President's Council of Advisors on Science and Technology (PCAST)

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John Holdren: If I can get everyone to take their seats. Let me start by welcoming everybody, the members of PCAST, the OSTP staff, the members of the science and innovation communities who are attending in person, the folks watching on the Web and of course our guest speakers for the morning whom I'll introduce in a moment. Just very briefly in the way of opening remarks, it's very exciting to have PCAST in town for its bimonthly meeting. We are gathered here at a time of great challenge, of course, particularly in the budgetary domain but also great excitement about the opportunities to continue and expand to apply science, technology and innovation to the full range of national priorities before us. We have enormous opportunities to apply science, technology, innovation, high-tech entrepreneurship to job creation and economic growth, opportunities to apply biomedical science and information technology and the intersection of those to getting better health outcomes for more Americans at lower cost. We have opportunities to bring science and technology more effectively to bear on the great challenges at the intersection of energy and climate change. We have enormous opportunities as well as responsibilities in the domain of making progress national security and Homeland Security and using science and technology to best effect in that end. And, of course, we have great opportunities and we place high priority on STEM education, on science, technology, engineering and mathematics education which in a way is the foundation of future progress in all of these applied challenges and, of course, in the great quest to expand fundamental knowledge, to better understand ourselves and our universe. I think all of us on PCAST feel that it's a great privilege to be advising the president of the United States and his other senior advisors on this range of topics at this particular moment in history. So before I introduce our speakers in this session this morning, our first speaker, let me ask my co-chair, Eric Lander, if he would like to add anything.

Eric Lander: No, just my general welcome and thanks to everybody for being here and to the PCAST for what has been just continued frenzy of activity on many fronts, some of which we'll be discussing today. I also want to thank the speakers for coming and discussing with us this very interesting and important point.

John Holdren: Let me very briefly introduce the panel. Because all of the members of PCAST have their bios in their book, I will not read them to you and take the time with the speakers, but let me just say that we will be learning about the American Chemical Society Presidential Commission on events in Graduate Education in the Chemical Sciences from Bassam Shakhashiri who is Professor of Chemistry at the University of Wisconsin at Madison. We will be hearing from William Banholzer who is Executive Vice President and Chief Technology Officer at the Dow Chemical Company and we will be hearing from Jackie Barton who is Professor of Chemistry at the California Institute of Technology and I do have to mention one item from her bio. She received the 2010 National Medal of Science from President Obama and it was a pleasure and a privilege for me to be present at that ceremony. So welcome to all of you and thank you for taking the time to come and share your insights with us about this very important report, and I'm going to turn first to Professor Shakhashiri.

Bassam Shakhashiri: Thank you, Dr. Holdren. We are grateful for the opportunity to present to the President's Council of Advisors on Science and Technology conclusions and recommendations from the ACS Commission on Graduate Education in the Chemical Sciences. We believe that fundamental changes are needed in the education of the scientists whose work impacts medicine, drug discovery, development of sustainable new fuels and other global challenges that society faces in the 21st century. The ACS Commission Report provides sharply focused recommendations related to reports issued recently by PCAST. I refer specifically to the report Engage to Excel and also to report The Future of the U.S. Research Enterprise.

Before I begin— before we begin—I wish to take a brief moment to share with you another contribution from the American Chemical Society that relates to President Obama's calling on all of us, scientists and citizens, to respond to the threat of climate change. The ACS Climate Science Toolkit was completed last year. It provides tools to better understand and communicate the *science* of climate change, to scientists, and to the public at large. It can be freely accessed by anyone at www.acs.org/climatescience. Dr. Mario Molina advised and contributed to the development of this toolkit. Thank you, Dr. Molina.

The state of graduate education in the chemical sciences is healthy and productive in many respects. However, practices of graduate education in our fields have not kept pace with the significant changes in the world's economic, social, and political environment since the end of World War II, when the current system of graduate education was formed. To address the nation's needs and to help assure quality graduate education, I, as president of the American Chemical Society, formed a blue-ribbon commission to undertake a wholesale review of graduate education in the chemical sciences.

The commission consisted of top national leaders from academia and industry, including members of the national academies, PCAST member Dr. Chad Mirkin. Thank you, Dr. Mirkin. University presidents, vice presidents from major chemical and life sciences companies, Medal of Science winners and distinguished faculty from across the nation. Dr. Larry Faulkner, President Emeritus of the University of Texas, served as commission chair. The charge given to the commission was to answer two main questions: What are the purposes of graduate education in the chemical sciences; and what steps should be taken to ensure that graduate education addresses important societal issues as well as the needs and aspirations of graduate students. The commission was also asked to consider fundamental, comprehensive, and systemic changes suitable for graduate education in the chemical sciences and to suggest actionable approaches for enhancing the quality of graduate education at all institutions. Furthermore, the commission was asked to address five major areas and determine if the current academic structure of departments is a strength or a weakness, to examine the employment issues of graduate students in both industrial and academic settings, to review the financial support mechanisms for graduate students, and to examine the current profile of graduate students in terms of diversity along various axes. And finally to focus on the expectations and aspirations of graduate students and whether or not universities are keeping the promises that they made to students, both explicitly and implicitly. The commission completed its work last December and issued a remarkable report. The commission was unanimous in its candid conclusions and unequivocal in its advocacy for change in the conduct of graduate education in the chemical sciences. And now to present the commission's conclusions and recommendations, I call on Dr. Jackie Barton and Dr. William Banholzer.

Jackie Barton: So as Dr. Shakhashiri said, we completed our report. I think you all have a copy of the summary report here. And we really wanted to deal with the important questions that Bassam had addressed to us. And we talked about the purposes of graduate education. And in thinking about what is the role of graduate education, there are some purposes that transcend the individual, what's important in terms of contributions to society. That's what this is all about: How can we further science in our country and in the world. And then also the purposes that are focused on the individual: How people are learning and becoming full-fledged graduate scientists. But at the end of the day, what we had were five conclusions and that's what I really want us to go through here.

The conclusions spoke to the educational experience of graduate students, the financial support of graduate students, safety as a culture, sustainability and opportunity in graduate programs, and the post-doc experience. Once we had the report, we brought it to a whole range of different audiences and you were one of them here because in fact, I think we really tried to look at some more questions, and we don't want this report to just be put away somewhere. I think it's important that there are actionable items and that we deal with them.

So let me really get to that. So the first conclusion: current educational opportunities for graduate students, viewed on balance, do not provide sufficient preparation for careers after graduate school. That's where we are now. And I think here, what's really important is that we need more buy-in of the professors that are mentoring the students by and large, across the way. We need the mentors to be helping in terms of teaching the students beyond their individual research projects, how to give a talk, how to communicate the science once they have it, how to learn new science. The science that they will be grappling with once they're on their own as individuals isn't the science—the facts are going to change, hopefully. We're going to be learning new things. So, how to teach the students how to learn and learn new things. How to collaborate on global teams. In bringing things forward, whether you're talking about an individual research group or whether you're talking about going into industry and having people with different expertise get together, it's important that students learn how to work together on teams, and global teams. The person that you're working with may be at the other end of the globe with different perspectives, but you've got to learn how to work together and talk the same language, not so localized and focused on the trees that you're not thinking about the forest.

And then to effectively define and do what you're doing in order to come up with a practical solution. At the end of the day as students are no longer students and they're having their careers, it's not a matter of being part of a research boutique. It's part of making something that's going to make a difference, and so having a goal of these practical solutions, not just science for the beauty of science.

And then importantly what has to underpin everything is the ethical conduct of research. And I think it's clearly important that we focus on the training of students in that context, not just on the facts and not just on their individual research projects. We also said that it was important that this, although we're asking a lot, that it should be done in a shorter period of time, which means that as you bring in more things to do, you're going to have to eliminate some other things.

The second conclusion I think is also one that's very important and one that this group in particular can be speaking to and that is that the system for financial support of graduate students probably needs to be changed. It's no longer optimum. It rests too heavily on individual research grants. And that raises all sorts of conflicts. What we have to do is change it so that there's this separation between funding of students, maybe not a complete separation, but there's the funding of students and then there's the funding of individual research projects. And that the goals aren't completely the same in those cases and so we have to consider that. So we need to decouple individual research grants from funding of students.

It used to be 20, 30 years ago that students were funded through NSF, graduate fellowships through training grants, and then one had, separate from that, funding of a research project. That's not the way it is in lots of places today and so that means that the students' focus has to be completely on the research grant and the mentor is completely on the research grant instead of the training of the students to be scientists. So we have to decouple this better. We have to have trial projects designed to come up with new kinds of training grants and bring more of those kinds of programs into place. The commission recommends graduate program grants to support graduate students, analogous to training grants. We have to have more of those.

And in saying this, and this was something that the commission talked about to a great extent, we're not asking for more money. We think this is sufficiently important that if there is a constant pot that has to be redistributed towards these kind of programs, rather than solely on individual research grants. And then I'll turn this over to Bill Banholzer who I think can articulate this next and very important conclusion.

Bill Banholzer: Thanks, Jackie. So another key finding from our commission was that safety has to be instilled as a culture within a university. Today in a research institution and the research industry, they are very similar but it’s eleven times safer to be in an industrial lab rather than academic lab using OSHA recorded results. Eleven times. Not two or three, that’s an order of magnitude. And we're doing the same kind of work, and I don't know why we would accept that. And an industry, even though we compete, we share our best practices on safety because it's in the best interest of the whole industry that we all operate safely, that we all create a safe environment for not only our employees but the products that we produce. We don't understand why that shouldn't be leveraged equally into an academic society. And in fact, we think it will actually have an element of effectiveness and that the graduate students, when we hire them now, typically have to have two to five weeks of training, remedial safety training, before we let them in an industrial lab. I don't understand why we'd allow that.

And finally, we've had some notable explosions, including fatalities, that could have been prevented in academic labs had they had the proper personal protection equipment and proper safety training. So we thought it was imperative as part of the future education of these students that they instill and understand safety as a culture. And it's a leadership thing.

Now, the first issue is it has to really be driven by faculty members. This is not about a lot of money. It's more about mindset and procedures, and it has to start with the faculty members. So it's part of the recommendations to the faculty we felt that we should not accept that we aren't going to be as safe as we can. We have an obligation to the students that come in, that they leave our labs and leave with their degrees as safely and as healthy as when they entered. So we think it's an institutional element as well in that there are certain things where you can have— you have to have harmonization across a department. It can't be that one group is safe and one isn't. So we thought for the institution leadership that they need to make sure that safety is applied uniformly and the tools and training are spread across every institution and the entire academic framework.

It's hard. You know, in academia you've got a lot of stakeholders but I think safety is just all about mindset. In industry, if we see an unsafe lab, we will shut the lab down. You cannot work. Our tenet is if you can't do the lab work safely, you can't do it at all. That's not exactly the framework that we have in all our academic labs.

The fourth conclusion, the second one that I'd like to talk about, is the most contentious, but I also am pretty proud of my colleagues for having the courage to bring it forward to admit the elephant in the room, which is there are too many PhDs being granted in chemistry for the amount of jobs out there. And this is manifested in several ways. First of all, people are now taking two and three post-docs. The post-docs have started to become a capacitor to try to buffer between the actual jobs that are out there and the number of PhDs that are being produced.

Second, there are some departments at some of the smaller or less research-intensive schools that have the majority—not a few—the *majority* of their PhDs from outside the United States because of the number of teaching load. And one of the conclusions was we have an undergraduate responsibility to teach chemistry to a broad group that aren’t all going to go into chemistry. But we can't use that as an excuse to say that's why we have to generate a bunch of PhDs. So the recommendation is that we need to seriously look at how many PhD chemistry and chemical engineering degree programs are there and decouple that from the undergraduate teaching load and supervision. And it's been done at several places effectively. And that we have to also recognize that not every program has to be the same, that people should try to differentiate and decide what the country needs but not everybody has to be world class in biotechnology and nanotechnology, and somewhere each department's got to look at what do they want to be world class in rather than every department thinking that every individual sub-discipline is going to be world class in everything. It just doesn't work that way.

Now, this is the most challenging. People are going to ask, well, how do you expect to implement this, and we recognize that it's probably one of the most difficult of the conclusions and recommendations to implement, but that did not deter us from saying, it has to be brought up and recognized that we probably are having too many PhDs granted, and some of the things that we thought we could do was, to repeat what Jackie went through: as we look at the funding of students, look at how many students we really want to fund and use that as one mechanism, but we also talked about transparency and said if we generated a database where people understood what the percent of people who are graduating are getting jobs, and where they are getting jobs and from what department and how long it's taking them to get their degrees, that students will vote with their feet. And so by trying to develop the recommendations for ACS that we would create some kind of survey, a database where people can go.

We have a survey of what the salaries are. So people know what people are getting for salaries. It's very privacy-protected. But if we had some survey where we would be able to understand what each department, where are their graduate students coming from, where are they going to, where are they actually finding jobs and how long is it taking them to get out, that students will look at that as they decide where they go and that might be one mechanism to sort of force a change. I recognize it's probably going to be very hard for a department to say, well, you know what, I'll give up my PhD program and I don't have to be a research institution; I want to be a teaching institution. That's probably not a natural act. But for the health of the chemical profession we thought it was a report of this magnitude had to have that recommendation included in it.

So the transparency initiative is *a* way. It's probably not going to be the primary forcing function but we felt that these are all information that students had the right to see. We have great mechanisms now. You can find so much stuff on the Web. This is something that the ACS can easily facilitate. So with that I'll turn it back to Jackie to talk about post-doc.

Jackie Barton: So the other piece of this is also that being a post-doc should not be a weigh station. A post-doc is an apprentice. A post-doc is an apprentice towards becoming either an academic scientist or in industry. And they need to be treated that way. And again, they need to be mentored in that regard.

In many universities, many that we know well, a post-doc is sort of in this island. They are not students; they are not faculty. What are they? And that has to change. And I think it really has to change in the context of thinking about how we train them, that a part of the post-doc experience should be mentorship, and we recommend therefore that funding agencies, when they're funding post-docs, should rare general mentoring plan. That happens in a lot of NIH programs. I think that needs to happen more generally and that's the way we feel about it.

Funding agencies need to become more receptive to requests for support of post-doctoral associates as independent scientists in various circumstances.

And then there's also the teaching post-doctoral associate. There are several programs that exist, but they're very small in terms of having postdocs that are part teaching, part research experiences. And I think those are the kinds of things from this spirit of mentorship that need to be extended further.

Also something that I forgot to mention in the context of financial support for graduate students but holds as well with respect to post-docs is this whole issue of international students coming in and how they're funded. And I think this group in particular could be serving a role of providing more pressure that different countries, when they send their people here for training, need also to provide some support for that. Some countries do that; many countries do not, and I think that's something that's important for us to try and focus on and create more of a pressure in order to accomplish that goal. So those are the recommendations, and we just look forward to your questions.

John Holdren: Great. Well, thank you very much, and we'll follow the usual practice of recognizing people in the order that their flags go up. And Mark Gorenberg was the fastest. Mark?

Mark Gorenberg: John, thank you. Thank you all very much for your report and your recommendations. They are really great and very broad. I'm curious about your position on a hot topic this year on online courses, particularly about MOOCs, Massive Open Online Courses. You didn't talk about it in your slide. You do make reference to online courses in your report and I'm curious if you have a position on that.

Bassam Shakhashiri: That was not a specific topic that the commission looked at. As we all know, MOOC is changing as we speak, but it is something that is of great concern in terms of the preparation, the proper technical preparation of the students who will enter graduate school, and the quality of instruction that is given via the latest part of the technologies in the electronic revolution that we have now. So one can visualize, for example, that the graduate students, when they are admitted to graduate school, would no longer be asked to take qualifying exams or placement exams and so on because they would have had that experience before. So specifically such details and aspects were not addressed by the commission but are indeed related to the commission recommendations.

Jackie Barton: You know, it is remarkable how little we talked about it, but I think the reason is that chemistry is basically laboratory science and at the end of the day in terms of a graduate education, you've got to get in the lab. Maybe that's part of the difference.

Bill Banholzer: There was one area where I think it's especially applicable, which is safety. So there are standard safety project hazard analysis and reactive chemistry and exothermic reaction analysis that you do that you'd like to have that standardized and disseminated quickly across the whole place and it seems online training would be the perfect place to do it. In fact, we're developing these modules within our corporation, Dow, for exactly the same purpose. We have sites all over the world and we want the same standards everywhere, and to try to teach that one-on-one is a tedious experiment. Plus, if you want to get it out quickly, that's the best way to sort of have the same standard taught everywhere. Now, whether it's followed and adopted is one thing, but I think in the actual dissemination of how do you do a lot of these safety practices and what constitutes a good safety program, I think the online academy, some way to train it, is ideal. And we're actually generating some modules, say, look, this is what we do. And then we're working with some universities to try to tailor that to be more applicable to the university. I think that’s one place that you could quickly disseminate because it's a standard. It's not going to change from place to place, and it sort of creates a, what I’d say a minimum level of what we're going to have. And I think that might be an ideal way where you don't have to worry about the content is pretty uniform and it shouldn't have to be tailored as much.

John Holdren: I have a long list and I'm going to try to do it in the order in which I saw the flags. If I get you out of order, I apologize. Barbara Schaal is next on my list.

Barbara Schaal: Thank you-all very much. This is a really interesting discussion. And also thank you for your leadership. It's very nice to see an academic discipline come forward and speak with a clear and consistent voice and I think that makes it very effective. I was very interested in your comments about decoupling graduate education from undergraduate TA-ships. That’s, I think, a real challenge for many universities and many of us have been really working and struggling with that to make sure that we do the best possible job of educating our graduate students in all the things that you mentioned:

presentations, etc. But at the same time we have an undergraduate mission and chemistry is at many universities a real core discipline for many of our undergrad students. You mentioned that there were several places where, in fact, there had been very effective decoupling, and I wonder if you could elaborate on that and how that was done and what kind of mechanisms have been put in place in order to really meet the undergraduate teaching needs but yet decouple it from graduate admissions and TA-ships.

Jackie Barton: You know, there are some schools that hire people to do the undergraduate TAs. So they are teaching assistants. The teaching assistant need not be somebody who is working on their graduate research. And that's one way that you can think about doing that. I think the whole question, again, of this question of what's the graduate program supposed to be? The goal of the graduate program should not be to take care of that undergraduate teaching. And so some programs will have a niche area and focus on that and have graduate students in that area, but teaching more broad-based, and hire people to do that.

Bill Banholzer: There is also a benefit of, if you hire professional people who have taught the same class, you get a better undergraduate experience than TAs who are just trying to do their own homework and do their research, and teaching is just a way they can get paid for the semester. And so there's been, I would believe a benefit of having consistency of training, and it decouples the need for, I've just got to have a bunch of Ph.D. students because I've got 15 sections of general chemistry to run. So I think that's the added benefit of the year-to-year consistency and the training. We all agree that if you're going to train people to be professors, they need to be trained how to teach. And that can be an essential part of it. But when it becomes the dominant way that you get your PhD program funded, that's where we thought there was an issue.

John Holdren: Okay. Next is Dan Schrag.

Dan Schrag: Thank you, John, and thanks to all of you. Your discussions about graduate training, support for graduate students and postdocs resonated I think with many of us in our report on the future of the research enterprise that Bill Press led. We really struggled with these exact same issues. Let me just read from page— it's buried a little deep, I apologize but it's Page 74 of our report. That in particular, graduate students and postdoctoral researchers bring a unique kind of creativity to their fields. Whenever possible, that creativity needs to be unleashed instead of restricting graduate students to a particular project or laboratory by providing their funding through a larger research grant, increased graduate fellowships or training grants could give graduate students the freedom to choose their research focus. So we're totally supportive of that view of the world. The problem is that there, you know, is in really engaging with, Dr. Banholzer, what you talked about which is the challenge of controlling the size of the population. One of the reasons we see so many people supporting graduate students off their research grants is they want graduate students, and the ones who get the lead graduate fellowships don't come to them. And they have a project they want to do and so this is a challenge. And we aren't elitist in the way that, for example, in the U.K., where they rank departments and assign graduate fellowships based on your ranking of departments. We don't do that. We are more democratic and therefore we have a much broader pyramid. We spread our research and our PhD programs around the country to more institutions. That's both a positive and a negative, and the balance of those is really difficult.

So I appreciate that you guys are confronting this challenge. It's not clear to me that you can really deal with it without sacrificing some of the sort of democratic virtue that's in our system.

Jackie Barton: That's why we really spoke about having also these training grants. That's one way to do it. That is, to provide—a department gets together and comes up with a program for training graduate students, which obviously by necessity is going to have a component of doing graduate research because that's part of how you train students. But they've got an outstanding program to mentor students, one that involves learning how to give talks, one that involves interacting with industry, what have you. And then funds are given to that department. That's a way to decouple it. And it's not necessarily the most elite department. It's the department that got together and said, how can we do a good job with mentorship?

Bill Banholzer: I think that's a profound point, it's one we struggle with. I mean, there was a lot, Chad was one who said, look, we can't shy away because it's hard to say it's a problem. And I give them credit for keeping us onto that. But, in my world we all have similar issues. We only have so much money and we have more ideas than we can afford. And in tough times you're forced to prioritize. And the one thing I've learned after 30 years of research is that you've got to feed your most important and your best things first or everything suffers and you'll end up with mediocre and then everyone says, why am I doing anything?

And so if we want to maintain our preeminence as a world-class research institution, we've got to, I think, balance a need for this democratic "everybody gets everything" with, but if you don't preserve the best and prioritize the resources to where we have the best chance, I think you run the risk of just trying to spread the peanut butter all over and at the end of the day, the best won't be the best. And we have global world competition who have got different criteria, a whole lot of money, and in my world, the way we do it is we don't— if I have a 10% budget cut, I don't cut 10% of everybody's program. I cut 100% of the bottom 10% of my programs because I can't— the most important things, they're important. I can't sacrifice those. I don't think that model's directly applicable but there's certainly elements of that in there and I think the fact that the world is competing with us and they certainly all want what we have, I think is a challenge and we're going to have to look at that balance of how do we decouple the need to service undergraduates, the need to do world-class research, and the need to try to be there where everybody thinks they can do research. We have, we believe, just too many departments and we've got to figure out how we specialize them. And it's not just academia. In our national labs, we have national labs doing the same thing. They compete for the same DOE proposals. That is redundancy and redundancy, leads to inefficiency, and I don't think we all have enough money to be able to have a lot of redundancy. So it's a gnarly, hard problem.

John Holdren: Okay. Next on my list is Mario Molina.

Mario Molina: Well, first of all, thank you for the excellent report. The question I have is the following: It seems to me that many of the recommendations that you make apply to other disciplines as well. So they are quite general. So I'm just wondering whether in the presentations you have already made or whether you actually thought about these recommendations that might be common, wouldn't it be easier for universities to change not just chemistry but whenever these other things need to be changed. And a related point is that I'm looking specifically at, say, Conclusion 1. I certainly agree lots of things need to change, again United States, not just in chemistry departments. But on the other hand there are some success stories. There are some best practices. There are some good things that have happened already. So it might be nice to come up with some examples of how to do these changes in practice; for example, new methods of teaching TAs. And so there's a lot that is happening that is very positive. So anyhow, that's my point that maybe this could be enlarged and could be even more concrete terms with good examples.

Bassam Shakhashiri: Immediately after the release of the report, we met with presidents of other scientific societies and they quickly said what is in this report is going to be used by them, they're just going to take chemical sciences out and put their own… [laughter] So you're correct.

And the other questions are also focusing on helping universities decide what they want to be in the 21st century. The model that we have used over the past 100 years, the German model where the professor is in charge and the students work for or with— I prefer with the professor—is the one that's being discussed here. And as to how change is going to take place, that's going to depend mostly on two groups: the faculty who have the responsibilities and the obligations for the graduate education and research programs, and on the funders. And what the funders expect from the grants that they make; that is, the federal funders, the state funders, as well as the private foundations and in industry. And this report aims to trigger thoughtful conversations everywhere, but focused on the chemical sciences because this is where we have expertise.

And I can tell you from visits that I have made repeatedly since last December to major universities and to the Office of Management and Budget and to NSF, that there's a great deal of interest in trying to figure out what to do next and how to go about addressing the needs of the 21st century.

What we're really talking about are—take a 22-year-old person in graduate school. What is their life going to be in the next 50 years? That is, what contributions are they going to make to address the grand global challenges that we have in society, whether it's in population growth or dealing with limited resources or climate change. These are very important challenges. Basically this report talks, Dr. Molina, about the chemical sciences, it talks about all sciences, it talks about the future of the university. And those are very difficult questions to deal with, but it is our expectation that the great talent we have at our universities, that is the faculty, and their creativity, that they will devote a fraction of that creativity to address important educational issues.

John Holdren: Thank you. Next on my list is Maxine Savitz.

Maxine Savitz: Thank you. And also I'm impressed that you were able to come to consensus with that diverse group of members. You mentioned, Bill mentioned that, there are too many PhDs in chemistry and chemical engineering. Are there a shortage of masters or technicians as you look out at this? And the reason I bring that up in the biological sciences, the Keck Foundation founded the graduate institute

11 years ago at the Claremont School to really put a terminal Master's degree program into place in the life sciences, which has a flavor both of advanced biological courses but also they do projects as if you were in business school, and much of them working directly, particularly with some pharmaceutical companies in the California area and beyond. So I just wondered, is there any thought given, or is there a need even, for some of this, you know, more than just a bachelor's degree but really don't need a PhD?

Bassam Shakhashiri: The commission looked at that question and specifically decided to focus, in the time available to them, on the PhD program, but in the report there's a mention that the Master's degree is one to be looked at very carefully and subsequently, ACS and other organizations will undertake that responsibility, so that the focus was really on articulating what the purposes of graduate education in the chemical sciences are, the two major questions that were asked. And the commission was very clear in its response. The primary purpose of graduate education *is* education. The proper first focus is to educate students to solve problems in society, including the effect of education of the succeeding generations. That applies of course to the PhD students but also to other students too. And so looking at Master's degree programs is part of what should be looked at next.

John Holdren: Thank you. Shirley Ann Jackson.

Shirley Ann Jackson: I have a couple of questions here, two things: One, maybe it relates to Maxine's question, and this is for Mr. Banholzer. How much use or utility are PhDs in industry?

Bill Banholzer: Okay. So I would say that I'm surprised that anybody in a high-tech industry wouldn't expect that PhDs are *the* critical resource that they have. So in research if you are manufacturing in your plants or your assets, that's what you worry about, and people that run them. But in research, talent is the only thing that matters, and a PhD is how we train people to develop new knowledge. So my view of an undergraduate is that's somebody who can apply knowledge. They understand, the equations have been written and they apply it. But when you look at the next generation of technology that we need, we need people that can understand how to formulate hypotheses, read the literature and then develop the next generation of knowledge. So I would say if you are— hope to be a high-tech industry, and I think it's broader than just the chemical industry and materials industry, a PhD is the key resource that you need to be able to do that.

So in our recruiting for R&D in Dow, we're the biggest chemical company in the United States, we hire, 70-80% of our new hires are PhDs. It's not that I couldn't hire BS people, and after seven or eight years teach them how to do research, but it's way more efficient for me to hire people who have worked with, under the tutelage of a world-class researcher who has taught them the fundamentals, how to develop a hypothesis, test it, and it doesn't matter what they did their research on; they've learned the scientific process and then they can work on whatever they are going to work on. Because I hire somebody for 30 years, I don't know that they are going to be working on RO membranes today and tomorrow I might need them to look on quantum dots for display. But if they've been taught how to think, which is what we sort of describe it as, and that's what a Ph.D. does. It teaches you how to develop new knowledge versus apply knowledge.

Now my disappointment is—and it was in our report—is that we've gotten *so* specialized. So we train people to think so narrow on their dissertation that they can't put it in the context of what society needs. So the way I put that is we need to stop educating people in *what's possible* and also add *what's practical*. So we have people that are doing all kinds of research but never can put in the context of, yeah, but we'll never do that, it costs too much, it's energy inefficient. All of society's problems that we have, be it climate change, energy inefficiency; I was at a meeting with a friend of mine and there was a very well educated scientific person who said, “Hey, did you see about the new Prius that's going to be powered by photovoltaic film?” Now, this is a technical person, not somebody who—they have an engineering discipline and they didn't understand enough that the energy density falling on the surface of Prius is never going to be enough to drive that car, yet they may have been exquisite on understanding the uniqueness of some elemental band structure.

So I think we've got to make sure education is both deep but also broad enough that people can put what they are doing into context. And that knowledge, I'd say, *that is* the key resource we need. It's kind of a longwinded answer to your question but I'd say it's imperative and it's not just verbiage because we hire, like I said, about 80% of the people we hire are PhDs, and the BS are not the people that we expect to be the, you know, the–

Shirley Ann Jackson: All right. I have a quick question for the academics. You know, the question is what are we trying to accomplish with the PhD programs? Is it to enable the students, or is it to put them into a certain channel for society? And how do your recommendations balance that? And what underlies this is this whole question about, do TA-ships really help anybody get an academic position?

Jackie Barton: Let me just say I think the bottom line here is not really, we've got too many PhDs in chemistry. In fact, we've thought about whether or not as a group we wanted to make that conclusion and we couldn't get unanimous consent on that, in part because we didn't have the data. We really don't have the data yet. But I think what *was* clear was that we aren't training them properly in order to enable them to be scientists. And I think that *is* the goal, is to enable them. And I think a part of all of that, I mean, in my own group, yeah, I do want people, my students, to teach because I want them to learn how to teach, and it takes away time from the lab. But that's important because then my graduate students, I want them to learn something. It's important that they learn how to write original research proposals. And so we had a whole thing in here, this is something that happens at Caltech that we care about enormously, that students take the time to learn how to put together a research idea, their own research idea. Now, that takes away time from them being in the lab. But I would argue that that makes them better in my lab and better in everybody else's labs thereafter and most importantly in their own lab.

And so these are important elements of the training. That's what distinguishes a PhD from an undergraduate researcher, and that we can't forget about that and that we have to be telling our colleagues, "Faculties, this is important," but then we also have to enable those faculties because they have the pressure that they've got to get their research results done. So we have to get across to them that this is going to help them to get their research results done but also we have to have other mechanisms for teaching for students.

Another thing I forgot to mention is involvement of the Department of Education in all of this. They have had a grant program, a graduate student fellowship program, and I don't know all the details of how that came to be and came to go away but that's another mechanism that we need to be thinking about in terms of independent funding for graduate students through that mechanism.

Bassam Shakhashiri: The discussion relates to the question that you asked, Dr. Jackson, what is the PhD degree for? Are we to produce PhD "technicians" or PhDs who are scholars and leaders in engaging in creative ways to address very important societal issues.

And this is a question that the faculty themselves have to answer because they are the people who are in charge of the education as well as the training of the graduate students and that's where the conflicts come in, in terms of the support mechanisms that are available. But there are, across the nation, institutions of higher education that use graduate students— I mean the word "use" now very respectfully— as teaching assistants. And is that really part of the Ph.D. training program or is it part of something else as we have addressed before.

So the discussion is really wide open, again, for each institution to decide for itself, what are the purposes of the graduate education programs in the chemical sciences for that institution? And I have great faith in the abilities and creativity of the faculty to address those questions. The question I really have is, what's the time scale for addressing them and what kind of support will they receive as they come up with new ideas from the federal government and the state government?

John Holdren: Thank you. Next on my list is Bill Press.

Bill Press: Thanks, John. And I want to thank the presenters for presenting a bold and very necessary report. I think it's great. I particularly want to call out my thanks to you for the safety message because I think that if we don't get our faculty PIs to embrace safety culture, it does double damage. They are putting their own people at risk and they are not training the next generation to have a safety culture.

But my question is really more on what was called out in the PCAST report as this problem of, if post-docs are really supposed to be training positions and therefore should not be technician positions, then where is that future workforce going to come from? In particular, it seems to me there's a danger that we'll be creating two separate classes of kind of transient workers at our universities: the teaching assistant class who will not have a real career opportunity at any given university and then also a laboratory technician class who don't have a career ladder to advance. And it seems to me this can't be good for universities if they are based on a labor pyramid that has people at the bottom who don't have career advancement opportunities. Where do you see that going?

Jackie Barton: Well, you know, when I talk to my own students about doing post-docs, I tell them that they shouldn't be doing post-docs in a lab like mine. That the whole concept of a post-doc is to go do something else in different areas. And so I think the post-doc has to be a different experience than the graduate student experience. Now, in terms of the university, you still have the post-doc, but maybe the biology post-doc came from a chemistry lab. I think that science has to get— is clearly more interdisciplinary, and people learning how to talk to each other, you know, there has to be more shuffling of the shells, if you will.

Bill Press: Maybe if I could just clarify my question: What's the career path for a technician at a university that has volatile funding of research grants that doesn't have stability and so on. In industry I understand that there can be a useful career path for someone without a PhD, but laboratory research in universities still needs that labor force, and what is going to be the career path of those people. Or where am I wrong?

Jackie Barton: I'm not sure the technician has as much a role in the university setting. A technician clearly has a role in industry but not quite so much in a university setting. University setting is about education. It's about learning.

Bill Banholzer: If I understand your question correctly, I think, my concern is that when we talk about the service element, there's people who get their entire PhD doing nothing but TAs and I don't think that's right. I think everybody who gets a PhD should at least teach a semester or two, and most schools have that requirement because it makes you a better communicator, and it makes sure that you understand how to communicate maybe complex things in multiple different ways.

But I think that is just an element of your education on a way to becoming a world-class researcher, and the outlet of that research should be somewhere you've fulfilled gainful employment. The challenge we had in the commission was there's so much— because chemistry's such a fundamental science, there's so many places you can go, from going into patent law to medicine to just chemistry to a lot of people going to biological sciences—that the fact that not everybody's going to go work in the chemical industry is actually a strength because the skills are portable to a bunch of different industries. So whatever's the right number we struggle with, well, just because there's not a market that everybody's going to go find jobs in pharma anymore doesn't mean that the entire chemical discipline isn't still critical.

But there was some growth signs, which is people are taking more and more PhDs. I don't, in my personal view, I don't think I need to hire post-docs. PhDs should be under a good professor and adequate training because we're going to have to train them the stuff that we need in our area anyway. So they sort of get their post-doc on the job, and I don't need that extra training. Now, if somebody decided that they were in an area like, let's say quantum mechanics, but they really, that led them to more interesting in quantum dots and wanted to go over and work in a materials group that's doing quantum dots, a post-doc might be a way to bridge that to get them more relevant to hire somebody who's doing quantum dots.

So I think there's that element, and then what Jackie said. If you’re going to be in the rat race to become a professor, that post-doc has now become essential to get your research ready so that you can hit the ground running when you start your tenure track discussion. So there's different elements to what the post-doc can do, but there’s a lot of them but people are taking them just because that's the only job they can get. And we interview post-docs now and it’s just because they couldn't get a job the first time. I think that's a macroscopic trend that is what worried us and it should be that these other opportunities should be presented and people need to understand that some of the issue we talked about was, what you need to know is that chemistry, here's all the options that you can do. Here's what a patent lawyer does. So that fundamental, technical—the best patent lawyers are the people who have a technical background because they have got to understand the chemistry that they are trying to patent.

And I think it’s, you know, the idea that we're ever going to get this right and you'll have exactly, well, this is how many openings we have and match it. But the belief is we've got a macroscopic trend of people who can't find jobs, there's too many post-docs and what's the purpose of a post-doc should be, what Jackie or I mentioned, is it's an element to further your education, not “It's the only thing I can get.”

John Holdren: Thank you. We are officially out of time but I'm going to let Eric Lander have the question anyway, but the question and the responses need to be fairly brief.

Eric Lander: You raise so many exciting questions and well-posed questions. I'm struck by the conflicting interests that you've identified of the institution, the professor trying to get his or her work done, and the student. You've suggested we could have a class of people who are teachers, a class of people who are staff scientists, and a class of people who were students, and think about filling those jobs with people who are dedicated to them. You could imagine having students who did some work teaching but it is very clear and transparent how much— it wasn't even that it was for the institution. There could be a social contract that says: we need you to spend 15% of your time doing it because that's how it works.

So what I was most struck by were your exhortations to transparency, transparency around outcomes for students, transparency around safety, transparency around the work you do in training at your university, what you're training for and the experience. So I ask you: In some sense for much of that, you don't need the federal government. Certain things you do need the federal government, as to whether we apply our training grants, whether we do training grants, funding to professors, to support graduate students who are funding directly to students. But for all the rest of it, if the right 15 departments banded together and agreed to be transparent as to a set of things that you've laid out here, it could be very powerful. If you just all said, “We are going to be transparent about our safety records and our safety processes. We're going to be transparent about what our expectations are and what our training is,” one could begin to ratchet a race to the top in a certain way because students would be able to see that students who go here really don't have much future, or students who go here really *don't* manage to learn how to give a talk or something. And what's great is once you start the Web and the students will keep you honest. Any institution that wished to overstate its case might find that it was brought back to, you know, some reality by the students. So why not implement your report by finding some set of fellow traveler institutions to just do it?

Bassam Shakhashiri: Dr. Lander, anything I say will detract from what you just said, [laughter] and I don't intend to do that. But that is one of the recommendations directed toward the ACS, and the ACS is taking that very, very seriously, despite some difficulties that you can think about in collecting such information. But you're absolutely right: The full transparency will truly drive the reform and the changes that are discussed in this report. That's going to require faculty to participate in this willingly;

it's going to require some direction from the federal government that provides supports for the research activities. And that's in the report. So thank you, Dr. Lander.

Eric Lander: Get five of you to do it, tomorrow.

John Holdren: Well, let me thank all of the panelists for a terrific set of presentations and a great Q&A session. We really appreciate the work that you did on this very important report, and we appreciate your coming to talk about it with us.

[applause]