You could be a Mathematician

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My education

I grew up in Australia, in a time and place where young girls were not encouraged to think in terms of lifelong careers. We might work for a few years before settling down to marriage and raising a family. Not only my teachers, but also my parents viewed that as the expected pattern of my life. It never occurred to me to question it. So I never dreamed of the life I would actually lead, as a scientist with world-wide connections to colleagues and an international reputation.

Fortunately, my parents valued imagination and curiosity. They treated me no differently from my brothers in the way they encouraged these skills, while ensuring that I also developed the skills I would need as a wife and mother. The school that I moved to in second grade was also a very fortunate choice for me, as its elementary school program had a progressive educational style, modelled on the thinking of John Dewey, that fostered individual motivation and intellectual development. Its high school program, while more formal and structured, was fortunate in the quality of the women who were its teachers. These were intelligent women, almost all of them unmarried, teaching was one of the few careers open to them. They valued and supported my eagerness to learn and challenged me to think.

I remember my excellent high school math teacher once strayed from the party line on careers. She said to me “Helen, you could be a mathematician” but added after a short pause “because you are so lazy. You refuse to do a problem the hard way, you always think until you find a clever way to solve the problem.” I was not sure whether I had been scolded or praised, but I was surprised by the suggestion that mathematics could be a career.

I never consciously decided that science was my path. The first time that I had a choice about what subjects I would study was in 10th grade. When I suggested a plan of study that did not include the most challenging level of science offered both my teachers and my parents insisted that was not the right choice for me. I took the courses they suggested. In the next two years the number of subjects one could study continued to narrow and the content of the courses deepened. I always took as many courses as I could, including all the science and mathematics courses. I think this was partly because those were the courses I excelled in, and partly because I was steadily encouraged in my interest in this direction particularly by my father, himself an engineer.

I matriculated from high school at age 16 and started at Melbourne University. At my parents' urging I applied for a number of cadetships. This is a system whereby a company or government agency supports a student through University, in return the student is required to work for that organization for five years after graduation. I accepted a cadetship offered by the Australian Weather Bureau to become a meteorologist.

One experience I remember vividly was that I was working at the Australian Weather Bureau in the summer of 1959 or 60, when satellite data of cloud cover first became available to Australian meteorologists. Since the weather for Melbourne comes mostly from a direction where there is nothing between the nearby coast and Antartica, Melbourne weather forecasting was until then based on weather maps that were an extrapolation of very limited data. The maps improved greatly with the satellite data. The difference between data and the customary extrapolations was dramatic! My skeptical approach to theoretical predictions today goes back to those pre-satellite weather maps for Melbourne.

In my second year at Melbourne University my father was invited to transfer to the US to work for the parent company of the small engineering firm he had led in Australia. The US company offered to move the entire family to the US for three years, or longer if we decided to stay. We all agreed that a three year stay in the US would be an interesting experience. We all stayed much longer than that!

I was released from my bond to the Weather Bureau; no one in that time and place would expect a young woman, not yet 18, to live so far from her parents for three years. I knew nothing about the US education system. I looked up and applied to two Universities that were close to where my family would be; Stanford and the University of California at Berkeley. Stanford was more generous about giving me credit for the work I had done in Australia, so I chose to go there. A physics major turned out to be the easiest one to complete. I could do it in one year and one quarter of study. Here I must thank Jerry Pine, the physics professor to whom I was sent to evaluate my placement. In effect, he let me place myself. So I became a physics major.

By the time I had completed my undergraduate degree I had become truly interested in physics, and Stanford faculty were actively encouraging me to go on to graduate school. I applied for Ph.D. programs, even though I doubted I would complete one. I did this simply because the schools that looked most interesting to me did not accept students for a Masters degree program. Secretly, I planned to complete a one year masters degree and then become a high school physics teacher. I simply did not yet have confidence that I could have a career in physics. But by the end of that first year I had become fascinated by the physics I was learning. I stayed and become a physicist. My specialty is particle physics.

A very brief outline of the rest of my life

I married a fellow physics student and we began our careers with postdoctoral appointments at DESY, a high energy physics laboratory in Hamburg, Germany. We then moved to the Boston area, where my husband taught at Tufts and I eventually became a faculty member at Harvard. We lived there for seven years and our two children were born during this time. (So I was, and am, a wife and mother, as well as being a physicist; indeed this year I am looking forward to becoming a grandmother). We returned to California in 1976, when my husband began a new career in decision analysis. I have been at SLAC (Stanford Linear Accelerator Center) since 1977.

My major scientific contributions

I am asked to tell you about my major scientific contributions. To do so I must first explain a little about the understanding we now have of the fundamental interactions or forces of nature. In our everyday world we recognize four very different types of interactions: gravity, which you know about because you feel it every day; electric and magnetic interactions, which again you have probably experienced in electric motors and magnets, and which at the more basic level are responsible for binding the electrons to the nucleus to form an atom; and two more types of interactions that operate inside the nucleus: the strong interaction, which binds the quarks which form the neutrons and protons, and also is responsible for the fact that protons and neutrons are bound together in the nucleus; and the weak nuclear interaction in which one quark type turns into another, thereby turning a proton into a neutron (or vice versa in certain circumstances) with the emission of some very light particles that escape the nucleus.

The first of my famous papers was at a time when particle theories had recognized that the strong, electromagnetic and weak interactions all have very similar mathematical properties, aside from their very different strengths. The similarity could be evidence that these three interactions might all be different aspects of a single or unified interaction, this idea is called a "grand unified theory". But if the interactions are unified, then why do they have such different strengths? Steven Weinberg, Howard Georgi, and I figured out how this could be.

We recognized that the interaction strength depends on the energy of the interacting particles, and that the different interactions change strength at different rates. We found that there is a very high energy scale where the three interactions that look so different at everyday energies, or even in the highest energy accelerator experiments, would actually look the same. We could explain also how the symmetry of the unified theory, a symmetry that relates these different interactions, could be broken in such a way that their strengths would differ at lower energies. The idea of grand unified theories is still very much part of particle physics thinking today, even though the energy scale involved is so high that we have no direct evidence for the additional particles or processes that such a theory predicts.

My second major contribution is even more technical to explain, and also is yet to be confirmed by experiment. However it is also part of many theories today, and certainly has not been excluded as the answer to the puzzle we, that is Roberto Peccei and I, were trying to solve. The strong interactions have a property, called CP symmetry, which the weak interactions do not. This property means that the laws of physic for matter and those for antimatter are exact mirror images of each other. (Antimatter has been observed in the laboratory so we know it exists, it is very like matter, except with a reversal of charges, so antiprotons have negative charge, while anti-electrons, which are also called positrons, have positive charge). The puzzle is that, in our standard particle physics theory, if you do not have matter-antimatter mirror symmetry for the weak interactions, then that lack of symmetry would more or less automatically infect the strong interactions too.

We found a class of theories, extensions of the standard theory, that maintain all the good properties but avoid this infection. As an added bonus, it turns out that these theories predict a new type of particle that interacts very little with ordinary matter and so is a possible candidate for the mysterious dark matter that pervades the universe. This particle is called the axion. It is not the only possible dark matter particle, but it is an interesting one. Very clever experiments are underway that can possibly detect the axions if they are the constituents of the dark matter in our galaxy. So far they have not yet been detected, but neither has this possibility been excluded yet.

Perhaps I will live to see one or other of these ideas confirmed by direct experimental evidence, perhaps not. One of the challenges of this type of theoretical work is that much of it is very difficult to test. Most of my research is closer to experiment, but that work is more a matter of examining the details of the theory and does not get the kind of recognition that the more daring new ideas do. These ideas are evaluated first by their impact on the thinking of others, only much later do we learn whether they are correct ideas about how nature works.