opinion

# To the postdocs

Steven Weinberg

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**In thinking over** what I would say this evening to a group of talented young postdocs at the beginning of their research careers, I naturally thought back to how things seemed to my generation of physicists when we were first starting out in research. Many of us were worried about how difficult it seemed to make progress in the state that physics was in then. (I am remembering how things were in my own area of physics, the theory of particles and fields, but I would not be surprised if similar remarks applied in other areas.) We had a theory of weak interactions that gave nonsense when pushed beyond the lowest order of approximation. The strong interactions were even more puzzling. We had no reason to believe in any particular theory, and no way to calculate the consequences of a theory of strong interactions even if we did believe in it. Some people thought that the path to understanding the strong interactions led through the study of the analytic structure of scattering amplitudes as functions of several kinematic variables. That approach really depressed me because I knew that I could never understand the theory of more than one complex variable. So I was pretty worried about how I could do research working in this mess.

I have to confess that on top of my pessimism, I felt a sense of envy of the previous generation of theorists. Perhaps many of my generation shared this feeling. We saw that the generation of Freeman Dyson, Richard Feynman, Julian Schwinger, and Sin-Itiro Tomonaga had at hand the 20-year-old theory of quantum electrodynamics. It seemed to me that all they had needed to do was to recognize how the measured values of the electron's mass and charge are related to the symbols $m$ and $e$ appearing in the field equations. Once this was sorted out, Schwinger could easily—or so it seemed to me—have calculated the magnetic moment of the electron to four decimal places. It all seemed much easier than the puzzles faced by our generation of physicists.

Of course, we were wrong to envy the previous generation, and for two reasons.

For one thing, I dare say that every generation of physicists has envied its predecessors. I know that some theorists of the generation of Feynman and Schwinger regretted that they had not worked in the 1920s, when quantum mechanics was discovered. After all, what was so hard about guessing the Schrödinger equation and then solving it for the spectrum of the hydrogen atom? I suppose that Werner Heisenberg, Wolfgang Pauli, Erwin Schrödinger, and Paul Dirac must have envied Albert Einstein, who only had to worry about classical field equations. And who in the world could Einstein have envied? Clearly, no one but Isaac Newton! And sure enough, Einstein's foreword to the 1931 edition of Newton's *Opticks* begins, "Fortunate Newton, happy childhood of science!"

Also, in every generation, those who thought that the problems of their predecessors were easier than their own had been wrong. It took courage for Dyson, Feynman, Schwinger, and Tomonaga to take quantum electrodynamics seriously. In the late 1940s, it was generally thought that quantum electrodynamics was only a low-energy approximation, which could not be trusted at energies above an MeV, and which had to be replaced by something entirely new. When Schrödinger wrote down his equation, he had no idea what the wavefunction meant; that had to wait until Max Born's work on scattering theory a few years later. And Newton didn't just invent a specific law of motion and a specific law of gravitational force—he had to invent the whole idea of dynamical equations. Before Newton, there had only existed a limited mathematical kinematics, worked out in the Middle Ages by Jean Buridan and others, and the worthless philosophical dynamics of Aristotle.


So the moral of my tale is not to despair at the formidable difficulties that you face in getting started in today's research. In fact, the opportunities for progress lie in just those areas of physics that seem most messy. My generation is not handing over to yours a clear set of tasks, like the problems in a physics textbook, but when has it ever been clear what is the next thing to be done? You are far better trained mathematically than any previous generation of physicists, and you have at your disposal tools, from personal computers to artificial satellites, beyond the dreams of earlier scientists. You'll have a hard time, but you'll do OK. ■