Theory, Phenomenology, and 'Who Ordered That?'

Harry J. Lipkin (PHYSICS TODAY, July 2000, page 15) writes that, on the basis of the past 50 years, scientific progress did not primarily result from experiments designed to check theory. Looking back at the same period, I strongly disagree.

The most exciting results immediately following World War II were the precision atomic experiments verifying the renormalized quantum electrodynamics of Richard Feynman and Julian S. Schwinger. Enrico Fermi's theory of the weak interaction incorporating Wolfgang Pauli's neutrino hypothesis predicted the interactions of neutrinos. The famous experiment of Clyde Cowen and Frederick Reines in 1956 was designed exactly to verify this prediction.

Hints from kaon decays led Tsung-Dao Lee and Chen Ning Yang to propose that parity was violated in the weak interaction. This idea led directly to the experiment of C. S. Wu, which showed the asymmetry of the emitted electrons from the decay of a polarized nucleus. Immediately thereafter, the V – A theory was formulated by Feynman and Murray Gell-Mann, and Robert E. Marshak and E. C. G. Sudarshan; a whole series of experiments that followed verified this theory, particularly precision experiments on muon decay.

Although the V – A theory was successful, except for the mystery of charge conjugation–parity (*CP*) violation, it was theoretically unsatisfactory because of its divergence problem. Steven Weinberg and Abdus Salam were then led to propose the spontaneously broken gauge theory. To check this, an experimental search for the predicted neutral currents in neutrino reactions was carried out, which led to the provisional acceptance of the theory.

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Proving that theory required detection of the W and Z bosons, which in turn required construction of the proton collider at CERN. The theory was precision-tested by electron–positron colliders built specifically for this purpose: the Large Electron Positron Collider (LEP) at CERN and the Stanford Linear Collider at SLAC.

As a result of many experiments, we now have a Standard Model that describes nearly all observed elementary particle phenomena in terms of a Hamiltonian that can be written on one line. Current experiments at B-meson factories are designed to test whether this theory also explains *CP* violation.

We do not have a theory of everything, although some of my colleagues dream of one. When new domains of energy are explored, we will not be surprised to discover that there are things in the heavens and on Earth that are not described by our present theory. Our goal, then, must be to find a more encompassing theory and design experiments to fully test it. That, I believe, is the scientific method.

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In his letter, Harry J. Lipkin says, essentially, that no fundamentally new theory in physics has emerged for the past 50 years. Many physicists will disagree.

A specific exception to Lipkin's premise can be found in the Yang–Mills theory of 1954 as an extension of Maxwell's equations. The theoretical Standard Model that Lipkin describes as hindsight is based on Yang–Mills particles (gluons; see Frank Wilczek, PHYSICS TODAY, August 2000, page 22), in conjunction with symmetry breaking mechanisms. The past 50 years of particle physics might then be seen as an experimental search into the validity of Yang–Mills theory and its renormalization. Furthermore, Lipkin's examples of great accomplishments in experimental physics were all taken from particle physics. The debate hardly stops with particles.

Having described such experiments, Lipkin then confuses theory with serendipity. Everyone knows that serendipity ("who-ordered-that") is an unstated part of any exploration initiative that searches where no one has looked before. NASA addresses it, sometimes explicitly. However, it is rarely stated because taxpayers don't like to fund it.

Physics is a model or paradigm where theory and experiment must work together. It is a search for understanding. A prominent goal is completeness and consistency, which is where theory plays its role. Theory is also important because it defines what is "observable" and what is "unobservable." The observable is where experimentalists find fame and fortune. The unobservable includes such things as axioms, boundary conditions, postulates in relativity, and Hilbert space. Take the most important concept in wave mechanics, the wavefunction ψ. It is unobservable. Is Lipkin looking for that experimentally?

The unobservable part of physics, the part that experimentalists can never measure, is fundamental to completeness. In a sense, it is metaphysics. Without it and the theorists who define it, Lipkin's world would be incomplete and inconsistent.

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Harry J. Lipkin forgets or disparages the important role of theorists in some crucial experiments in modern particle physics. Unfortunately, such an ahistorical view by a well-known particle physicist feeds into the present misunderstanding of science in some segments of academia, and should not be left uncorrected.

Lipkin asks, "How would physics have progressed in the second half of the 20th century . . . if theorists had been ignored?" and gives as one of his "who-ordered-that" experiments the discovery of charge conjugation–parity (*CP*) violation in neutral K decays. But in his Nobel Prize

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