nature

BOOKS & ARTS

Unburdened by proof

String theorists are setting a worrying trend by downplaying the need for experimental evidence.

The Trouble With Physics: The Rise of String Theory, the Fall of a Science, and What Comes Next
by Lee Smolin
Houghton Mifflin: 2006. 416 pp. $26


W. CROCKER/GETTY

At breaking point: string theorists' approach to evidence is threatening to split the physics community.

George Ellis

String theory — the proposal that physics is based on two-dimensional entities ('strings') vibrating in ten-dimensional space-time — is viewed by many physicists as the most promising approach to unifying all the fundamental forces of nature. It could, they claim, provide the ultimate 'theory of everything'. But they are seemingly facing a dead-end in their attempts to turn string theory into an experimentally verifiable, fundamental theory of all physics.

There are several problems. The mathematics is so complex that realistic solutions are hard to achieve. The energies involved in testing most versions of the theory are beyond those attainable in particle accelerators. And a recently discovered 'landscape' of string theory predicts that the theory can lead to many versions of low-energy physics depending on the circumstances. What's more, because string theory, if true, can explain virtually anything, it cannot be disproved by any local physical experiment. As a result, some influential string theorists are pushing for the traditional evidence-based approach to science to be replaced by one in which the beauty or elegance of a theory largely replaces experimental confirmation as the basis for belief in its veracity.

In *The Trouble with Physics*, Lee Smolin writes that the theory "has failed to make any predictions by which it can be tested, and some of its proponents, rather than admitting that, are seeking leave to change the rules so that their theory will not need to pass the usual tests we impose on scientific ideas". This would leave not just physics but the whole of science facing something of a crisis. If the grounds of proof that have been the basis of scientific success for the past three hundred years are to be changed, our understanding of what is genuine science will be brought into question.

Most of the recent popular books on uniting gravitational theory and quantum physics present a positive view of string theory and its successes. But Smolin's book and Peter Woit's *Not Even Wrong* (Jonathan Cape, 2006) are critical both of string theory itself and of the effect it has had on theoretical physics by dominating the field in recent decades.

Smolin begins with an excellent presentation of the foundations of fundamental physics, laying the ground for an understanding of the roots of both the present aims of string theory and its problems. He makes the excitement and promise of such a unifying theory come alive. He then carefully examines what the theory can and cannot explain, explores the difficulties in subjecting it to experimental verification, and discusses problems in its structure.

One problem Smolin highlights is that string theory does not take on board one of the main lessons of the general theory of relativity: a properly formulated theory of fundamental physics that includes gravity should not be based on a fixed background space-time. A major problem is that string theory is not yet a well-defined theory, just a broad programme of research: "What we know of string theory consists mostly of approximate results and conjectures." It has been conjectured that these various results are unified in a deeper theory called M-theory, which involves entities called membranes living in 11 space-time dimensions, but the nature of this theory is unknown. Discussing the string-theory landscape, Steven Weinberg said: "It wouldn't hurt in this work if we knew what string theory is."

A practical problem is that all explicitly known string theories disagree with established facts about our world — for example, most specific cases where we can do exact calculations have unbroken supersymmetry, which is not true of the real world. Celebrated results attained with regard to black-hole entropy do not refer to realistic black holes that might occur in astrophysics. And in terms of actual results, string theory makes no new predictions for experimental observations, even though its proponents are aware of the need for such predictions. String theory's major strength is that it impressively unifies the kinds of particles and forces we already know about, but it cannot, for example, predict the parameters of the standard model of particle physics, one of the main aims of such a unifying theory.

String theory's most important prediction is that there are many more dimensions than determined by everyday physical experiment. Either these dimensions are wrapped up so small that we cannot detect them, or we live trapped on a four-dimensional surface (a 'brane') embedded in a larger 'bulk' space-time, and so are unable to directly experience these higher dimensions. But so far there is not the slightest evidence that the claim of extra dimensions is true. Despite this, many string theorists are dogmatic about them because their mathematical theories demand that they exist, even though there is no evidence that these theories apply to the real Universe in which we live. Simpler theories can explain just as much as string theory, but a unified description would be far preferable. However, until we have proof that a unified theory exists, its existence remains no more than conjecture.

Given these problems, some string theorists now have the more modest goal of understanding high-energy physics by means of some interesting dualities that enable easy calculations to give results for very hard ones. But this aim has not received the same publicity as that of finding a unified 'theory of everything'.

So, a theory that is unable to produce any testable new predictions has dominated theoretical physics for 30 years. Given the difficulty of the task, there is nothing wrong with this: we can hope it will eventually work out, and it is reasonable to expect such a fundamentally important enterprise to take a long time. More problematic is the attitude of some string theorists that it is not worth investigating alternatives. There is an unquestioning assumption that string theory's claims must be true, even though there is no solid evidence for them, and this is often expressed with considerable arrogance and an attitude that nothing else is worthwhile physics. String theory has dominated appointments to academic positions in theoretical physics for decades, effectively impeding a broader investigation of quantum gravity and the fundamental nature of spacetime. It is claimed to be the only game in town, but insofar as the aim is to quantize gravity, there are alternatives, and Smolin briefly outlines some of the more promising ones.

Some of the sociological issues that come into play here are the subject of interesting chapters, based on Smolin's own experiences. A sad aspect is the *ad hominem* attacks made on those who question the theory, including serious thinkers being labelled by the derogatory term 'popperazzi'. This term makes clear how some string theorists regard their views as so overwhelmingly convincing that it is no longer necessary to retain experimental testing as the core of the scientific approach. Smolin crystallizes what many in the physics community feel about these extravagances of string theory.

Those advocating a focus on 'beauty' and 'miracles' when evaluating their theories don't seem to have thought through the implications. The weakening of criteria proposed by some string theorists will, if accepted, open the doors to many other faith-based enterprises that would be only too glad to be viewed as science. In particular, scientific opposition to 'intelligent design' centres on an insistence that for a theory to be scientific it must be testable, observationally or experimentally. Proponents of intelligent design must surely welcome the freedom from evidential constraints that some string theorists are proposing.

What is crucially needed in developing string theory is a serious attempt to engage with the philosophy of science, developing an approach to theory validation that is adequate where insubstantial evidential support has to be supplemented by other principles of inference. So far, this has not been done. ■

George Ellis is in the Department of Mathematics, University of Cape Town, Cape Town 7701, South Africa.

Developing diversity

The Regulatory Genome: Gene Regulatory Networks in Development and Evolution
by Eric H. Davidson
Elsevier: 2006. 304 pp. $69.95, £43.99

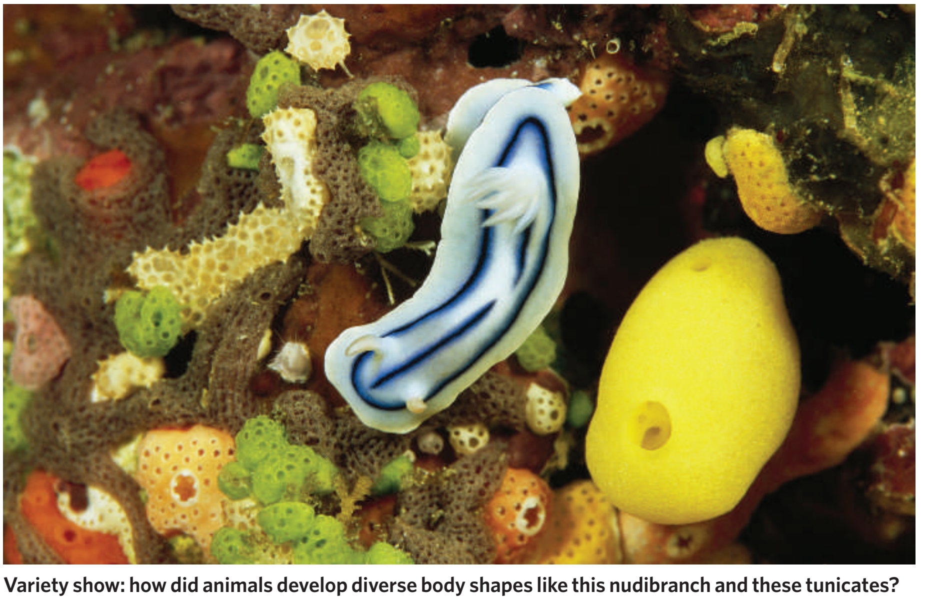
Michael Karin

All living organisms deploy similar evolutionarily conserved mechanisms to generate energy, replicate their genomes, use genetic information and synthesize basic building-blocks for their cells. Yet the myriad shapes and forms of both plants and animals are overwhelming in their variety and extremes. What is even more amazing is that most plants and animals start their life as a single diploid cell (a zygote) created by the union of a sperm and an egg. How these simple cells give rise to such complex creatures with diverse body shapes is a major preoccupation of developmental biologists.

Developmental biology mainly deals with the processes and regulatory mechanisms that guide the conversion of a unicellular zygote into a multicellular organism. The progression of body shapes and forms over evolutionary time is another fascinating topic that occupies students of development and evolution alike. As Eric Davidson convincingly argues in his book *The Regulatory Genome*, animal (and plant) development is driven by a "dynamic progression of regulatory states, defined by the presence and state of activity in the cell nuclei of particular sets of DNA recognizing regulatory proteins (transcription factors), which determine gene expression". An equally important contributor to development is the "genomic apparatus that encodes the interpretation of these regulatory states". Over evolutionary time, "the alteration of body plans is caused by changes in the organization of this core genomic code for developmental gene regulation". The genomic code that dictates animal development and the genetic apparatus that implements it are the main topics of the book.

Initially a descriptive science, developmental biology has benefited hugely from the revolution in molecular biology of the past 30 years. Indeed, *The Regulatory Genome* is entirely different from Davidson's first book, *Gene Activity in Early Development* (Academic Press, 1968), which preceded molecular cloning and rapid DNA sequencing. However, even in the earlier book, which I remember reading as a graduate student, Davidson championed a quantitative, biochemical and mechanistic approach to the study of developmental biology. His latest book goes many steps beyond that, explaining the basic processes of development and evolution in terms of information processing and computational logic. *The Regulatory Genome* incorporates and integrates many recent advances in understanding gene regulation and genomic organization in a quest for a unified model to explain animal development and the evolution of body shapes and forms.

As a scientist interested in gene regulation and signal transduction, I think the most important and valuable message conveyed by the book is the central role of the DNA elements, the *cis*-regulatory elements and control units, in both development and evolution. Most molecular biologists are occupied as I am with the study of regulatory proteins, either transcription factors or signal transducers that eventually modulate transcription-factor activity. So it is a refreshing and sobering realization that the *cis*-regulatory elements — the genomic DNA units recognized by sequence-specific transcription factors — occupy a more central role in the design of the genetic circuits and networks that control developmental



T. LAMAN/GETTY

Variety show: how did animals develop diverse body shapes like this nudibranch and these tunicates?