decades, and yet can the reader name even one distinguished American scientist employed by either company, much less a Nobel laureate?

14. Hobbyists, ideologues and amateurs are challenging traditional science in two separate ways. Many are literally challenging the reliability of research coming out of the established scientific community. This is clearly illustrated in the health and medical area. One has only to turn to the Internet to be confounded by the tremendous lot of truths, half-truths, lies, falsifications, and misunderstandings to be found there on any health issue. The Internet also widely propagates the occult and semi-occult. Many people still believe that something special went on at Roswell, many people believe that there are extraterrestrials visiting us - and kidnapping some of us. Others still doubt that man has walked on the moon.

On the other hand, the development from hobbyist into an amateur scientist brings us all benefits. Now it is possible for thousands of people with surplus time on their computers to link into large scale scientific experiments to do data processing, gratis, as public service. Repeatedly, amateurs are making astronomical discoveries of substantial importance.

The scientific community needs to develop better ways of coping with the ideologues and the ignoramuses and at the same time promoting scientific hobbyists and talented amateurs.

15. There is growing tension from the strong pressure for useful results-on schedule-in government, business and foundation funding of R&D.

The commitment to the bottom line in business is what underlies the pressure for scheduling what usually cannot be scheduled. It is not quite so clear what the driver for "results on demand" is in government funding agencies. The net effect is to drive out attention to what is and which must be uncertain in its outcome and timing. Science is now becoming a victim of a concept made famous in a different domain by Henry Kissinger: "The urgent drives out the important."

16. There is a continuing call for technology assessment, but not under that name. The Congressional Office of Technology Assessment, after a quarter of a century of distinguished service to Congress and therefore to the nation was deep-sixed by a group of aggressive conservatives new to the Congress and not understanding how it worked or what support it needed. Technology assessment is not now conducted anywhere in the United States, but the cry for it comes up in many comers, including Capitol Hill. A recent example is Bill Joy's plea for better understanding of the future consequences of self-reproducing and intelligent robotics, genetics, and nano devices. His near-frantic plea for understanding showed that he was unfamiliar with the concept of technology assessment and what can be done and what had been done, but the plea is nevertheless justified. While the concept of T A is thriving in Europe and growing elsewhere in the industrialized nations, we who have the largest economy and the largest commitment to R&D and to the ubiquitous use of technology see our political and business leadership remaining staunchly indifferent to anticipating what side effects and unanticipated outcomes could be.

Conclusion

These notes on trends shaping the future of science do not cover the rich texture of forces more specifically shaping the individual sciences, nor do they probe the manifold pressures on public and private science policy. Nevertheless t hey offers a framework for policy discussion and a pattern into which more detailed forces and factors can be integrated.