

## 1. Edward Witten - How Do Scientific Breakthroughs Happen?

### Closer To Truth

"Asymptotic freedom," the last big breakthrough, was discovered by Gross, Wilcheck and Pulitzer just before I started my graduate school. It took me a year to understand what was happening in the world of physics. The standard model involved new mathematics unfamiliar to both physicists and mathematicians at the time, and whose exploration proved to be very rich. The standard model is based on a nonlinear version of Maxwell's equations, where two waves interact and scatter each other but cannot be treated classically the way light waves can be treated, so it has to be treated quantum mechanically. In 1976, right after I finished my graduate school, there was a breakthrough in the math of nonabelian gauge theory applied to these strong interactions. In 1982 and 1983, John Schwartz, Michael Green and Lars Brink made enough progress in string theory that I started to take their work seriously, though I knew it was a long-term proposition. In 1984, a colleague who had just returned from Aspen mentioned the development that had been achieved, and at that instant, I knew I would be working on string theories because it was like magic.

The breakthrough of Green and Schwartz in August 1984 made the difficulties in elementary particle physics go away. It had a huge impact on me, and I was sure that my interest would never be the same again. By the mid-1980s, I had caught up to where others were. As a graduate student, I was obsessed with the fact that the equations of the Standard Model are challenging to solve because the quantum effects are significant. In 1994, Cyborg and I collaborated on an interesting instance of what people in the physics and mathematics fields call "Cyborg written theory." The equations of the Standard Model are tough to solve because quantum effects are large, and it proved to be particularly captivating. The story that I presented in a lecture at USC (University of Southern California) in 1995, where I sort of unified the string theories, really resulted from an attempt to disprove some of them. In 1995, I was successful in doing something similar for string theory. I tried to reduce the number of string theories by showing that some were inconsistent.