Empirical incompleteness and the search for a theory of everything

First, let me provide a disclaimer. Contrary to widespread popular belief, a theory of everything, a complete description of how elementary particles interact, can’t really cover “everything.” It would be foolish to believe that one could step up from fundamental particles to explain why Earth has a single moon or why humans evolved here.

A complete description of something is implicitly final: It implies that nothing else fundamental to it and capable of changing our views remains to be discovered. To imagine such a complete description as an achievable goal in an empirical science is, to me, untenable. Were we to construct a complete theory of everything by unifying the four known interactions, nothing else fundamental in particle physics could be discovered. The assumption is that no other possible forces of nature and no deeper level of more fundamental particles lurk behind our current ignorance. How can we be sure? For example, the running of the coupling constants—the property that the strengths of the interactions become comparable at high energies—even if true, doesn’t exclude other possible forces.

Our knowledge of physical reality is based on what we can measure. Even though our instruments are always getting more accurate, we are bound by empirical incompleteness. The LHC, amazing as it is, will probe physics some 12 orders of magnitude below the grand unification scale of about 10^{16} GeV. That’s a huge gap. Cosmology will surely help, as we gain an improved understanding of dark matter and dark energy. Still, it’s hard to imagine that our instruments will one day be able to measure all there is to measure. So how do we determine that we have a complete theory?

Many say that Albert Einstein was fated to fail in his search for unification because he left out the two nuclear forces. Even if supersymmetry is discovered and we find a unified description of the four known interactions, could we state that we are done? Think of how Kepler would have reacted had he known of the existence of Uranus and Neptune. Certainly we should search for more simplified descriptions of reality. We will only know how far we can go by trying, and there is much to discover. The standard model of particle physics, with its 20-plus free parameters, still holds many secrets. In the coming years, we can expect the LHC and the many ongoing and future cosmological experiments to bring us new challenges and possibly allow us to reach new partial unifications. But the notion that nature possesses an overarching symmetry, although aesthetically appealing, need not be right. Apologies to John Keats, but beauty need not be truth. Judging from all the symmetry violations in the weak interactions, perhaps we should rethink what we call beautiful in nature.

The standard model is not a true unification, as it mixes three symmetry groups. Proton decay and magnetic monopoles, the experimental signatures of the almost four-decades-old grand unified theories, have so far failed to materialize. Gravity, many now speculate, may not be a fundamental force. The expectation of a complete unification based on a single symmetry group is the modern incarnation of the age-old Pythagorean dream. We have to wonder if nature really is so tidily packaged or if that is just how we would like it to be.

References

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HBCUs need better marketing

Quinton Williams’s Opinion piece about undergraduate physics programs at historically black colleges and universities (HBCUs; Physics Today, June 2010, page 47) inspired me to write this response and challenge.

I gathered from the piece that some,