

## Denice D. Denton Distinguished Lecture Series November 8, 2013

### Welcoming Remarks and Introduction by Lydia Zepeda and Jenn Sheridan

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**LYDIA ZEPEDA:** Hi, how you doing? My name is Lydia Zepeda, and I'm a faculty member in Human Ecology. Welcome to the Annual Denton Symposium! I'm a member of the committee honoring Denice Denton's memory, and I just want to acknowledge the other committee members here, and also WISELI for sponsoring this event. So I'm actually the intro to the intro, so [laughs] bear with me. So, Amy Wendt, right here, Vicki Bier and Jenn Sheridan, without whom, who's basically done everything, we just, we ratify everything, I think. I also want to acknowledge that Carolyn Mabee, Denice's mother, is here.

For those of you who don't know, or didn't have the pleasure of knowing Denice, she was a very dear friend of mine. I first met her in 1989. We were both assistant professors here, and I think we met at one of the women mentoring or women gatherings for new faculty. Denice was a great friend and mentor. She was the one who actually got me my tenure guidelines from my division, thank goodness. She also would do things like, you know, go out and have a beer with me, babysit my son, stop by my house at 5:59 and ask what was for dinner. [LAUGHS] But, she also was a great role model, because she was an amazing teacher, she was dedicated to Pre-K through infinity science education. She always did say, that preschoolers did ask the best questions in science.

She also was an advocate for diversity in academia and leadership, and I think there's a great quote by Donna Shalala, I'm just going to paraphrase it. Basically, not only did she kick down doors, but she held them open so that other people could get through them. So, in her memory, every year we have a symposium to honor both Denice and her ideals of Pre-K through infinity science education as well as diversity in academia and leadership. I hope that you might consider donating to the fund honoring Denice. We have some of these lovely flyers outside [laughs] at the reception afterwards. So please do consider so we can make this all happen. Thank you very much.

I will now introduce Jenn Sheridan, who is a member of the committee, who will introduce Jo.

**JENNIFER SHERIDAN:** Thanks, Lydia. Hello, and thank you all for coming to the 2013 Denice Denton Distinguished Lecture. It's my privilege to introduce Dr. Jo Handelsman. And really, it's hard to think of another speaker who exemplified all the different areas that Denice also cared about so much, so we're delighted to have her here.

Jo is no stranger to our campus, of course, nor to many of you in this room. As you know, her expertise covers many different areas. And at the risk of giving any one of them short shrift, I will attempt to give you a glimpse into the career of this enormously talented woman. I will say, the first version of the introduction that I wrote took me ten minutes to read, so since you'd probably rather hear from Jo than about her, I've condensed her copious achievements to maybe five minutes, and I'll beg your forgiveness if I left out something important.

First and foremost, Jo is a microbiologist. Her research aims to understand the structure and function of microbial communities and the signals that govern them. She is probably most well-known for her pioneering work in a new methodology that she named, "metagenomics." Her scientific contributions have been recognized through such honors as being named a Howard

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Hughes Medical Institute professor, a fellow of the American Association of the Advancement of Science, and by being named a revolutionary mind by SEED magazine.

Jo's scientific contributions in microbiology are not only important in and of themselves, but they're important because they're a launching pad for an agenda of broadening participation in science through diversity, mentoring, and teaching. I have had the privilege to work with Jo since 2002, when she and Dr. Molly Carnes hired me to help run the new Women in Science and Engineering Leadership Institute, or WISELI, that they had just formed. Jo's work on issues for women in STEM extend into the national arena, not only through the work WISELI does, which is disseminated to universities all over the United States, but via Jo's work at the National Academies committee that produced the *Beyond Bias and Barriers* report; her foray into the 2005 Larry Summers incident; her cofounding of the Rosalind Franklin society, which is an organization that promotes women in the life sciences; and most recently the publication of original research demonstrating that gender bias is alive and well among current science faculty. For her work in the area of gender equity—exactly! [LAUGHS] Very famous in the women in science community, it's blockbuster. For all her work for gender equity, she received a Cabinet 99 Award, a WYCA Women of Distinction Award, she was named a fellow of the American Women in Science organization, and in 2012, *Nature* magazine named her one of ten "People Who Mattered" this year for her research on gender bias in evaluation of scientists.

But Jo doesn't just work at the institutional level to broaden participation in science. She works at the individual level, as well. Jo is nationally known for her incredible work in mentoring. She realized that no one was teaching faculty and postdocs and graduate students how to be good mentors, a crucial step in keeping science students advancing through the pipeline. In 2005, she published a short course in mentoring. In 2011, she received the national honor as being selected for the Presidential Award for Excellence in Science Mentoring, presented by President Barack Obama in the Oval Office.

Finally, we reach the topic of Jo's extraordinary achievements in the teaching of science, particularly biology, to a new generation of scientists. Jo was winning awards for her own teaching from the beginning of her career, but her interest blossomed in the early 2000's when she began to craft her vision of scientific teaching. Encouraging scientists to approach their teaching like they would the rest of their science: testing new approaches, measuring outcomes, and continuing to improve student learning. The importance and visibility of this work resulted in her taking a leadership role in a White House committee looking at how to produce one million new STEM bachelor's degrees. Jo presented the 2012 *Engage to Excel* report to President Obama. He was obviously impressed with her work, because earlier this year, he selected Jo as his nominee for Associate Director for Science in the White House Office of Science and Technology Policy. While she is still awaiting Senate confirmation for this position, she's already thinking about what she can to affect national science policy when she gets there.

We are very lucky that this revolutionary mind will be shaping our science policy from inside the White House for the next several years. And we are also lucky that she's here with us today, to speak about the national transformation of science education. Please give a warm welcome to our own Dr. Jo Handelsman. [APPLAUSE]

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Dr. Jo Handelsman: Remembering Denice Denton

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**JO HANDELSMAN:** Thank you, Jenn, for that extravagant introduction. I hope people aren't too bored by that. What Jenn didn't mention was probably the greatest honor that I've been given in my career, was the privilege of being a faculty member at the University of Wisconsin for almost a quarter of a century. That really shaped who I am and what I care about in education and science, and I still consider UW more of a home than any place on earth, and that includes the White House. [LAUGHTER] So, thank you all for sharing my return to Madison and talking about a person who meant a lot to me, as well.

I overlapped with Denice for many years. We started on the faculty close to the same time, and although we were in very different fields, I was in the biomedical and agricultural sciences and she was in the engineering, we somehow found each other. There were only three women on campus then, so it was easy, and we found that we had incredible interests in common in both women in science, because we were both experiencing the isolation and challenges and discrimination that any woman in science dealt with in the 80's, but also our interests in education. And so, we remained friends for a very long time. I followed Denice's career when she left Madison, and she published a number of just incredibly important papers and reports really doing seminal work in education as well as equity in education. I learned a tremendous amount from her, but I think one of the things I learned more than anything, is she said in a talk at the National Academies, about 8 years ago I believe, "Speak truth to power." And, I'm going to remember those words over the next few years, and I'll think of Denice every time I do.

One of the things about Denice that was so fantastic was that she was not only the kind of superhero that Lydia described, having just so many interests, and doing everything she did with gusto and energy and love and commitment, but she also was a very human person. And sadly, that's why we lost her. That she really was a superhero, larger than life to many of us, and we forgot, I think, just how vulnerable she was as a person. And that was, maybe, Denice's last lesson that I learned, and that is specific to women in science but probably to everyone around us, that sometimes the strongest people and the ones who look most fit for whatever they're doing, have the same kind of pain inside that everyone else does, and can be very vulnerable.

Denice always looked like a cat to me. I don't know, I think her mane, but also her eyes, she had these great cat eyes. I always heard this phrase used about her when she was meeting some challenge, "Oh, she's like a cat, she'll land on her feet." That is a phrase that's often used to avoid giving people support and sympathy. I just want to say that is one of the lessons that Denice's death gave me, and I think will live with me forever, and I'd like to pass it on.

It's a real privilege to talk here today and particularly to talk about science education in Denice's memory. She was the first director of the National Institute for Science Education, or NISE, which was here. That was long before science education was a popular topic and something you'd see in the *Annals of Science and Nature* and the newspapers. She was a real pioneer in science education and the National Science Foundation recognized that, and so she was used as national model and also an innovator to transform science education. I wish she were here for many reasons, but I think she would be just enormously gratified to see where we've come since she and I worked on that struggle to improve science education years ago. There's been

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enormous growth and change. I'll talk today about just a little piece of that, which pertains to a little bit of what I hope to do in the White House.

**JO HANDELSMAN:** I wanted to start with an explanation of science policy. Because since I was first asked to consider being the Associate Director for Science in OSTP, I have learned so much about how policy is made and how Washington works, and how we as the normal, everyday scientists in the world can intervene in that process. I had absolutely no idea. Many of you may be more savvy I was, so maybe this won't be as enlightening as I think, but it was a real revelation to me how the decisions are made. So, I wanted to start with how policy is made and then give you a very specific example of one policy document, which was the PCAST report that Jenn mentioned. Then I'm going to narrow my comments to one recommendation in it, and then tell you about a project we've done at Yale to use, to implement that recommendation and how I want to take that with me to Washington. From what I've seen, and this is clearly a slice of Washington that I saw in my time getting ready for Senate hearings, which are really fun by the way, and I'm not kidding. I think that in science, we do things like they do them in Senate hearings very often. I think like graduate exams, PhD exams, are a lot like this, so it felt absolutely normal to me. It felt like standard science discourse and everyone else was quaking. Anyway, I think [LAUGHTER] those of us who grow up in academic science maybe are prepared for the rigors of a Senate confirmation.

One of the sources of information and ideas and policy changes is the National Research Council, which many people in this room have served in various capacities, but one of their most important jobs is to issue reports that are called consensus expert reports. I think they are the most influential reports, there are lots of other kinds from other places and well as from the National Academies, but I think the consensus reports are powerful because they have large groups of expert scientists come to a consensus. Every person have to sign off on a report, with a few exceptions, and then the report goes out for peer review, and the review is rigorous. There was one report when I was at the Academy once, talking about a report, they told me they were reading a hundred page review. That was the review, it was as long as the report, so that was just to make me nervous. I did not get a hundred page report on mine, thank goodness. But these are really rigorous and represent the community's view, or a defensible view based on data. I was struck, having served on some of these committees, just how much these reports are used and in fact revered in Washington. I saw them on the shelves of people in OSTP's offices, I saw them in Senator's offices, so these are really read. So for those of you who devote years of your lives to these things, they're grueling, it really is worth it. The good reports have had an enormous impact.

Another body that's very important is the President's Council of Advisors. That's the PCAST. Right now it's co-chaired by Eric Lander, who's a genomics professor at MIT. John Holdren, who would be my future boss, the Science Advisor to the President and Director of OSTP. They discuss a wide range of topics in science and technology, and they have experts from many different perspectives, people in science, people outside of science, industry, and academia: it's a stunning group of people. Then when they decide a topic needs to be explored, they find a real blue-ribbon kind of panel. Their reports are not consensus reports. They sometimes are a little bit more radical, because you don't have to get complete sign-off on these reports, and so they sometimes have pretty aggressive and interesting recommendations. It's surprising to me that the White House reports are actually the ones where the radical ideas show up more often than the National Academies reports. Then finally, there's a council called the National Science

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and Technology Council. They are representatives of all the 13 science agencies: DOE, Department of Energy, Department of Defense, all those. They have representatives on this council, and they take the recommendations from PCAST and try to turn them into practical actions that they as the funders of science can take. So, those are some of the sources of information and ideas.

Of course, what I missed, was that a lot of the ideas just come from individual scientists. People go to the OSTP, and they just tell whoever is there their ideas, and they say, "You should do this," and sometimes it takes root. An example of that is the brain initiative, which you may have heard of. President Obama cited it in his State of the Union address in January, and then announced the roll-out of the initiative in April. This is a massive initiative that will bring funding from many sources, not just government, into studying the brain, in a process called mapping the brain. That is understanding all the neurons and all the connections in the brain. It has gotten a lot of attention, a lot of funds, and that was the product of a few scientists simply going to OSTP and saying, "You should do this." So, that's a route that I certainly never took advantage of when I was thinking about issues. The place that a lot of this information goes is the Office of Science and Technology Policy. The President interfaces with that office, and then the science agencies interface, not directly with the President, but through OSTP. It's this group of three that develops science policy, largely, in this country, at least what comes out of the Executive wing. Then there's the Office of Management and Budget, and I'm not going to say anything about them because I might get in trouble, that actually writes the budget. And so my challenge, if I'm confirmed in the OSTP position, will be managing the Office of Management to make sure that they spend money appropriately, because they're not scientists unlike people in science agencies and OSTP. They don't always know what makes sense in the science community. That's one of the biggest roles of the OSTP people, is keeping OMB on track, to make sure that they actually invest in science and not something else.

I want to say a few words about OSTP and where I'll be in that structure. As I mentioned, John Holdren is the current President's Science Advisor, and he is also Director of OSTP. He has four Associate Directors and two are up for confirmation: the Energy and Environment one and Science, and so I'm Science. Every time I see that I just cringe, I can't believe I have to represent all of Science. [LAUGHTER]

I see Bob Mathieu here; I have learned more astronomy in the last two months than I ever thought I would know. One of the things that's in my purview are the big instruments, so I have to keep an eye on the big telescopes and things like that. In that office is biomedical, agricultural, basic sciences, any other kind of science that we want. We are absolutely the owners of STEM ed, or science, technology, engineering, and math education. Other groups throughout the agency work on STEM ed issues, but it's owned and coordinated through the Science office. I mentioned big instruments, and then I would have three institutions, agencies that would be mine to I guess feed and water, kind of. And that's because NASA, NSF, and the Smithsonian don't answer a cabinet secretary like the Department of Energy Secretary, or the whatever Secretary. So, like DHHS is a place that NIH reports. These three agencies don't have secretaries of their own, and so that would be me. I think the biggest job is keeping these groups functional, solving their problems when OMB does something to them that's not right,

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going back and negotiating for them and making sure that funds are being expended in the right ways.

Going into one of the routes for providing information and ideas, this is the PCAST report that was issued in January of 2012 and I co-chaired the panel that developed this report and we called it "*Engage to Excel: Producing One Million Additional College Grads in STEM.*" I'd like to just tell you a little bit about the recommendations from the report and how that's shaped my work since then.

We first looked at the economics of science. I think everyone to a person was shocked at the estimates of how many scientists we're going to need in the next decade. This is not PhD scientists, and we've all heard those debates over the years, about do we need more PhDs, do we train too many? This is at the bachelor's level and community college level. Two-year and four-year degrees in science are going to be in demand. That's based on which sectors of the economy are growing, and it turns out that STEM collectively, jobs associated with STEM, are in the top five of the most rapidly growing areas of the economy. That does not count healthcare, at all. So if you imagine that at least some of the people that we train in STEM would be represented in healthcare, the million deficit is actually probably conservative. Right now, STEM jobs, as they call them, represent about five percent of our economy's gross national product. It will be up to 5.3, now it's not even 10 years anymore, in the next 6 to 8 years. That says that we need a million workers that are either trained in this country and come from this country or are imported from elsewhere. We can't necessarily count on the availability of workers from other countries who are more and more using their own scientists in their own workforce. All of the economists said this is a very serious lack and this is something we need to address.

We looked at what was needed and what was the most efficient and effective way to generate a million more graduates in the STEM fields in such a short period of time; that just seemed overwhelming. What we realized was there was an opportunity as well as a problem. If we solve the problem, then we would have the opportunity. That is that fewer than forty percent of college students who come into college intending to major in a STEM area actually complete a degree in STEM. They complete degrees, but they've moved to another field, usually the social sciences. This represents an enormous community of very competent students, because it turns out that the grade points and performance of the students who leave science are not that different from the students who stay. We're losing really good students. But this is an opportunity to recruit, because these are people who are already like science. They came in with an interest, and we're the ones who discouraged them. There's an even further opportunity that as ethnic minorities become a larger and larger part of the college population, we're probably going to be discouraging a larger percentage of students from STEM if we keep going the way we are. The retention of White men is about 34%; the retention of Black men is 17%. So, there's definitely an ethnic influence that is really going to present a problem for meeting the needs of the workforce. The reasons that they leave are, we found, the high performers, of which there are many in this group, complain about the uninspiring intro courses. The low performers very often have a math problem, and that's probably no surprise to anyone who's taught an introductory class. So, what we need to meet the need is a 33% increase in the STEM degrees, starting now. That kind of was daunting to me, to raise, to increase the size of

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every major by a third, but that would generate somewhere between 3 and 4 million STEM workers over the next decade. But what we realized was that if we increased retention from this dismal 40% up to 50%, that would generate three-quarters of the million workers right there. It really did seem, the more we looked at this, that the best approach to generating more STEM degrees or graduates was through retention.

The question was, what can we do and what kind of universal acts can we perform that will have an effect on retention of students in STEM? In the end, we decided to focus on the first two years of college. That had a number of reasons behind it. One, it focused our thinking, and we had less of an expansive landscape to cover. It is the first two years that actively discourage students from STEM, so it also made sense to go where the problem is. Once they get past the first two years, they're much more likely to stay. The first two years are also common to all institutions, and we focused quite a bit on the two-year institutions across the country. About half of our college graduates, of any type, going to any kind of college, have spent at least some time of their degree in a community college. The community colleges are an enormous influence on our students and where they go and what they do. We wanted to think about the coordination of the community colleges and the four-year colleges, so that we could keep students who go through the community colleges on the STEM track even when they transfer. Every time we did a calculation, we found that retention was a lower cost way to do it. What we realized is that we didn't have to increase the size of the very expensive introductory courses, we were recruiting essentially from those courses. That definitely made this the lowest cost approach that we're not increasing the courses that cost the most, we're just going to do them better, hopefully.

The committee came up with five recommendations, and this is where some of our radical language was, not in the overall recommendations but in what was under them. The first was to use evidence-based teaching practices in the first two years. The second was to replace the so-called cookbook labs with research experiences, and specifically research courses. In math, we kind of had to deviate from our other recommendations. Scientists, when you get them together and ask them to solve a problem, the first thing they say is, "Do a study, we need more data." And we didn't want to say that, but in math we kind of had to say it. We didn't feel there was a good enough analysis of why students do so poorly in math and what we could do about it. I've made many, many enemies in the math community by suggesting that if the math faculty didn't teach math, we'd be a lot better off. Although I know that sounds amusing and hostile, all the evidence points to it. That if you have engineers, physicists, biophysicists, teaching calculus for example, students respond much better. This is at the high school level and the college level. I think we should be recruiting from outside of math as well as staff, who are dedicated to teaching. At Yale, for instance, we have two staff members who teach calculus and they are beloved. They are great courses. Calculus has been an absolute disaster at Yale, for decades before they came. We recommended that we need more data, this is the one area where we can't make concrete recommendations that are evidence-based, we really do need some data. We also talked about the importance of diversifying the ways students can enter STEM careers, because more and more of our students are nontraditional in one way or another. They're coming back to college, they're starting at a community college and moving to a four-year, many models, and we needed to be a little bit more flexible with our "on-ramps and off-ramps," which

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is the phrase they like to use. We need to look at all the different ways that students get degrees in STEM, and then find ways to accommodate their lives in that process. Finally, we recommended creating a Presidential council on STEM ed, because we felt that education initiatives weren't sufficiently focused on STEM. The sciences always seems to get lost in the Department of Education and a lot of other education initiatives, and the scientists tend to focus on the science, the research and not on the education. So, we felt that in developing policy at the federal level, there was an importance in keeping the President's attention on STEM education, not just as a side product of what some other committee does, but really develop a group that would keep the pressure on to improve science education.

I'd like to say a few words about the first two recommendations. The first one, the actual wording, was to "catalyze widespread adoption of empirically validated teaching practices." This is basically what Jenn mentioned, either scientific teaching or teaching-as-research. There are a lot of different phrases for it, but the concept that we should be using an evidence base when we choose our teaching techniques. We shouldn't just do what was done to us, but we should be evaluating with data, both in the literature and in our own classrooms, how student learning is fostered. There's a clear line of evidence, this was the clearest thing in all of our work, was the vast literature that shows that students who are actively engaged by any means, and we found dozens of different types of active engagement, if they're engaged by any means in the classroom, they learn more and better and retain more than if they're taught in lectures. We also found that most of the introductory courses in this country are taught with lectures. So right there we have an opportunity to improve learning. If anyone is interested who doesn't know this literature, we created a massive bibliography, the committee did, and we wanted to make use of it. They didn't let us use it in the report because it took up too many pages and was too expensive to print for the President. But, yea, [LAUGHS], just like everywhere. But we wanted to make use of it, because it was a lot of work. So, there's a bibliography on active learning.

So, what can we do about this recommendation #1? National and local opportunities to train faculty in evidence-based or tested teaching practices is absolutely essential. All the literature said they won't change their methods unless they're taught to use new methods, and especially to be taught themselves with those methods. Then the second piece is training for future faculty. I think UW is the model for doing this. I can't find another campus in the world that pays as much attention to training programs for graduate students and postdocs. A lot of that is the CIRTTL program, so we interviewed Bob Mathieu as part of our deliberations and got a real education on how you develop one of these programs and what the best attributes are. We suggested that training in teaching be tied to training grant support, and this was probably our most radical thing. We debated whether it should go in there, and some people thought it shouldn't, but I snuck it in one weekend when nobody was looking, and so it's in there. Very interestingly, the training grant announcement that recently came out from NIH says that by 2014, October 2014, training grants need to pay attention to professional development. That's broad, that's not just teaching, but all of the experiences that foster professional development in scientists. That is radical. I think that's big news. I don't know if that's because of what we said or not, it was buried in the report, so I don't know if anyone read it. But the big news is that if NIH does something on training grants, then it becomes the principle of graduate education. This has happened before. The ethics requirement became a requirement just for trainees on

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the training grants, and then it spread to graduate programs that those training grants funded even though some of the students weren't on the training grant, and then eventually became ubiquitous in science education, or graduate education.

There's a model for this, it's pretty easy, and we were really excited when we heard that NIH was doing this. They're not making an out-and-out requirement, they're just saying that panels will start paying attention to it, but of course, that's the equivalent of a requirement. So, professional development and teaching specifically, training in teaching, are coming into requirements that are associated with the money that funds research. We felt it was really important to provide funds for faculty to make the transition from passive to active learning, that in the long run it wouldn't cost more, but the start-up is quite enormous. A number of programs at the National Science Foundation, in particular, have been maintained and we hope that in the 2014 budget will be expanded to enable this process.

My favorite is recommendation #2. This one was my other radical one, and I introduced this and thought they were all going to roll their eyes at it, but they didn't. They let me put it in. There's a lot of evidence to support it, so maybe that's why my committee didn't protest. That is, to get rid of our standard laboratory courses that are typical of the introductory science curriculum, and replace them with research courses. I'll talk a little bit about what research courses are. We agreed that it was impossible to get all undergraduates in their first two years into research labs. That just wouldn't work, and it probably wouldn't be a very good idea for the research labs. But, they could have real research experience in courses. The evidence is that students who engage in research early in college, the first two years, are much more likely to stay in STEM. There's no surprise here for anyone who's done research, that's the part of science that we like. They're more like to stay in STEM, they receive better grades. One study I think showed better grades across their curriculum, not just in science. They complete their degrees more quickly, which is of significant concern to the government and many institutions. The evidence certainly suggests that having a research experience is a positive thing, and we could find no negatives. Most of us thought that the cookbook labs that we introduce students to and try to tell them that's what science is, really would not be missed if one or more courses replaced them. We recommended this across the intro curriculum. Wherever there's a lab, turn it into a research course. This has been done in a number of places and the evidence from Sally Elgin at Washington University, who has done a direct comparison of the impact of summer research programs and research courses, the evidence shows that they have all the same effects by the measures she used. We don't have long-term data of persistence over long periods of time, but everything we saw in the data looked like students who engage in research in the laboratory of a faculty member, have many or most of the same outcomes as those who engage only in a research course. This is a much more efficient way of covering more students, it's a way of keeping the students that really hate research out of faculty members' labs, it's a way of keeping students who don't really belong in science, there are some of those, out of faculty members' labs, and it's a ways of training them in a much more efficient way as a group in the practice of science.

It's actually kind of funny to write recommendations to the President about teaching. We sat there saying, you know, what's the President going to do, we can't expect him to walk into classrooms and tell faculty how to teach. Some of the wording of some of our

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recommendations are perhaps a little odd, but that's the basis for the "advocate and provide support" phrase, that we really wanted the President to get out there and talk about the value of research, of all research, but then specifically bring it to the classroom level. We think, of course, that would be great for all of science. I promise I will work on that, and I hope that he will see the wisdom of this recommendation and takes it to heart and acts on it by advocating for research. Which, he does, but not often enough to suit us. So then we also thought, we've got to fund some implementation, because these are hard to get going. The calculations are, in the places that have done it, that the research courses are no more expensive than standard introductory lab courses, but they're hard to work out, they're hard to develop in the first place, so we have to have a federal level of funding. The second thing is that some institutions may not have the research infrastructure that would be needed to run some of these courses, particularly the two-year community colleges would benefit from linking up with research universities, industry. We heard a lot of interest from industry to collaborate with colleges and universities in providing access to laboratory experiences and courses. There's one experiment that I think is really interesting, where companies suggest topics for these courses and they explain to the students how solving a particular problem or figuring something out would help that industry. Apparently, that's been very successful on the campus where it's been done. There are a lot of ways to engage larger colleges, universities, as well as industry in the smaller community colleges.

Just to mention, there's actually a lot going on, on math now. I don't know if there are new programs, I haven't studied it, but it looks to me just from the anecdotal evidence that the current programs are going in the right direction of gathering the data that we need to make recommendations about what needs to change. The diversification of paths has gotten a lot of attention because of the President's goal of 8 million college graduates in the next, by 2020, and that pertains more to the community colleges than any other group. The interface of the smaller and larger institutions in different stakeholders is beginning to happen. He has also brokered some interesting relationships with some of the very large industry, to gain some new funding for science education and science, and I think some of those partnerships will also suggest new ways that we can accomplish training, and provide those "on-ramps and off-ramps" as they like to call them in Washington, for people to be able to participate in science.

Finally, this has been done. The President created a council on STEM education. It's comprised of the representatives of the agencies that currently fund science education. There are 226 programs in science education across all the science agencies, and so there's one rep from each of those on the council that if I'm confirmed I will chair. This phrase, "If I'm confirmed," they taught me to say it so much that I say it in my sleep, I'm not kidding. [LAUGHTER] And, "I look forward to working with you, Senator, on that problem," as my escape from a question. That's the other line that I just love. My students picked up one in the hearing that was just priceless. My colleague, Cathy Sullivan, who was being confirmed for another position, was being questioned by the same committee at the same time. When one of the Senators asked her something about fisheries, which she got a lot of questions on, she said, "I'm sorry, Senator, but I don't usually function at that level of detail." [LAUGHTER] So my students are going to start using this on their exams: "I'm sorry, Professor, I don't function at that level, oops!" So, I learned all sorts of things.

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The PCAST group brought this report to the President. That's a picture of him reading my report, but I couldn't be there, it was so annoying. They went into the White House and the entire PCAST went and delivered it, but I was part of the working group that did the work for PCAST, so I couldn't go because I didn't have security clearance. At the time, I said, "Oh, come on, how long could it take to get security clearance? You know, I don't have a really dangerous history." Well, after the last nine months of being vetted by the FBI, some of you I know were contacted by the FBI so you know, I understand what security clearance means. I understand they could not have gotten it done in time for a meeting with the President. The good news was, despite the fact that I didn't get to see this personally, I got detailed reports and the President smiling in this picture is said to be what he did throughout the meeting. He was late to the next meeting because he enjoyed the discussion of this so much. The President is just enthralled with science and science education. He feels stymied, I believe, by the current situation, and I think we shouldn't assume that the administration doesn't want change, just because we've been unable to foster it in Congress. There's also, the good news is, a lot of enthusiasm for science education across Congress, Democrats and Republicans. I think we do actually have a bright future, but I have to say that, because you know, otherwise I'd wonder about my sanity going to this job.

There are a number of actions in the Executive Branch, when the 2014 budget is finally settled on it may not look so good. There was an increase in STEM ed funding across the 13 agencies. There was a proposal to coordinate the programs among those agencies and see if we could find efficiencies, so more money could be pulled out for other activities. Then the President has this project called "100K in 10," which is 100,000 new STEM teachers, K-12 teachers, in 10 years. That was a few years ago, so I think we're down to seven years or six years now. This is going really well. They took advantage of a very well-studied program called "U Teach," which trains science teachers and then sends them out into the world. They have a very high rate of staying in teaching. One of the worst problems with K-12 teachers is that, I think the average stay is five years on the job. The students who go through the U Teach program, which is an intensive, short-term fast certification program that was started, I think in Texas, has been really effective at creating teachers who were trained in STEM but also stay in the school systems longer.

There's also a new element of the President's strategic plan in science education that pertains to graduate education. I never see graduate education mentioned at the Executive wing level, so that's kind of cool. I can't tell you about all my initiatives, I guess, but hopefully they'll be a lot more to add to this list in another year. Some of my particular interests are in probability, and getting the concept of probability in the K-12 curriculum throughout, and not just in the science curriculum, but in English and in everything else. Looking at ways to change the image of women in science to young girls, because there's some evidence that the major reason that girls turn away from science is that they see being a scientist in conflict with their image of themselves as a woman. They feel they have to make a choice when they're at that critical middle school time. I'm hoping I can work with some of the people who produce the most popular television shows and see if we can work some women scientists into them.

The one thing I can talk about is how my group has addressed this recommendation #2, as it's been called. There are a lot of people thinking about it. What we did was something that really

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wasn't new, but it had some nice wrinkles that I'd like to share with you. Research courses have been shown over and over to be highly effective in stimulating interest in science and educating. The outcomes are good. I was a member of the pool of HHMI professors, as Jenn mentioned, and a number of the projects of those professors was research courses. I will admit that when I went there the first time in 2002, I was extremely skeptical of the concept of a research course. I said, "You've got to be kidding, that's not going to do the same thing that research in the lab does." Of course, I was wrong, and I was thinking very small. Other people have thought very big, and one HHMI-supported program is at UT-Austin, the largest institution in the country. They have created a thing called the Freshman Experience, which has undergraduate freshmen doing research in their intro bio labs, rather than doing the classic cookbooks. They have scaled up, they're beginning to offer this to all of their freshmen, which is a pretty vast job.

Another program comes from HHMI itself, one of the HHMI professors, Graham Hatfull, developed a PHAGE course, which is about discovery of phage from soil. For those of you who don't know what phage are, they are viruses that infect bacteria. This now is centralized at HHMI, where they train instructors from across the country to offer this course a couple of times a year. There is a fabulous genomics network across the country that was started by Sally Elgin at Wash U. She has a lot of data to show how her genomics modules are being used across many different kinds of institutions and what the impact on learning is. It is actually Sally's project that I liked the best in the early years of these, because her students couldn't get the answer without each other. In the early years, and I would assumed that the major genomes have been done now so she probably changed it, but she used to give every student a piece of a chromosome. Each one had their little piece, but they couldn't piece together an entire chromosome unless the whole class worked together. I thought that was such a beautiful lesson in the interdependency of science and getting students to work together and integrate other people's data into their own.

Fly genetics research lab has been going on now for well over a decade at UCLA. Utpal Banerjee started this, and it's the longest course ever taught, I believe, because he uses this continuous model where each group of students pass on their fly stocks to the next group of students, and so they're building on the research from the previous course.

At Yale, there was a program developed by Scott Strobel, whose father is a very famous and infamous plant pathologist, so probably the Plant Path people know the name. His father being a plant pathologist and being interested in fungi actually helped Scott develop this course. It's call the Rainforest Biodiversity course. They would take students to Ecuador, to the rainforest, to collect plants and isolate endophytic fungi, so fungi live inside the plants, every year. This project was kind of scoffed at by everybody not at Yale, and they would roll their eyes and say, "Well yeah, Yale can do that, but we can't, we don't have the money." In fact, Yale couldn't do it, and they couldn't keep supporting it once the HHMI money dries up. It clearly was not a sustainable model, but the beauty of the course is that the students would do a lot of work beforehand. They would pick a group of plants that was going to be their group to sample, and they could use any cross-section of the plant world they wanted: medicinal plants, one student did, another one did all the plants that come up in *Harry Potter* books, anything they wanted was fine as long as they learned something about those plants. Then they would go down and have

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to recognize their plants, and sample them, and then they would get the fungi living inside, bring the cultures back to Yale and culture them, and study them for interesting chemicals that might have medicinal uses. A really interesting part of his project was that he fanned the students out across campus. Everyone in Biology kind of knows about Scott's students coming back from the rainforest, and we know that sometime after Spring Break we're going to get a horde of students coming and saying, "I want to use your assay." It's really, it's kind of an interesting way of pulling the campus together through these undergraduates that assays from about a hundred different labs are being used to screen the rainforest isolates.

I took Scott's program and I said, 'How can we turn this into something that is feasible, inexpensive, and simple, that could be done in any classroom across the country or the world?' I took three concepts with Scott's program. The first was this national mandate, the sense that if we don't have disseminatable and easily replicated programs to offer the community, that recommendation #2 is not going to be very active. People need programs that they can implement. I'm also, as Jenn said, a microbiologist, so I wanted to integrate my interests in infectious disease, and also an interest I have had for a long time, in new strategies for isolating antibiotic producing bacteria. We call this the Small World Initiative, and it's a version of crowdsourcing biology.

Just for the background, for those of you who don't know about the antibiotic crisis, there has been a dramatic rise in antibiotic resistant pathogens, to the point that the resistance in many cases is so extreme and so many antibiotics that these pathogens can no longer be treated. The kicker in that story is that as antibiotic resistance has increased, and this is just one example of one pathogen over a seven-year period and the proportion that became resistant; I find that appalling. During the same time, from the 80s until now, the discovery of new antibiotics has waned. Whereas in its heyday, the antibiotic industry was pumping out 15 new antibiotics, on average, per year, and that was sustained for quite a while. Since the 80's, this is over four-year periods, that has now diminished to [INAUDIBLE] a trickle of new antibiotics. Most of them are just variations on old themes, they're not really new structures. We have a problem that is threatening [INAUDIBLE] world health in a really excruciatingly serious way. I think this is one of our most urgent health problems, and it's largely being ignored. There have been a few programs to try to give incentives to companies to come back into the discovery mode, and that hasn't worked. There has really been nothing successful to generate large-scale change.

So just a little background on antibiotics. 75% of the ones we use today come from soil bacteria. It's estimated by some people, others would disagree, that there are probably one hundred thousand or more new compounds that could be isolated from the soil through the organism *Streptomyces*. Most of them, of course, remain to be discovered, and the question is, can we discover them. Industry has claimed, ever since the 80s, that 99.9% of what you discover when you look for compounds in the soil have already been discovered. They call it their "99.9 rediscovery rate." I cited this in all my grants and talked about it for years, and I handed out the reference to all my colleagues. Then, last year, I just started looking at the data, and the answer is that there isn't any. I quote my colleague in Plant Pathology who used to bellow at people, "You've got a dogma with no data!" It seems that the 99.9% might be one of

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those, that there is an assumption that we can't find new antibiotics, but in fact, no data to support that assumption.

My hypothesis has been for a while that there are a lot of unknown chemicals produced by soil bacteria, and our job is to figure out how to find them. I think there are a lot of ways that we can do that. But, if they're right that the 99.9% rediscovery rate is real, we're going to have to look at an awful lot of compounds to find new ones. At that rate, it would be one per thousand, and getting the structures of a thousand compounds is not trivial, but we think it's perhaps possible.

Our Small World Initiative is designed to attract students to this engaging problem, this urgent world issue on global health, and then have them do authentic research that has the chance, and they understand that they're probably not going to solve the problem and discover the next penicillin, but have the chance of doing that, or contributing a little piece of data that might lead to that discovery. We want to then link them together in a global network, so they can talk to each other and share data. We'll have a general data repository that all of them can put data in. We really have the means in this to test the hypothesis that no one could do in their own lab. By collectivizing all of these thousands of students across the world, we can test the hypothesis that, in fact, there are compounds out there, and find out whether this this low one-in-a-thousand rate or something greater.

We're focusing on new habitats, and that will be implicit in where the classrooms are, because no scientist has gone out there and sampled in all the places where our collaborators will be across the world. By definition, new habitats will be sampled. We hope that our students will get creative and introduce new screens into the process. The students collect soil and cultured bacteria, and then they test those bacteria for antibiotic production. These are just a few results from our course last year. You can see, this is the bacterium that's producing an antibiotics that's creating inhibition of the bacteria around it. That's an indication of antibiosis. The students absolutely love this because they get colored bacteria. They are not usually the new ones, but they are really cool. All my students wanted to do was take pictures of their colored bacteria, because they were so neat. They competed to see where the most colored bacteria, the most antibiotic producers came from. This was the collection of sites they sampled from, although that one was mine. It was really quite remarkable, the frequency of antibiotic-producing isolates that they had. This is just from a class of six students. We didn't get approval for the course until right before the semester, so we only got the word out one day before they were signing up. We had six first-semester freshmen, and they came up with 370 antibiotics producers.

We have data on their learning through their posters and their reports at the end of the course. This is the lobby of my current building, not anywhere as beautiful as MSB, I'll comment. We did it there so that every time someone went to the elevators that day, they would have to pass our students' posters. We got a lot of colleagues dropping in. One of the comments that was the most pleasing to me was, "I thought they were graduate students." I heard that from a number of postdocs and faculty who stopped in. They were pretty accomplished, and this was first-semester freshmen.

We now have a model, a prototype, and the question is can we expand it? We're going to offer more sections at Yale, advertised in advance. Now we're replicating on other campuses. We

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held a training program this summer, and we have 25 instructors from 25 different campuses, community colleges, small liberal arts colleges, and big universities, who are teaching it in the spring. They're all going to teach it simultaneously in their respective institutions, and then work on ironing out the kinks together, so these are our pilot partners. While they're doing that, we're hopefully going to be developing the international notebook so we can put this in a centralized source of data. Also, during the course, we're going to be training a group of international scientists that have been collected by the American Society for Microbiology, who are interested in teaching this course. I thought, when we first put out the ad for anyone want to come for this training, we had written in the grant that we would train three people the first year, because we thought, how many places do we need it taught to vet the materials, three should be enough. We got 80 applicants and we could only accommodate 25. In the international world, the same thing seems to be happening, that when ASM (the American Society for Microbiology) let it out that this was happening and they were looking for people to run the course in other countries, they've been flooded with requests. As soon as we can get visa problems worked out, we'll be training a whole group of people from Nigeria, Guadalupe, and a number of other places to teach the course and hopefully discover antibiotics.

As you might imagine, this is just the model. There are dozens and dozens of different kinds of scientific problems that come to mind that could be addressed by what we call the crowdsourcing approach. One question is, what other science can we crowdsource, and how can we find out what that science is, and get more courses developed in computer science and meteorology and chemistry. How can we use this kind of science diplomacy to make the world a smaller place? I used to think of this in terms of warring nations getting together, but I realized over the time when I was prepping for the Senate hearings that science diplomacy is the way to bring Congress together. I met with Republicans and Democrats and there was no division, they just wanted to talk about science. I think this diplomacy is quite a lesson in the kind of neutral topic, nonpartisan topic, science is and how it can bring people together.

I think we need to start thinking of our undergraduates as a highly skilled, trained, and intelligent group of workers, and use them as part of our scientific workforce. Instead of having them run labs that have been done for a hundred years, just copying what somebody else did, why not make them our major research team on some of these problems that need the volume, the many, many participants to be effective.

The Small World Initiative was done in my group largely by Tiffany Tsang, who is a postdoc, who came to me from the University of Michigan and has just really taken the program. I haven't done anything, I just sit and watch her. It's quite amazing. She's had help from a number of people, including Michael Thomas from the Bacteriology department, who came and worked with us in the class last year. He also directed me to the first crowdsourcing paper, which you may know, the *Nature* paper where they crowdsourced the folding of an HIV protein and it was gamers who actually solved it. He has generated a lot of ideas on this project. We've had funding from the beginning with HHMI and then recently the Helmsley Trust has invested. It was a real lesson in how microbiology does infect people with enthusiasm. We had the CEO or President, I forgot what he was called, of Helmsley come to the training this summer. He was in there with a lab coat and goggles and excited about it, and we had to actually physically pull him by the arm to get him out of the lab. He hated biology when he was

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a student. I mean, he talks about it with great passion, how horrible biology was. That's a really great selling point, is not only to have our students do science, but have lots of other people that we'd like to introduce to the power of science.

On the PCAST report that I mentioned, it was co-chaired by four of us: Jim Gates, Peter Lepage, and Chad Merkin. The staffer from OSTP that worked on it as well was Danielle Evers, and she did a tremendous amount of work. The first thing I did when I was asked to take this job was say, "How can we get Danielle back?" and she's now working in the Science Division at OSTP, so I hope that I will have good help there.

So, with that, I'll stop, and I'm sorry it ran a little bit over. I'll blame Jenn, how's that?  
[LAUGHTER] Thank you very much! [APPLAUSE]

Question and Answer Period

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**JENNIFER SHERIDAN:** So thanks, Jo! Would you be willing to take a question or two?

**JO HANDELSMAN:** Absolutely.

**JENNIFER SHERIDAN:** So, we are taping this, so if you don't mind speaking into the mic.

**AUDIENCE MEMBER:** Thank you so much, that was really exciting. Can you give us an idea of how you evaluate students in that kind of course, you know, just to give us some idea?

**JO HANDELSMAN:** We have standard evaluations of learning that pertain to the course itself, just content in terms of exams, and that's actually something that our pilot partners are working on with us, is assessment instruments that we can all use, that we all agree test knowledge and understanding and skills. But, we intend to take it further and follow the students from their freshmen or sophomore years when they take the course and see what happens to them in terms of their science curricula. Do they stay in science? Do they take more science courses? What are their grades generally, grades in science, and what are they graduating and do next? In fact, one of the criteria for our partners was that they have access to that kind of data on their campus. I'm sure some of them won't be able to do it, but we're hoping we'll have close to a couple of dozen campuses gathering data. We think that the learning at the time is important, but the achievement later on in a more global sense is probably a better measure.

**JENNIFER SHERIDAN:** And we have one right here.

**AUDIENCE MEMBER:** Hi Jo, I just wanted to follow up on that. So were the students who were recruited to the course, and who your partners will recruit, intending to major in science, or was it a non-science majors course open to everybody?

**JO HANDELSMAN:** That's a good question. Our course was supposed to recruit non-majors, or just anybody, and it ended up recruiting only people who were very interested in science. That was not the population we were aiming for, but we're hoping by doing it a little bit more, with a little bit more lead time, we'll be able to get a different population this year. The pilot partners vary. Some of them are teaching general courses, general biology courses that are taken to fulfill a requirement for non-science majors. We actually have four models. We have the non-majors course; we have the general biology, which sometimes is also a non-majors course but is the one used by majors; we have cell and molecular biology courses, which in some places are the introductory curriculum; and then we have microbiology courses. We wanted the first three more than the microbiology courses because we wanted to focus on the first two years. There are some campuses that teach microbiology in the first two years. The pilot partners are helping us write teacher manuals for all of those, trying to figure out what are the differences in classrooms of those types, and how do we need to modify the materials and our instructions.

**JENNIFER SHERIDAN:** OK, can we do one last one, here?

**AUDIENCE MEMBER:** I wonder to what extent, in terms of getting adoption of research labs in all the thousands of institutions across the country, you'd need to lean on the commercial textbook industry, and to what extent you have levers or ways, or whether that relies on individual faculty to write the curricula. But how much is that important to get these kinds of

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Question and Answer Period

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things to permeate all the thousands of institutions in what your strategies are regarding adoption?

**JO HANDELSMAN:** I think that's a really important focus, and I would say that our experience in my teaching group here has been that some, at least, of the textbook companies are way ahead of the scientific community in terms of thinking about new pedagogy. They are looking for ways to introduce new pedagogy, but it's hard to do it in new textbooks and some of them don't know how. Some of them are holding courses, teaching active learning, some of them are doing supplements, there are a whole bunch of different models. The one that we've done the most aggressively, and hopefully this could be used by other crowdsourcing courses in other topics, is we're working with the microbiology textbook that we particularly like; our students picked it, actually. We're referencing pages in it. The textbook companies really like that, of course, we're referencing their book, and you can fill in the blank and use a different book, but the encouragement is to go to that book. I think that if the textbook companies feel that their content is going to be referenced, then they'll help with this and hopefully take advice on how to build their textbooks around this kind of science. We taught, essentially, a general biology course when we taught the antibiotics. The material was all around, the introductory material was biology, not just the microbiology. We found that to work really well, and we could use almost any textbook for biology or microbiology with it.

**JENNIFER SHERIDAN:** Thank you, Jo. It's quarter after and we do have a reception outside. I saw many hands shooting up, but this time after was intended to all talk amongst each other, have a chance to see Jo and ask any other questions you might have. I know there's lots of other hands, but please, join us outside, corral Jo with your other questions. The donation forms are out there, too. Thank you so much for coming, and thanks especially to Jo Handelsman. [APPLAUSE]