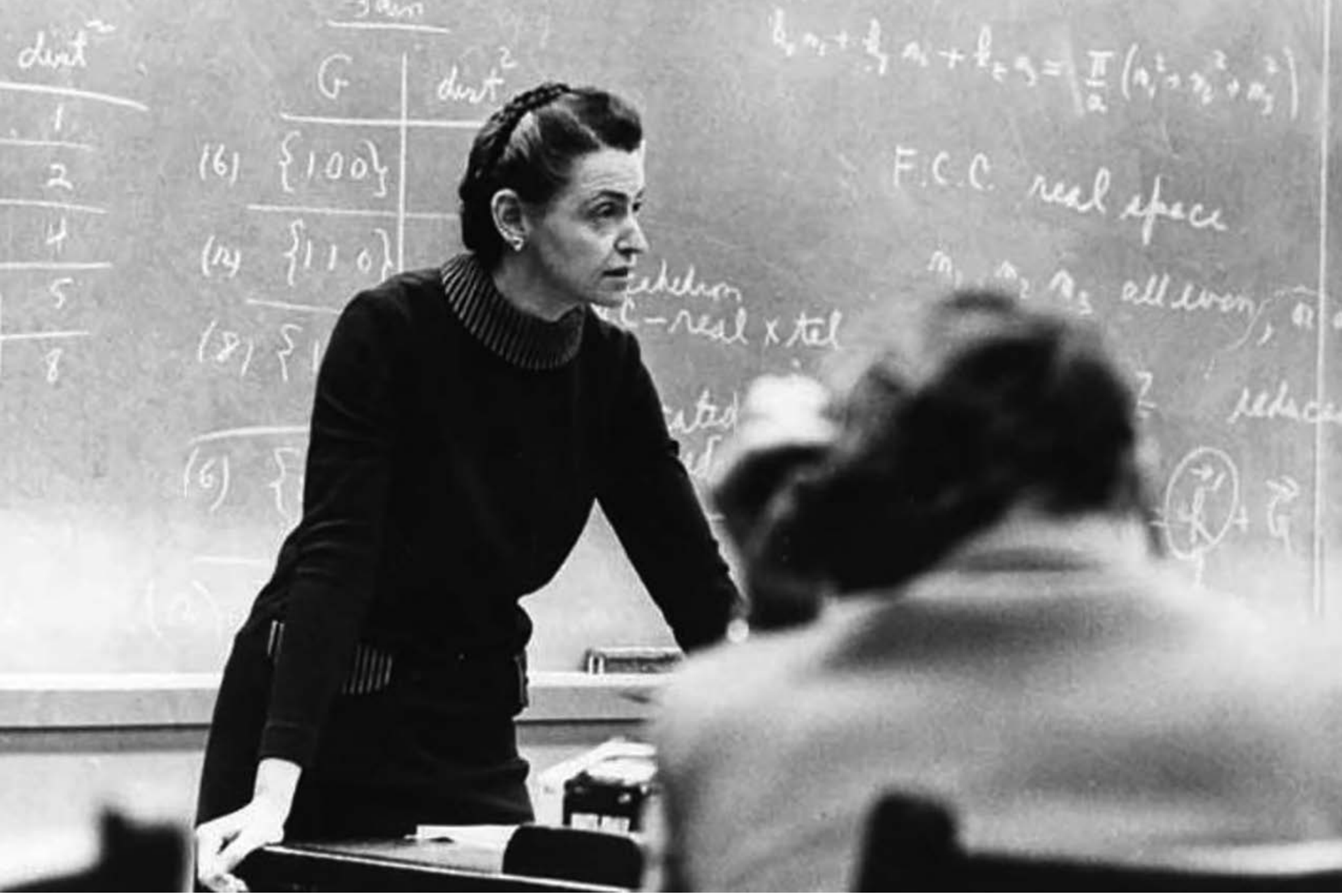

HOW ONE SCIENTIST CAN MAKE A DIFFERENCE

Millie Dresselhaus died last year a much-honored legend. She was the first woman to become a tenured full professor at MIT and the first woman to win the National Medal of Science in engineering, among many other firsts. She was a pioneer in what is now called nanoscience, predicting the existence and fundamental properties of carbon nanotubes, studying their properties, and enabling the development of a field that has impact across the science spectrum, from high-strength materials to cancer biology. She also helped develop the science of thermoelectric energy conversion—bringing nanoscience approaches that enabled noiseless cooling systems for nuclear submarines, among other applications. Her stature and impact in the field of nanoscience was unmatched—from her scientific contributions to her leadership roles and her mentoring of young scientists. But none of those accomplishments were obvious from her beginnings.

Dr. Millie Dresselhaus early in her career as an engineering professor at the Massachusetts Institute of Technology. *(MIT)*

Dresselhaus began life as the child of poor immigrants in the Bronx. She had planned to become an elementary school teacher, but at Hunter College she was mentored by Rosalyn Yalow (who would go on to win a Nobel Prize herself), and Yalow encouraged her to pursue graduate studies in physics instead. She did so, first winning a Fulbright Fellowship at Cambridge University and then going on to earn a PhD at the University of Chicago in 1958. There one of her teachers was the famed physicist Enrico Fermi, who as it happened lived in the same neighborhood as Dresselhaus; the professor and student formed the habit of long conversations about science while walking to and from the university. These mentors had a big impact on Dresselhaus, which is perhaps why she herself became a noted mentor of her students and later of younger faculty, spending many hours with them, inviting them to dinner at her home, providing detailed suggestions to their draft research papers or grant proposals, and writing compelling recommendations to support their careers.

Back in the 1950s and '60s, navigating a career in academic science was not easy for a woman—especially not in physics and engineering, especially not while raising four children with her supportive husband and fellow physicist, Gene Dresselhaus. In her early career, Dresselhaus slowly climbed the academic ladder: after Chicago, a 2-year post-doctoral fellowship at Cornell, then a research faculty position in solid state physics at Lincoln Laboratory near Boston for 7 years, then a visiting professorship in electrical engineering at MIT, where her qualities as a teacher were quickly noted. A year later, in 1968, she was appointed a tenured full professor of electrical engineering, the start of nearly half a century on the MIT faculty. She was 38, and her distinguished research career was just beginning.

Dresselhaus subsequently headed MIT's Center for Materials Science and Engineering, and was also appointed a professor of physics, then an MIT Institute Professor (the first woman so honored). She served as President of the American Physical Society and the American Association for the Advancement of Science, as an officer of the National Academy of Sciences, and briefly as the director of the Office of Science in the U.S. Department of Energy. Despite these administrative positions, Dresselhaus continued to produce seminal research throughout her career

Top: Dresselhaus was a devoted mentor for hundreds of students and junior colleagues throughout her career and was a notable advocate for women in science. Here with Luna Lu, now a professor of engineering at Purdue. *(Luna Lu)*

Bottom: Dr. Dresselhaus was a prolific scientist and authored more than 1,700 research papers over the course of her career, helping to initiate the field of nanotechnology. *(MIT)*

and into her 60s, 70s, and 80s, usually arriving at her MIT office by 6 A.M. carrying a batch of papers she had worked on the previous evening. She served as an active member of dozens of scientific advisory committees, supervised the graduate studies of more than 100 future scientists, and was an early and skillful advocate for women in science.

But it was the originality and the quantity of her research output—more than 1,700 research articles and 8 books—that defined Dresselhaus as a scientist. When she began to study the physical properties of the different forms of carbon, it was not viewed as a promising or glamorous field. Nonetheless, she began to analyze the properties of graphite compounds (graphite, familiar as common pencil lead, is one form of carbon; diamond is another; and there are more). She studied the ways carbon atoms bond together—which led to understanding how to grow carbon fibers and to documenting their exceptional strength. Such fibers are now used in space capsules, airplane wings, and other applications requiring a high-strength but lightweight material. She was one of the first scientists to study *fullerenes*—including the soccer ball-shaped carbon molecules known as "buckyballs", which are so small that they are often cited as the beginnings of nanoscience. That led to her predicting the existence of carbon nanotubes before anyone had actually seen these tiny but very strong structures, which are now used in applications ranging from solar cells to rechargeable batteries and boat hulls. She turned her attention to the properties of *graphene*—a sheet of carbon atoms one atom thick—and similar nano-structured, layered materials.

This dogged persistence on studying carbon over 40 years produced a remarkable body of knowledge, nearly all of it supported by federal grants for individual investigators: Dresselhaus's work was the essence of small science. Her infectious passion for her work brought other scientists to the field: most of her research was done with collaborators, including 900 different co-authors. In effect, she built a tightly interconnected network of scientists to advance carbon science (see box). It's not surprising that Dresselhaus was often called "the Queen of Carbon."

Dresselhaus also found time to make a significant contribution to the field of thermoelectric materials, which can convert heat into electric current, or electric current into cooling. She got interested when she was approached by some scientists working with the French Navy who were trying to improve thermoelectric cooling devices on submarines (normal refrigerators are too noisy). Again, it was not exactly a sexy, high-profile area of research. But Dresselhaus realized that some of the nanoscience approaches she had developed for carbon might also be useful in thermoelectrics and found solutions that could significantly improve the conversion (in both directions) of thermal energy and electricity. Today, thermoelectric materials are used in a wide variety of niche cooling applications—in nuclear submarines, in office water coolers, and to maintain very stable temperatures in lasers and optical detectors—and as thermoelectric generators in cars to transform their waste exhaust heat into an additional electric power supply.

In addition to her productive research career, Dresselhaus held many administrative positions and served on numerous advisory panels for the Department of Energy and other federal agencies. *(DOE)*

Dresselhaus once told a reporter that science was a great career for women, because "the work is very interesting and you're judged by what you do and not by what you look like." What she did was good enough to attract major scientific prizes and worldwide renown. But how she did it is quite characteristic of nearly all successful science: persistence, an ability to recognize unusual phenomena, and the curiosity to ask "Why?" She also noticed people, especially young women and minority scientists, and helped to catalyze and encourage their careers—just as she had been encouraged. Dresselhaus was special in another way as well: her research helped usher in the age of nanoscience and nanotechnology, which now defines one of the most important frontiers of research in physics, chemistry, materials science, and even biology. One scientist can make a difference.

Box

NOVEL WAYS TO SUPPORT SCIENTISTS, FOSTER COLLABORATION, AND GROW THE SCIENTIFIC WORKFORCE

Some of Dresselhaus's later research was supported by a novel BES-funded approach called Energy Frontier Research Centers (EFRCs). These fund a collaborating group of scientists at different universities or research institutes to tackle a major problem. Given Dresselhaus's preference for collaboration, this mode of funding—for a group, not just individual scientists—was a natural for her, but it has also proved very productive for others as well. Over the past 8 years, BES has funded 60 such collaborations in 40 states, including 1,300 scientists in universities, national laboratories, industry, and non-profit research centers. In addition to the new knowledge produced, the EFRCs have helped train more than 5,500 graduate students, postdoctoral researchers, and technical staff—stoking the pipeline of future scientists by engaging them in cutting-edge research.