The Science Literacy Gap: A Karplus Lecture

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The great American experiment in mass higher education has failed completely in the sciences, where we have a small educated elite and an illiterate general public. Our graduate education in science is the best in the world, and contrary to the belief of some, we do not face a future shortage of scientists. However, the rest of our educational system is bad enough to constitute a threat to the ideal of Jeffersonian democracy. "The Mechanical Universe," a video series produced by Caltech and aimed at high school physics teachers, is described. Although that project has been very successful, much more must be done. The educational infrastructure must be strengthened to the point where science can be taught gradually, throughout the school years and beyond. Furthermore, those of us who are professional teachers of science must become better teachers, both by increasing our own mastery of our subjects and by better understanding the difficulties our students have in learning science.

KEY WORDS: Science literacy; "The Mechanical Universe"; Richard Feynman; physics education.

It's very nice to be here in Seattle to speak to you today, because this is where I started in physics, as a graduate student at the University of Washington. Much as I loved it here, though, it was a real thrill when I was called for a job interview at Caltech. That was just about 23 years ago. However, nothing prepared me for what happened on that trip when I arrived in Southern California.

I was met at the airport in Los Angeles by Jim Mercereau, himself an estimable scientist, and taken directly to a topless restaurant where we met the great Richard Feynman for lunch. All I can remember thinking during that hour of intense culture-shock was, nobody in Seattle is gonna believe this.

I hope somebody in Seattle is going to believe what I have to say today, because it deals with very important matters concerning science education. I can't think of a better place to start than with Feynman himself. Feynman liked to tell us a story of a conversation he had once with the Princess of Sweden and some friends of hers. Of course, he would leave fastidiously unidentified the occasion on which he happened to be speaking to the Princess of Sweden, although we, of course, all knew that it was when he got his Nobel Prize. The story is that at a certain point during the conversation, the Princess, to be polite, turned to him and said, "And you, Sir, what is your field?" And he said, "Physics." And she said, "Oh, well, we can't talk about that. Nobody knows anything about physics." And he said, "On the contrary, Madam, we can't talk about physics precisely because somebody does know something about physics. What we can talk about is philosophy or psychology, because nobody knows anything about those subjects." And he would go on to say that subjects like philosophy and psychology are hard, but physics is easy and that's precisely why we know so much about it.

Well, if physics is easy, the question is, why do we do so badly at teaching it? Now I'm not an expert on the subject of science education, but I have listened to the experts, I've read their papers, listened to their speeches, read their surveys, gone to their
conferences, and I've come to the conclusion that this is one of those hard subjects Feynman was talking about. Nobody knows anything about it, and so I feel free to speak about it.

Usually, anybody who talks to you about a subject like science education drowns you with statistics—with quantitative information that proves they've done real research and found out something that you ought to know. I won't bore you with a lot of statistics, but let me recite just two simple facts that everybody agrees on. One of them is that American children at every level of education rank near the bottom of those from any advanced nation in their knowledge of science and mathematics. The other one is that approximately 95% of the American public is illiterate in science by any rational definition of what we mean by science literacy. I'd like to discuss briefly the American system of education that has led us into this fix.

To the best of my knowledge, we are the first nation on earth to have tried to create a system of mass higher education. More than half of our young people go on to some sort of post-secondary education, and something like one third actually graduate from college. Historians will probably trace this development back to the Morrill Act of 1862, creating the land-grant colleges. The big boost, however, really came with the GI bill of rights after World War II, which started higher education on a booming growth that lasted nearly 25 years. This has been a truly noble experiment. Instead of an educated elite, as one would find, say, in England or France, we have tried to create an educated nation. Unfortunately, that experiment has failed completely as far as the sciences are concerned. In the sciences, and in mathematics, we still have a small, educated elite, and a basically illiterate public.

Let me be very clear about this: those who are trained to become scientists are not cheated by the education we offer them. To be sure, our science education is abysmal up to and even including college, but our students catch up, in physics at least, in about the second year of graduate school, and after that they are second to none. Unlike many others who worry about science education, I don't think we face a shortage of scientists or engineers, and furthermore I think the ones we do produce are and will continue to be among the best in the world. The reason I feel that way can be appreciated by looking back at the situation in about 1970.

At about that point (when I was a young assistant professor), the great postwar academic boom had come to an end, and as a result, for the first time in many years, people with newly minted PhDs in physics were having trouble finding jobs. Alarmed by this trend, I tried, as physicists are wont to do, to analyze the situation, understand its causes from first principles, and predict where it was all leading us.

In the course of that investigation, I read a book by Derek da Solla Price, called *Little Science, Big Science*. In it he pointed out that the size of the scientific enterprise, as measured by number of journal pages published, number of PhDs granted, or almost any other quantitative measure, had followed a continuous exponential growth, with a seven-year doubling period, since about 1800. That growth had continued smoothly through World War II without even a kink in the curve. Continued growth at the same rate would mean that by the year 2050, every man, woman, and child in the United States would have a PhD in physics. Now I was really alarmed. Obviously, that was not going to happen. The drying up of the academic job market wasn't just a temporary inconvenience. It signaled the beginning of a permanent change caused by the unavoidable ending of the long era of exponential growth. We would have to create a world with a constant, not growing, number of PhDs in physics. ZPG, for zero population growth, was a popular slogan at the time. What would ZPG mean for physics graduate schools?

It meant that each professor in a research university could turn out no more than three or four graduate students per lifetime: one to replace the professor, and two or three others for all nonreproductive jobs, such as teaching in four-year colleges, working in industrial and government labs, and so on. The actual average number being turned out at the time was about 15 per lifetime. That's why I was so alarmed. As an experimental physicist in a research department, what was I going to do without graduate students? Who was going to do the real work? Like it or not, through clever planning or by the force of events, the rate at which we fed graduate students into the engines of our research was going to have to decrease by a factor of five!

The president of Caltech at the time was Harold Brown, later to become Secretary of Defense. I went to Harold and explained the problem to him. Hadn't we better plan for an orderly transition to the new era that was facing us? My other