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Thank you for inviting me to speak this morning. I have been reading your products all my life, and appreciate the service you provide in translating the content and experience of science into (generally) comprehensible language. Even scientists get much of their information about technical fields outside their own from popularizations and articles in general science publications. So science writers are part of the machinery of science itself, and bear some responsibility, along with the scientists themselves, for getting it right.

Science is a subject that poses very serious problems for those who write about it. It is above all a subject that is not well-defined. Science is a method, a collection of facts, a collection of stories, a way of life, a culture, a profession, an object of study by sociologists and philosophers, a symbol of many different things exploited by many contending and overlapping factions within society.

Nor is the word "science" a neutral word. In different circles it denotes different stereotypes – cold and calculating, amoral, mercenary, trapped in a bargain with the devil in return for dark secrets best left undiscovered – or passionate, idealistic, rigorously honest, in a selfless pursuit of truths that will ease the pains and burdens of long-suffering humankind, and enrich human culture with magnificent insights into the operation of the universe.

Today I want to focus on four challenges to science writing, two intrinsic to science and two extrinsic. I'll give them short but cryptic titles. They are the challenges of: 1) language; 2) ambiguity; 3) power ; and 4) ecology.

**1. Language:** I hardly need to mention that the language of science is arcane. Not only are the words themselves never used in ordinary discourse – words like 'deoxyribonucleic acid' – but those that are, like 'momentum', or 'field', or even 'particle', mean totally different things to scientists. This is a challenge that science writers have always had to contend with, but the challenge of language I have in mind is different, and much more difficult to overcome.

Language carries with it a world view we use implicitly to classify experience. Unfortunately, our understanding of nature has been evolving much more rapidly than ordinary language. It is not only the individual words that are new and strange, but the underlying conceptual structure. The problem is greatest and has the longest history in my own field of physics. The revolution that began in the 19$^{th}$ century with Maxwell's account of electromagnetism and produced breakthroughs in the 20$^{th}$ with relativity and quantum theory changed the ground rules for thinking about nature. Brilliant journalists appeared almost immediately to explain the new ideas, and today we have many books for popular audiences that attempt to describe the new paradigms in common language. The common language is changing, but not fast enough. Journalists and science writers today feel they can safely refer to Heisenberg uncertainty, time dilation, and gravity as curved space. But these concepts, expressed even in current popular literature in misleading and naive terms, are more than three quarters of a century old, and the ideas important in today's science incorporate them implicitly and go far beyond. The highly geometrical conception of nature assumed as basic by today's particle theorists, for example, is virtually unknown to the public.

This obsolescence of language has the important consequence that very few are able to sense the deep coherence of modern science, or appreciate the compelling nature of the new discoveries. We have excellent reporting on physical science issues like multi-dimensional spaces and dark energy, but it is very much at a "gee-whiz" level. A similar problem may exist in public appreciation of biology research, where the close relationships among all living things that scientists take for granted is still not part of the common understanding. I suspect a similar disconnect has occurred in the social sciences.

Science writers live with these language problems every day, but they will continue in the future, and they are becoming more serious as science continues to build new layers of understanding upon the still unfamiliar foundations of the past.

**2. Ambiguity:** Stripped of all its symbolism and sociological baggage, science remains at its core a method, a way to learn about nature. The foundation of this method is empirical testing – actually looking at what is happening rather than simply theorizing. The cycle we all learn in school of hypothesis, experiment, feedback, and modification is very much alive in science and dominates practice in every field. That said, some fields are more congenial to this method than others. All scientists would love to succeed as physical science does in predicting the behavior of physical and chemical systems. The laws are relatively simple, and the systems can be characterized with few enough variables that they can all, or at least enough of them, be controlled in experiments.

Unfortunately, some of the fields most important for society do not lend themselves easily to controlled experimentation. In health, environmental, and behavioral sciences the number of variables is huge, the systems exceedingly complex, and our ability to measure and characterize them very weak. In these fields, only when a single cause obviously outweighs all others do empirical methods give unambiguous results. The challenge of science in these fields is to devise experimental approaches that reduce complexity and narrow choices. When the subject is a naturally occurring condition, such as an ecosystem, or the world's climate, the only option is to examine simplified models that ignore huge numbers of variables.

In these cases of extreme complexity, that "sociological baggage" becomes very important. Even experienced and sophisticated professionals can be misled by prevailing ideas and their own prejudices and expectations into forming hypotheses that are not supported by empirical data. Spotting and correcting such errors is what science is all about. Making them in the first place is expected. The reason science requires publication and communication is that every hypothesis is suspect all the time. The challenge to science journalism is to convey this tentative nature of all hypotheses in the face of confident statements from the scientists themselves, and especially by their sponsors, about the significance of their results.

I do have some advice for journalists and others writing in these fields: the data rarely, if ever, speak for themselves. Interpretation of data within a hypothetical framework is always necessary, and that framework is always subject to doubt. Sociological factors are very strong especially when the object of the science affects wealth, or health, or cultural values. It is not uncommon for large coalitions of opinion to form within communities of knowledgeable people in favor of one or another hypothesis, none of which are supported unambiguously by data. These truths dictate the strongest and most systematic kind of skepticism about conclusions drawn and expressed in these fields. My physics colleagues poke fun at post-modernist critics who say science is nothing but a subjective product of negotiation among scientists. I am very sorry to say that in these fields that are both highly complex and highly important to society, the baby of true science is sometimes difficult to discern in the murky bathwater of negotiated positions.

**3. Power:** Science is perceived, correctly, as powerful, and this is responsible for a good bit of what I called its sociological baggage. The symbols of scientific power are twentieth century icons: the mushroom cloud, the conquest of disease, information technology. No matter that these are icons of technology and not science. Science provides the conceptual infrastructure that enables these marvels.

The discovery during the past century that science has real power beyond anything previously imagined has altered traditional attitudes toward science in several ways. It has certainly increased general suspicion of science and scientists, and led to various well-documented anti-science movements. The power of science cuts both ways. Environmental and health impacts of technology can be negative as well as positive, and everyone knows it.

Another response to the immense power of science, just as important and just as predictable as anti-science, is the recruitment of the symbolism of science by advocacy movements of every kind, responsible and irresponsible. That science has undeniably discovered powerful truths about nature establishes it as the gold standard in the credibility marketplace. Ads with white coats, microscopes, intricate equipment in the background, testimonials by Ph.D.'s, 'technical articles', and an endless sequence of websites are part of a huge contemporary apparatus parasitic on the established power of science.

The challenge here to science writers is to avoid getting caught up in advocacy power games. Unfortunately, such games themselves can be newsworthy. I wish I didn't have to read that kind of news. As science journalists, you have to try to separate the games from the science, which is difficult. It is deplorable to misrepresent the science when writing about the games, or worse, to misrepresent the games as having something to do with science. The best advocacy groups are at most guilty of dismissing countervailing facts or ambiguities. The worst are fabricators. Editors' tendency to favor stories that vindicate the underdog, or the individual against the establishment, or sentiment against reason, all tend to magnify the abuse of science as a symbol of power.

**4. Ecology:** The greatest weakness in the public understanding of science is not the content of science, but how science works. Science has its own ecology in the larger environment of society.  It needs people, money, institutions, and an elaborate infrastructure of communication, evaluation, and consensus taking.  Much has been written about this, and as skeptical as I am about such literature, much of it is worth reading.  But the literature of the ecology of science is mostly addressed to academics, and the lessons it can teach us are missing from the public discourse.

I once gave a talk on science advocacy in which I described the priorities of science reporters.  They "care first about significance, second about scientists, little about institutions, and not at all about sponsors."  That is beginning to change in view of concerns about conflicts of interest, but that is not the main issue.  About half the research and development activity in this country is funded by the United States government through a surprisingly large number of agencies and programs.  The other half comes from a diverse private industry.  Who does what for which parts of science, and why and how they do it, are important and, I would hope to many people, interesting questions.  These questions are so important as to warrant some passing reference in every story.

Even many scientists are ignorant of the processes by which sustenance comes to their laboratories.  They know part of the chain, but not the whole, and they – perhaps I should say "we" – tend to focus on their (our) own field and ignore others.  One consequence is that scientists are often not effective advocates for their own interests.  Another is that policy advice from scientists often fails to close gaps critical to its implementation.  Science writers and journalists are in a position to relate the forest to the trees, and have a responsibility to do so. The challenge of dealing with an intricate and non-intuitive ecology of science is growing larger with the scale and complexity of research, and the information technology revolution that is affecting science as profoundly as any other sector.

These four themes were the first to come to mind when I received your invitation to speak today.  I think about these things often because it is my responsibility to relate science to the processes of government at the highest level.  I count myself fortunate to have this responsibility at a time when science is universally valued and strongly supported.  This Administration, and thoughtful people everywhere, want it to remain that way, and count on your integrity to help us make it so.

Thank you.