From the issue dated February 11, 2005

Reinventing Physics: the Search for the Real Frontier

By ROBERT B. LAUGHLIN

A few years ago I had occasion to engage my father-in-law, a retired academician, on the subject of the collective nature of physical law. We had just finished playing bridge late one afternoon and were working on a couple of gin and tonics in order to escape discussing movies of emotional depth with our wives. My argument was that reliable cause-and-effect relationships in the natural world have something to tell us about ourselves, in that they owe this reliability to principles of organization rather than microscopic rules. The laws of nature that we care about, in other words, emerge through collective self-organization and really do not require knowledge of their component parts to comprehend and exploit.

After listening carefully, my father-in-law declared that he did not understand. He had always thought that laws cause organization, not the other way around. He was not even sure the reverse made sense. I then asked him whether legislatures and corporate boards made laws or were made by laws, and he immediately saw the problem. He pondered it for a while, and then confessed that he was now deeply confused about why things happen and needed to think more about it. Exactly so.

It is a terrible thing that science has grown so distant from the rest of our intellectual life, for it did not start out that way. The writings of Aristotle, for example, despite their notorious inaccuracies, are beautifully clear, purposeful, and accessible. So is Darwin's *Origin of Species*. The opacity of modern science is an unfortunate side effect of professionalism, and something for which we scientists are often pilloried -- and deservedly so. Everyone gets wicked pleasure from snapping on the radio on the drive home from work to hear Doctor Science give ludicrous answers to phone-in questions such as why cows stand in the same direction while grazing (they must face Wisconsin several times a day) and then finish up with, "And remember: I know more than you. I have a master's degree in science." On another occasion my father-in-law remarked that economics had been terrific until they made it into a science. He had a point.

The conversation about physical law started me thinking about what science had to say about the obviously very unscientific chicken-and-egg problem of laws, organizations of laws, and laws from organization. I began to appreciate that many people had strong views on this subject, but could not articulate why they held them. The matter had come to a head recently when I realized I was having the same conversation over and over again with colleagues about Brian Greene's *The Elegant Universe* (W.W. Norton, 1999), a popular book about string theory -- a set of speculative ideas about the quantum mechanics of space. The conversation focused on the question of whether physics was a logical creation of the mind or a synthesis built on observation.

The impetus for the discussion was never an existential problem, of course, but money, the lack of which is the universal common denominator of world science. But the subject always seemed to drift back from there to the pointlessness of making models of the world that were beautiful but predicted no experiments, and from there to the question of what science is. After this happened a number of times in such disparate venues as Seattle, Taipei, and Helsinki, it struck me that the disagreement spawned by Greene's book was fundamentally the same problem that had occupied us that day after bridge. Moreover it was an ideological dispute: It had nothing to do with what was true and everything to do with what "true" was.

It is commonly said in physics that good notation advances while bad notation retards. This is certainly true. A phonetic alphabet takes less time to master than a pictorial one and thus makes writing more accessible. Decimal numbers are easier to use than Roman numerals. The same idea applies to ideologies. Seeing our understanding of nature as a mathematical construction has fundamentally different implications from seeing it as an empirical synthesis. One view identifies us as masters of the universe; the other identifies the universe as masters of us. Little wonder that my colleagues down in the trenches of experimental science had become so animated over the question. At its core the matter is not scientific at all but concerns one's sense of self and place in the world.

The threads of these two worlds run very deep. When I was a kid I drove with my parents to Yosemite for a rendezvous with my aunt and uncle, who had driven in from Chicago. My uncle was a brilliant and highly successful patent attorney who seemed to know everything and was not shy about sharing this fact. On this occasion he and my aunt checked in at the Ahwahnee, the fanciest hotel in the place, held court there with us, consumed a few buffet breakfasts, and then left to drive over Tuolumne Pass to the desert and home. I don't think they saw a single waterfall up close. There was no point, since they had seen waterfalls before and understood the concept.

The worldview motivating my uncle's attitude toward Yosemite, and arguably also Brian Greene's attitude toward physics, is expressed with great clarity in John Horgan's *The End of Science* (Addison-Wesley, 1996), in which he argues that all fundamental things are now known and there is nothing left for us to do but fill in details. This pushes my experimental colleagues beyond their already strained limits of patience, for it is both wrong and completely below the belt. The search for new things always looks like a lost cause until one makes a discovery. If it were obvious what was there, one would not have to look for it.

Unfortunately this view is widely held. I once had a conversation with the late David Schramm, the famous cosmologist at the University of Chicago, about galactic jets. These are thin pencils of plasma that beam out of some galactic cores to fabulous distances, sometimes several galactic radii, powered somehow by mechanical rotation of the core. How they can remain thin over such stupendous distances is not understood, and something I find tremendously interesting. But David dismissed the whole effect as "weather." He was interested only in the early universe and astrophysical observations that could shed light on it, even if only marginally. He categorized the jets as annoying distractions on the grounds that they had nothing in particular to tell him about what was fundamental. I, by contrast, am fascinated by weather and believe that people claiming not to be are fibbing.

I think primitive organizational phenomena such as weather have something of lasting importance to tell us about more complex ones, including ourselves: Their primitiveness enables us to demonstrate with certainty that they are ruled by microscopic laws but also, paradoxically, that some of their more sophisticated aspects are insensitive to details of these laws. In other words, we are able to prove in these simple cases that the organization can acquire meaning and life of its own and begin to transcend the parts from which it is made.

What physical science thus has to tell us is that the whole being more than the sum of its parts is not merely a concept but a physical phenomenon. Nature is regulated not only by a microscopic rule base but by powerful and general principles of organization. Some of these principles are known, but the vast majority are not. New ones are being discovered all the time. At higher levels of sophistication the cause-and-effect relationships are harder to document, but there is no evidence that the hierarchical descent of law found in the primitive world is superseded by anything else. Thus if a simple physical phenomenon can become effectively independent of the more fundamental laws from which it descends, so can we. I am carbon, but I need not have been. I have a meaning transcending the atoms from which I am made.

I am increasingly persuaded that all physical law we know about has collective origins, not just some of it. In other words, the distinction between fundamental laws and the laws descending from them is a myth -- as is therefore the idea of mastery of the universe through mathematics solely. Physical law cannot generally be anticipated by pure thought, but must be discovered experimentally, because control of nature is achieved only when nature allows this through a principle of organization.

One might subtitle this thesis the end of reductionism (the belief that things will necessarily be clarified when they are divided down into smaller and smaller component parts), but that would not be quite accurate. All physicists are reductionists at heart, myself included. I do not wish to impugn reductionism so much as establish its proper place in the grand scheme of things.

To defend my assertion I must openly discuss some shocking ideas: the vacuum of space-time as "matter," the possibility that relativity is not fundamental, the collective nature of computability, epistemological barriers to theoretical knowledge, similar barriers to experimental falsification, and the mythological nature of important parts of modern theoretical physics. The radicalness is, of course, partly a stage prop, for science, as an experimental undertaking, cannot be radical or conservative but only faithful to the facts. But these larger conceptual issues, which are not science at all but philosophy, are often what most interest us because they are what we call upon to weigh merit, write laws, and make choices in our lives.

The objective, then, is not to make controversy for the sake of itself but to help us see clearly what science has become. To do this we must forcibly separate science's function as the facilitator of technology from its function as a means of understanding things -- including ourselves. The world we actually inhabit, as opposed to the happy idealization of modern scientific mythology, is filled with wonderful and important things we have not yet seen because we have not looked, or have not been able to look because of technical limitations. The great power of science is its ability, through brutal objectivity, to reveal to us truth we did not anticipate. In this it continues to be invaluable, and one of the greatest of human creations.

The idea of science as a great frontier is timeless. While there are clearly many nonscientific sources of adventure left, science is the unique place where genuine wildness may still be found. The wildness in question is not the lurid technological opportunism to which modern societies seem so hopelessly addicted but rather the pristine natural world that existed before humans arrived -- the vast openness of the lone rider splashing across the stream with three pack animals under the gaze of mighty peaks. It is the choreography of ecologies, the stately evolution of minerals in the earth, the motion of the heavens, and the birth and death of stars. Rumors of its death, to paraphrase Mark Twain, are greatly exaggerated.

My particular branch of science, theoretical physics, is concerned with the ultimate causes of things. Physicists have no monopoly on ultimate causes, of course, for everyone is concerned with them to some extent. I suspect it is an atavistic trait acquired long ago in Africa for surviving in a physical world in which there actually are causes and effects -- for example between proximity to lions and being eaten. We are built to look for causal relations between things and to be deeply satisfied when we discover a rule with cascading implications. We are also built to be impatient with the opposite -- forests of facts from which we cannot extract any meaning. All of us secretly wish for an ultimate theory, a master rule set from which all truth would flow and which could forever free us from the frustration of dealing with facts. Its concern for ultimate causes gives theoretical physics a special appeal even to nonscientists, even though it is by most standards technical and abstruse.

Learning about these things is an intellectual roller-coaster ride. First you find that your wish for an ultimate theory at the level of people-scale phenomena has been fulfilled. We are the proud owners of a set of mathematical relationships that, as far as we know, account for everything in the natural world bigger than an atomic nucleus. They are very simple and beautiful and can be written in two or three lines. But then you find that this simplicity is highly misleading. The equations are devilishly difficult to manipulate and impossible to actually solve in all but a small handful of instances. Demonstrating that they are correct requires arguments that are lengthy, subtle, and quantitative. While the basic ideas were invented by Schrödinger, Bohr, and Heisenberg in the 1920s, it was not until powerful electronic computers were developed and armies of technically competent people were generated by governments that these ideas could be tested quantitatively against experiment over a wide range of conditions.

Thus 80 years after the discovery of the ultimate theory we find ourselves in difficulty. The repeated, detailed experimental confirmation of these relationships has now officially closed the frontier of reductionism at the level of everyday things. Like the closing of the American frontier, this is a significant cultural event, causing thoughtful people everywhere to debate what it means for the future of knowledge. At the same time, the list of even very simple things found "too difficult" to describe with these equations continues to lengthen alarmingly.

Those of us on the real frontier listening to the coyotes howl at night find ourselves chuckling over all of this. There are few things a real frontiersman finds more entertaining than the insights from people back in civilization who can barely find the supermarket. I find this moment in history charmingly similar to Lewis and Clark's wintering on the Columbia estuary. Through grit and determination their party had pushed its way across a continent, only to discover that the value had not been in reaching the sea but in the journey itself. The official frontier at that time was a legal fiction having more to do with property rights and homesteading policy than with a confrontation with nature. The same is true today. The real frontier, inherently wild, may be found right outside the door, if one only cares to look.

The important laws we know about are, without exception, serendipitous discoveries rather than deductions. This is fully compatible with one's everyday experience. The world is filled with sophisticated regularities and causal relationships that can be quantified, for this is how we are able to make sense of things and exploit nature to our own ends. But the discovery of these relationships is annoyingly unpredictable and certainly not anticipated by scientific experts. This common-sense view continues to hold when the matter is examined more carefully and quantitatively. It turns out that our mastery of the universe is largely a bluff -- all hat and no cattle. The argument that all the important laws of nature are known is part of this bluff.

Thus the end of knowledge and the closing of the frontier it symbolizes is not a looming crisis at all, but merely one of many embarrassing fits of hubris in civilization's long history. In the end it will pass away and be forgotten. Ours is not the first generation to struggle to understand the organizational laws of the frontier, deceive itself that it has succeeded, and go to its grave having failed. One would be wise to be humble, like the Irish fisherman observing quietly that the sea was so wide and his boat so small. The wildness we all need to live, grow, and define ourselves is alive and well, and its glorious laws are all around.

Robert B. Laughlin is a professor of physics at Stanford University and a 1998 Nobel laureate in physics. He is on leave from Stanford to serve as president of the Korea Advanced Institute of Science and Technology, in Taejon, South Korea. This essay is adapted from A Different Universe: Reinventing Physics From the Bottom Down, *to be published in March by Basic Books.*

----

http://chronicle.com
Section: The Chronicle Review
Volume 51, Issue 23, Page B6