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Chairwoman Johnson, Ranking Member Lucas, and members of the Science, Space and Technology Committee, thank you for your efforts in support of science and thank you for the opportunity to appear today to offer perspective on this important question: how do we cultivate science and technology to flourish in a highly competitive world, training the future workforce to enable us to continue to compete and win, while continuing to find innovative solutions to hard problems?

As an inventor, teacher, entrepreneur and researcher for the last 35 years at Caltech, a jewel of an institution and a model for many across the world who have looked on U.S. research and innovation output with envy, I have seen where scientific innovation succeeds and also how it can fail. Great science and technological innovations do not just happen—they must be nurtured, and that requires thoughtful leadership and investment in people and infrastructure. Sadly, we have not kept pace with those investments in our future, and our position as the undisputed leader of science and technology, and innovation, is looking more and more vulnerable. The quest to understand our natural universe is one of the finest manifestations of human creativity, worthy of a great culture. Such scientific exploration is also the foundation of wealth. The rest of the world appreciates the power of science and technology as the driving forces of economic prosperity, and they are making the necessary investments to compete.

I am but one of the significant number of Nobel Laureates this country has produced. However, I am the first American woman to win the Nobel Prize in Chemistry as well as the first woman to win the Charles Stark Draper Prize of the National Academy of Engineering. I have many such 'firsts' on my resume (including the first woman to appear playing herself on "The Big Bang Theory").

I am also the product of government investment in science 40 years ago.

Allow me to introduce myself by giving you a taste of the mixed set of experiences that I have been able to draw upon in my career. I have been everything from a waitress to taxi driver (fulltime for the Yellow Cab company of Pittsburgh in 1974 and part-time during college) to a mechanical and aerospace engineer working for the nuclear industry in Spain and Italy, and later building solar energy facilities in Brazil, Korea and Colorado. After earning a PhD in chemical engineering and doing basic research in biophysics, I became a professor, an inventor and co-founder of several companies. I was never particularly expert at any of these professions, but through these diverse experiences I acquired resilience and learned how to adapt to a rapidly changing world. Importantly, I acquired skills and knowledge that I could recombine to solve problems in a unique way. I did not follow any one else's path to science, but I did require the support of many along the way.

I am an engineer inspired by the astounding engineering feats of the biological world. The most complicated engineered systems on this planet were not designed by human engineers. They are the products of 4 billion years of evolution. I chose to become an engineer of this biological world, with the goal of tuning Nature's catalytic machinery to do clean chemistry for us. The problem was that no one knew how to do this. I chose to use the design process that Nature invented, evolution, to explore where biological systems could promote human wellbeing. My 'test tube evolution' worked very well, in fact, for rewriting the code of life, and the rest is, well, history. With the powerful tools we now have for manipulating biology, including CRISPR gene editing for which the Nobel Prize in Chemistry was awarded in 2020 to another American woman, I have little doubt that this will be the century of biotechnology. We will be able to engineer biology to make everything from pharmaceuticals to fuels to food, to cure cancer, and to fight pandemics.

Role of federal grant support

My work has largely relied upon research funding provided by federal government agencies, especially the National Science Foundation in the early stages, but also the NIH, DOE, Office of Naval Research and Army Research Laboratory. That funding supported not only cutting edge science, but contributed to training more than 200 postgraduate researchers who themselves are now at top universities, government laboratories, and industry. Several have started their own companies that today employ hundreds more.

The federal research grants which enabled my seedling ideas to take shape were not sufficient to create the many commercial products that have eventually come out of our research. Getting products and technology into the hands of users, making research truly useful in other words, requires a much bigger innovation ecosystem. In rare cases, my research laboratory can simply pass a technology or product directly to industry for commercialization, but this only happens when existing or anticipated short-term industry needs are matched to the invention. It is much more often the case that technology transfer requires a development phase, especially for innovative technologies not directed to filling a company's current needs. Sometimes we can start that development phase in the academic setting, taking a demonstration to a level where industry starts to see short-term commercial value. But often development requires a different set of skills, a larger level of investment than we can conjure up, or involves timelines and milestones not compatible with the open structure of a university, where teaching, training and knowledge transfer are also critical functions. Maybe a start-up company can do it, but that requires people with very different skills…and money. The people are often harder to find than the money.

The federal government, which supports this science enterprise responsible for so much of U.S. innovation over the last 75 years, has an incentive to ensure that the knowledge and ideas created are advanced when appropriate. Ways to do this are, on a small scale, to expand federal grants that support the seedling idea stage or proof of concept and, on a larger scale, to focus resources around laboratories of innovation – the kind that bring in ideas from different fields, ideas from different types of stakeholders, and skills from across the science and commercial ecosystems. Traditionally, our nation's basic research agencies, namely NSF and NIH, aren't set up to focus on either of these ends of the spectrum. Yet, increasingly, this is what's required to move at the pace of innovation or replicate successful models from the past and present. Competition is extremely healthy for maintaining a vibrant science and innovation ecosystem—ideas that are not competitive should be allowed to die, but it is a shame when a brilliant idea dies before it even has a chance to compete.

Academic structure and innovation

My group's research is highly interdisciplinary, cutting across engineering, chemistry, biology and computer science, and our contribution to molecular engineering by directing evolution likely would not have been possible within a traditional academic research structure. As a young engineer with little experience in molecular biology, I was trying to do what structural and computational biologists thought only they could and should do, engineer new protein sequences using the new tools of molecular biology. But I was at Caltech, in a chemistry division that created new disciplines all the time. I could reach out to top biologists to learn new methods of manipulating DNA, and top chemists would share their insights into the most challenging problems. Importantly, colleagues simultaneously criticized my approach and challenged me to reach higher. I could recruit students and postdocs from across all the disciplines needed to establish the breadth of science and technology that our work would require. This continues today as we transition from fully empirical evolution to using the data in machine learning-guided enzyme engineering, a field that did not even exist when I was trained. The students trained in this environment are fully equipped to do fundamental research as well as solve real-world problems. These students also know how to learn and are in a position to lead science and technology in a rapidly changing world.

Importantly, we do not separate fundamental science aimed at understanding the natural world from research that is aimed at specific applications. To me they go hand in hand, and separation would impoverish both.

The nature of the institutional structure is important. In fact, it is the lack of structure (at least the classic academic form with departments set in prehistoric stone) that promotes creativity. Unfortunately, the world, and for that matter just about everything else, changes faster than academic structures. As a result, research leaders have to actively overcome barriers to cross-disciplinary work and training. This can change with good leadership and understanding of what drives innovation. A carefully designed structure can promote diversity of thought and creative problem solving from the bottom up without enforcing silos of entitled researchers who are terrified by change.

Building a broader science workforce

The most insidious barrier to innovation is hierarchy. The strength of the academic research system in this country comes from the empowerment of younger scientists—assistant professors are fully responsible for their own work, for better or for worse. It is also important to empower researchers when they are still undergraduate and graduate students so that they can experience the joy of being a research scientist or engineer. Such empowerment is inherently dynamic and actively combats hierarchy and ossification. I favor supporting the most talented of our young people with portable fellowships for graduate study, because they are fully capable of deciding where the future lies—what science fields, what problems—and they will choose the universities and research settings that meet their expectations. A combination of support across science, focused in strategic areas, and to the best of our youth will pay off many times over in the generation of science and engineering leaders. Fellowships and non- or less-restricted grants to the most promising young research leaders will allow and even encourage them to take risks and will pay off with research that is truly innovative rather than conservative by design. These individual PIs are thereby freed to formulate whole new questions outside the confines of big projects whose goals are already set in stone.

I was fortunate to receive support with few constraints early in my faculty career in the form of an NSF Presidential Young Investigator award and a transformational 5-year fellowship from the Packard Foundation. Such support encouraged exploration of new ideas, before they were competitive for a grant and therefore for which there were few means of support. Make no mistake, not all ideas are good, nor do all such investments lead to breakthroughs. Just as entrepreneurs and venture capitalists know that most startups are doomed to fail, scientists know that there may be no pot of gold, or Nobel Prize, at the end of their little rainbow. But rather than reverting to the mean and funding only the most conservative of proposals, as happens far too often now, I believe we should reward exceptionally talented scientists who have identified ways to tackle the high-risk, high-reward problems. An interesting piece of information: all three US women who have won Nobel Prizes in the sciences since 2018 were supported in their early years by the Packard Foundation. This is remarkable, and it is not a coincidence.

I wish to point out that it is this competitive vibrancy of our academic enterprise that attracts the brightest students from all over the world to U.S. universities for PhD and postdoctoral studies. Our research programs are greatly enriched by these international students, who often stay to make their careers in the U.S., where they see the opportunity to compete without political, cultural or other limitations experienced in their home countries. This great brain attraction enhances the U.S. science enterprise as well as the innovation ecosystem: we only need to look at the large fraction of Nobel Laureates, national medalists, and founders of high technology companies who are immigrants to appreciate this. They are risk-takers and value the opportunity to do it here. We should continue to welcome them and their contributions.

I have talked mainly about science as a competitive enterprise, often led by elite institutions such as Caltech. That should not be surprising, because this is from where my experience derives. I cannot leave, however, without talking about diversifying the scientific workforce beyond those coming from elite research universities. Cutting-edge science is not limited to the elite institutions. Competition that leads to excellence is good for science, but there are ways to help level the playing field for the excellent programs that are not at the most elite universities. For example, I believe that portable fellowships can help to level the playing field, as could fellowships directed to geographical areas (still allowing students to choose specific mentors and fields of research) serve to support the best regional programs. Similarly, adding or reserving prestigious fellowships and early career awards for Minority Serving Institutions and emerging research institutions will ensure that some of those promising faculty have the same head start from which I benefitted and provide an opportunity for their students to train under a creative environment. This is not about awarding those who are less deserving but finally seeing those who have been deserving all along. This is the only way we can truly change the system. Finally, there are challenges best understood, tackled, and scaled on a regional level (e.g. feedstocks to help usher in a new bioeconomy or energy supply, integration, and resiliency), leveraging local ecosystems or circumstances or talent pools. These are just some of the ways in which the federal government should more fully engage on this issue. I know you all share my concerns and belief that talent exists all over this country, and it is incumbent upon us to foster it for the benefit of the nation.

Moreover, consideration should be given to the importance of programs aimed at scaling up and building out entrepreneurial corps among our nation's scientists and thought leaders. While care should be taken to only do this where the problems are important and where entrepreneurial or industrial investment and commitment are lacking, we must acknowledge that the next generations will not follow a linear path in their careers. Where there is interest, we should foster scientists and engineers who are both interested in studying a problem and potentially seeing those ideas implemented for the benefit of society.

It is very challenging, however, to become a scientist or engineer, especially if one falls behind in math and science in middle and high school. Talent is evenly distributed, but access to quality education in this country is not. Thus the pipeline is constricted by access already in early years. On the other side of the pipe, science and engineering need to compete with other careers that may be attracting the brightest students from all groups. The more that young people can see the kind of impact they can make through science and engineering, the more they will be willing to pursue this career. Therefore, we scientists need to tell our stories better and not hide in the quiet ivory tower. No PI has a 'right' to taxpayer money to support their personal curiosity quest—we all have an obligation to give back, in one form or another. Enhanced understanding of our universe can give back just as much as a potential cure for a disease, but the story must be told. And, all of these quests should involve and train the next generation of scientists and engineers.

Finally, let me offer a little bit of my perspective as a woman. I love what I do for what it can do to alleviate suffering of people and the planet. I never based my career choices on how much money I could earn, but instead on the degree to which I would be free to learn and determine my own trajectory and impact. It was easier, however, 35 years ago to start a career in academic research—we did not spend two-thirds of our time in department meetings, writing proposals or making sure we were complying with regulations. Instead, we focused on research, mentoring, and teaching. That has degraded. With additional responsibilities that women have with respect to family, it is very difficult to compete, and almost impossible to enjoy the process. The competitive environment that has been highly effective for finding competitive scientists is not always the best for finding the most effective scientists, especially where teamwork is critical. The most talented people have multiple choices, and they take other paths.

Research scientists don't earn huge salaries; younger academic scientists and those still in training earn much less than their contemporaries who chose lucrative careers in law or finance or even those who don't go on for advanced degrees. Childcare, as you know, is very expensive and is usually beyond the means of a graduate student or postdoctoral researcher, forcing many young women in particular to choose between a research career and family. Would-be researchers from less-privileged backgrounds face similar challenges.

I am honored to be testifying before this Committee today. I appreciate the recognition that each of you has given to these issues in recent legislation and your further recognition that we must do more if we are to solve the hard challenges of tomorrow.