Philip Flip Kromer
J. Leon PHL 329U
April 5, 2005

The Epistemology of String Theory

The long history of scientific inquiry has yielded a rich edifice of scientific thought, encompassing a remarkable range of physical phenomena. We can explain the evolution of the galaxies and the evolution of the species. We can describe the interaction of planets and stars across the broad reaches of the universe, and we can describe the interaction of quarks and electrons within the recondite recesses of the atom. These theories are accepted as true because they are self-consistent and because they have been extensively verified by experiment.

String Theory, a theoretical framework that aims to unify and explain general relativity and quantum field theory, cannot now – and may never – make direct, falsifiable experimental predictions. Yet some adherents of the theory make a surprising claim: that if a coherent, unique and self-sufficient formulation of String Theory is found it should be accepted as true[1]. They maintain that coherence, beauty, uniqueness and self-sufficiency (the exact meaning of these terms is explained further below) are not coincidental properties but rather the hallmarks that show the theory to be true. Steven Weinberg writes that he believes "this particular period will be remembered as a heroic age when theorists cut themselves temporarily free from their experimental underpinnings and tried and succeeded through pure theoretical reasoning to develop a unified theory of all the phenomena of nature." [Weinberg, "The Elegant Universe"]

Philosophy of Science

This marks a new front in an old debate on the epistemology of science, the argument about how we determine what is true. Broadly speaking, epistemological theories of science are either Rationalist (knowledge is obtained through reason and introspection) or Empiricist (knowledge is obtained through observation and experiment). The proponents of String Theory seem to belong to the school of Rationalist thought known as Coherentism, which holds that our theories of the universe are justified by their self-consistency – by their coherent integration in our total web of knowledge. For a Coherentist, ideas are not justified by deduction from foundational axioms, and they are not justified by the problematic means of experiential observation. They are justified by the totality of our knowledge. The more we know and the more tightly constrained our framework the less possible that our knowledge is flawed.

Empiricists, on the other hand, demand 'correspondence:' agreement with experiment or observation. They grant priviledged, foundational primacy to measurement of nature, and say that our theories of the universe are grounded in the bedrock of experience. For empiricists, experiment forms the ultimate and only test of truth:

> "... We compare the result of the computation to nature, with experiment or experience, compare it directly with observation, to see if it works. If it disagrees with experiment it is wrong. In that simple statement is the key to science. It does not make any difference how beautiful your guess is... if it disagrees with experiment it is wrong. That is all there is to it." [Feynman, Character of Physical Law 150]

There are several ways to frame the Empiricists' objection to String Theory. First, however, let's look at how the proponents of String Theory justify their belief in its eventual success.

Thesis: Nature is Mathematical

Besides consistency and correspondence with experiment, scientists have noticed that successful physical theories are uniformly found to have several surprising additional properties. Successful theories are 'beautiful' – they appeal to scientists' sense of mathematical elegance. They are

[1] Right now there is no single accepted formulation of String Theory, rather a framework within which we may work out a unified theory. We do not know if we will ever arrive at one. Many String Theorists hold out hope that we will.

'productive' – they extend well beyond the domain in which they are formulated. They are 'unique' – a small change to the theory destroys its self-consistency or its correspondence with experiment.

Each of these features is not necessarily to be expected. Mathematicians develop their ideas simply on the basis of what seems 'elegant' or 'interesting,' with no regard to utility or correspondence with nature. “The concepts of mathematics are not chosen for their conceptual simplicity ... but for their amenability to clever manipulations and to striking, brilliant arguments.” [Wigner, “Unreasonable Effectiveness...”] These concepts nonetheless consistently apply to the description of the laws of the universe. Furthermore, scientific ideas developed on the basis of their conceptual beauty are remarkably successful. Einstein's developed his theory of General Relativity by adopting two basic principles (relativity and equivalence) and from them deducing a coherent physical framework, yet he found that not just Newton's dynamics but a whole host of physical explanations emerged.

Successful theories are often found to apply well beyond their domain of formulation. When you carry Newton's conjecture – that the attraction between celestial objects and the earth is the same as between terrestrial objects and the earth – to its logical conclusion, it predicts not only the elliptical orbit of the planets but the shape and trajectory of all range of astronomical objects. It also implies the finite speed of light (the Roemer result) and the existence of other planets (the discovery of Neptune)[2].

Perhaps this “unreasonable effectiveness” is no coincidence – perhaps it reveals that the universe, at a deep level, is mathematical.

Successful Scientific Theories are Unique

Another surprising feature of advanced scientific theories is that they are 'theoretically unique:' change the theory in any small way and it quickly becomes untenable. Weinberg writes,

> “It is easy to think of ways of changing most physical theories in small ways. ... It is striking that is has so far not been possible to find a logically consistent theory that is close to quantum mechanics, other than quantum mechanics itself. ... I simply do not know how to change quantum mechanics by a small amount without wrecking it altogether. This theoretical failure to find a plausible alternative to quantum mechanics ... suggests to me that quantum mechanics is the way it is because any small change in [it] would lead to logical absurdities. ” [Weinberg, DFT 89-93]

This doesn't mean that there is *no* other theory, but it does mean that coherent and predictive theories are hard to come by: “It seems to me that our best hope is to identify the final theory as one that is so rigid that it cannot be warped into some slightly different theory without introducing logical absurdities.” [DFT 17] It also leads to a further surprising feature of String Theory: its proponents belieive that, in its final formulation, it may be a self-sufficient theory – one with no adjustable parameters.

> “In my view, our best hope along this line is to show that the final theory, though not logically inevitable, is logically *isolated*. That is, it may turn out that, although we shall always be able to imagine other theories that are totally different from the true final theory..., the final theory we discover is so rigid that there is no way to modify it by a small amount without the theory leading to logical absurdities. In a logically isolated theory every constant of nature could be calculated from first principles; a change in the value of any constant would destroy the consistency of the theory. ” [DFT 249]

General Relativity identifies the local curvature of space with the local gravitational field, which naturally yields the inverse-square law of Newtonian dynamics. Newton could not explain *why* the force diminishes as 1/r^2, rather than, say, 1/r^2.0001. In General Relativity this fact becomes *necessarily* true: the exponent cannot be changed, even a little. As Einstein said, “The chief attraction of the theory lies in its logical completeness; ... to modify it without destroying the whole structure seems to be impossible.” [DFT 142, quoting *American Scholar* 48:323]. Similarly, String Theory tightly constrains a whole range of physical parameters, and naturally explains a host of messy coincidences (such as the 'generations' of the Standard Model). Just as the geometry of General Relativity determines the 1/r^2 exponent, String theorists hope to eventually arrive at a framework in which topology determines everything from Planck's constant to the reason there are six quarks.

---

2 This example taken from Feynman, The Character of Physical Law p 12-14.

Proponents of String Theory believe that such a theory – one that is not only beautiful and self-consistent, but also self-sufficient[3], tightly constrained and theoretically unique – must be true.

Objection: A Theory can be Consistent and Wrong

Empiricists object, pointing out that a system of knowledge can be coherent, plausible – and wrong:

> "What is necessary 'for the very existence of science,' and what the characteristics of nature are, are not to be determined by pompous predictions, they are determined always by the material with which we work, by nature herself. We look, and we see what we find, and we cannot say ahead of time successfully what it is going to look like. The most reasonable possibilities often turn out not to be the situation." [Feynman, CoPL 141-142]

String Theory fails as a theory because it doesn't even show up to be tested:

> "No experiment can ever check up what's going on at the distances that are being studied. No observation can relate to these tiny distances or high energies. All we can do is look at the distant consequences, 10 or 20 orders of magnitude removed from these effects." [Glashow, EU]

According to an Empiricist, correspondence with experiment is the only judge of truth, and without it String Theory can make no claim to correctness.[4]

Response: String Theory Coheres and Corresponds

However, String Theory *does* correspond with a myriad of well-tested experiments. Since a successful String Theory consequentially includes the Standard Model and General Relativity, the many and careful tests used to justify these theories also serve to justify String Theory. Furthermore, there are experimental facts that appear coincidental in the standard theories which are explained by String Theory. For example, the black hole entropy theory arises as an ad-hoc hypothesis in general relativity but as a natural consequence of String Theory. [Bekenstein]

Objection: Falsifiable Predictions are the Test of Scientific Truth

This leads many Empiricists to make a more nuanced rejection of String Theory: that if it doesn't say anything *new*, it is neither right nor wrong but in fact does not belong to science at all.

> "The string theorists have a theory that appears to be consistent and is very beautiful, very complex, and I don't understand it. It gives a quantum theory of gravity that appears to be consistent but doesn't make any other predictions. That is to say, there ain't no experiment that could be done nor is there any observation that could be made that would say, "You guys are wrong." The theory is safe, permanently safe. I ask you, is that a theory of physics or a philosophy?" [Glashow, EU]

> "String theory and string theorists do have a real problem. How do you actually test string theory? If you can't test it in the way that we test normal theories, it's not science, it's philosophy, and that's a real problem. We think now with our current understanding of string theory that it's very hard for string theory to make the kind of detailed scientific predictions that you normally make with a theory. We just don't understand how to do that with string theory yet." [Lykken, EU]

> "At the end of the day, if string theory does not provide us with a testable prediction—whether it be in the context of elementary particle physics or cosmology and black hole physics—then nobody should believe it." [Gates, EU]

This accords with Karl Popper's philosophy that "a theory should be accounted scientific if and only if it is falsifiable." [Wikipedia on Karl Popper] Since, for the Empiricists, observational accounts have epistemological primacy, a theory that cannot make connection to observation and experiment simply lies outside of anything we can say to be true or false.

Response: String Theory's Self-Sufficiency Gives it Foundation

However, experiment and observation are deeply problematic processes. The philosophy of science is fraught with ways in which our senses can lead to inconsistent and unreliable information.

---

3 We don't know whether a completely self-sufficient theory is possible. The 'Landscape' argument implies that we will not. Many String Theorists hold out hope that we will.

4 This paper examines the argument that String Theory is true even in the absence of new testable predictions. We don't know whether, when a complete String Theory emerges, we will be able to make testable predictions or not. Many String Theorists hold out hope that we will.

Furthermore, Quantum Mechanics – our (experimentally verified and theoretically coherent) understanding of the universe – shows that experiments are necessarily physical processes. Our rationalist framework is essential for understanding the mechanism by which an observation or measurement is carried out. How can we grant epistemological primacy to observation when we need theory to understand the process of observation itself?

While Weinberg may be reluctant to call a self-sufficient String Theory "logically inevitable," only "logically isolated," perhaps we should not be so shy. As Einstein said, perhaps "Nature is so constituted that it is possible logically to lay down such strongly determined laws that within these laws only rationally completely determined constants occur (not constants, therefore, whose numerical value could be changed without destroying the theory)." [Einstein, Albert Einstein Philosopher-Scientist 63] If String Theory is able to explain the laws of nature with no free parameters – if it unveils a tightly constrained yet coherent vision of how the universe operates, in a completely self-sufficient manner – then we should feel quite comfortable granting the truth of such a framework.

Objection: Possibility of Multiple Theories

It is important to note that, although practicing physicists may disagree on what makes an idea true, they overwhelmingly subscribe to Realism, the belief that scientific truth mirrors an underlying and independent reality. Steven Hawking famously said "If we find [a complete theory], it would be the ultimate triumph of human reason - for then we would know the mind of God." [Hawking, A Brief History of Time 191]. Weinberg explicitly puts himself down as "taking what a historian of philosophy would call the 'Realist' position – ... of believing in the reality of abstract ideas." [DFT 48] Others frequently reference the 'tapestry,' 'blueprint' or 'design' of nature [e.g. Feynman, CoPL 28]. The whole notion of a "Final Theory of Everything" implies an independent, ineluctable structure of the universe that the human mind can uncover.

However, philosophers from the Anti-Realist camp raise the Underdetermination objection – "that there exists an unlimited number of different options to fit any set of physical data." Theoretical Uniqueness argues that there are no coherent theories *similar* to the ones we believe, but cannot rule out an equally viable but quite distinct theory. In fact, they point out, this has happened – the theory of General Relativity replacing Newton's Gravitation, for example.

Response: No Miracles

However, the remarkable success of mathematically elegant theories, even beyond their domain of fomulation, argues that the theories are not arbitrary constructs. "Scientific Realists claim that scientific success and prediction of new phenomena in particular had to be seen as a miracle [unless] the statements of science are at least approximately true ... the 'No Miracles' argument." If there are several true theories that cohere with everything we know, how do we keep picking the right one – the theory that will extend well beyond the facts used in its development and proof, to explain a host of unexpected consequences? It is because there *is* an independent reality, and our minds are capable of uncovering and comprehending it.

It is important to point out that although two theories may explain the same phenomena – say, String Theory and the Standard Model – this argues *for* their validity, as one theory coherently includes the other.

> "The Standard Model is here to stay. It is a full mathematical theory – a multiply connected and highly stable edifice. It will turn out to be one piece of a larger such edifice, but it cannot be 'wrong.' No part of the theory can fail without a collapse of the entire structure. If the theory were wrong, many successful tests would be accidents. It will continue to describe strong, weak, and electromagnetic interactions at low energies." [Kane, "Dawn of Physics Beyond the Standard Model"]

An Analogy

Imagine that we are doing a jigsaw puzzle. After much work and careful searching we have pieced together two large sections of the puzzle, one of them depicting quantum mechanics and one of them depicting gravity. They each are consistent: all their internal pieces fit together in a satisfying and complete manner. Futhermore, we have the box the jigsaw puzzle came in, with a picture of the assembled puzzle. Our large sections correspond, in every way that we can tell, with the picture on the front of the box.

However, these two large and important sections of our puzzle don't fit together at all, and it's clear that a fair number of additional puzzle pieces will be required to join them together. Even more worrisome, we've covered most of the solution shown on the front of the box – we might get to verify an interstitial piece here or there, but it appears the complete puzzle will extend well beyond what we can compare.

Now, what if we were able to come up with a well-fitting structure of pieces that not only meshed with the existing sections, but also *extended all the way to the edges*. This additional structure has nice, straight edges – a self-justifying form for which no externally contextualizing pieces are required or even possible. Once this structure is in place, the position of everything within it is uniquely determined, in the sense that no minor rearrangement of pieces is possible. We can't prove that, if we tore down a huge section and reassembled it, we couldn't find another solution – but barring such a major reconstruction our placement of the pieces seems uniquely constrained.

In this case, would we be justified – even without access to the full picture of the solution – in saying that we had completed the jigsaw puzzle?

Conclusion

The Empiricist would say that we can put the puzzle together however we please, but we cannot say that we have 'solved' the puzzle without comparing it to the box top. The Positivist would admit we've done *something* by completing the puzzle – but that something is not useful or interesting. It's just not good “jigsaw-puzzling” unless our solution allows definite, testable comparison to the box top in a new and falsifiable way. The Anti-Realist would object that there can be many, perhaps infinite, ways to assemble the remaining pieces. We may only discover one, or only discover one that we find 'elegant,' yet we can never prove that others don't exist.

The Unique Coherentist (such as many proponents of String Theory) argue that all of our experience in assembling jigsaw puzzle lends confidence that our solution is correct, simply because it is elegant and consistent. Our solution *does* demonstrate significant correspondence – it agrees with as much of the box top as we have available. In solving the puzzle up to now, we have found that large chunks of the solution *are* unique. Sure, sometimes we've had to tear off a couple of pieces around the edge to incorporate a new element or unify two sections of the puzzle, but the bulk of any coherent section of the puzzle always seems to survive as part of the new, larger chunk. And finally, the fact that we have found nice, clean edges to the puzzle – a sensible and autonomous structure – is too much of a coincidence to deny. It would seem undeniable that such jigsaw puzzles, like scientific theories, are meant to be understood in a unique and elegant final form, one whose elegance and autonomy shows its essential correctness.

Bibliography

Bekenstein, J.D. “Information in the Holographic Universe,” *Scientific American* 289:2 p. 58 (8/03).

Bousso, R & J Polchinski. “The String Theory Landscape,” *Scientific American* 291:3 p. 78 (9/04).

Dawid, Richard. “Scientific Realism in the Age of String Theory,” http://philsci-archive.pitt.edu/archive/00001240/01/re+str.PDF

Dawid, Richard. “Undetermination and Theory Succession from a String Theoretical Perspective,” http://philsci-archive.pitt.edu/archive/00001744/01/Underdet._&theor._evol..doc

Einstein, Albert. *Albert Einstein, Philosopher-Scientist*. Open Court 1988.

Encyclopedia Britannica Online. “Philosophy of Science.”

Feynman, Richard. *The Character of Physical Law*. Modern Library 1994.

Greene, Brian, with Scientific American. “The Future of String Theory: A Conversation with Brian Greene,” *Scientific American* 289:5 p. 68 (11/03).

Hamming, R.W. “The Unreasonable Effectiveness of Mathematics,” *Am. Math. Monthly* 87:2 (2/80).

Hawking, Steven. *A Brief History of Time*. http://library.thinkquest.org/28550/concl.htm

Hawking, Steven. *The Universe in a Nutshell*. Bantam Books 2001.

Hedrich, Reiner. “Superstring Theory and Empirical Testability.” http://philsci-archive.pitt.edu/archive/00000608/00/superstr.doc

Kane, G. “The Dawn of Physics Beyond the Standard Model,” *Scientific American* 288:6 p.68 (6/03).

Mukhi, Sunil. “String Theory and the Unification of Forces.” http://theory.tifr.res.in/~mukhi/Physics/string.html

PBS' Nova Series. “Viewpoints on String Theory,” from “The Elegant Universe” website. http://www.pbs.org/wgbh/nova/elegant/viewpoints.html

Weinberg, Steven. *Dreams of a Final Theory* (preprint edition). Pantheon Books 1992.

Weinberg, Steven. *The First Three Minutes*. Basic Books 1988.

Weinberg, Steven. “A Unified Physics by 2050?” *Scientific American* Special Edition 13:1 p.4 (5/03).

Wigner, Eugene. “The Unreasonable Effectiveness of Mathematics in the Natural Sciences,” *Pure Mathematics* 13:1, Feb 1960.

Wikipedia.

“Coherentism”	http://en.wikipedia.org/wiki/Coherentism
“Black Hole Entropy”	http://en.wikipedia.org/wiki/Black_hole_entropy
“Philosophy of Science”	http://en.wikipedia.org/wiki/Philosophy_of_science
“Epistemology”	http://en.wikipedia.org/wiki/Epistemology
“Karl Popper”	http://en.wikipedia.org/wiki/Karl_Popper#Popper.27s_philosophy

Woit, Peter. “String Theory and Philosophy” from “Not Even Wrong” website. http://www.math.columbia.edu/~woit/blog/archives/000108.html