Nobel Round-Table Discussion #1: The Future of Interdisciplinary Research and Training

Moderator:
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Participants:
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Dr. Steven R. Goodman, Moderator:

The first question is: "How do we prepare K–12 students for the new interdisciplinary world of science?" Dr. Russell Hulse will be the initial respondent.

Dr. Russell A. Hulse:

Thank you, Steve. And thank you all for inviting a physicist into the biological lair here. This is an interesting question. Certainly there is a large issue of how to better prepare everyone for the new interdisciplinary world of science, but to focus on K–12 is a particularly interesting challenge. Let me start by noting that as we discuss preparing K–12 students for the world of interdisciplinary science, we must first remember that K–12 is only the initial stage in a very long process—and a stage where the first priority must naturally be on the fundamentals. With that said, attitudes and habits of mind are formed during this period, and K–12 is none too early to start to develop the broadly based capacity for flexible, self-directed learning and creative thought, which is essential to doing interdisciplinary science. We should also remember that not all K–12 students are destined to become interdisciplinary Ph.D.s. However, educational goals related to interdisciplinary science have a strong overlap with the need for improved science education for all. As a result, much of what I will discuss here will be of benefit to a broad range of students.

To my mind, the essential core of a capacity for interdisciplinary work is a rich intellectual toolkit, together with a mindset that can flexibly meld creativity and discipline in the exploration of unfamiliar territory outside the comfort zone of what one has already been taught. I suspect that a fair part of anyone's tendency towards diverse interests is inborn, but as with most things, life experience also plays a big role. In my case, my parents supported me in a wide range of youthful scientific interests with approval and the early opportunity to engage in a lot of early formative experiences with do-it-yourself projects. It also helped that my father, who was not formally trained in any of the skills involved, built a house for us with his own hands—a remarkable learning opportunity for a young kid. All of this helped instill a valuable notion that one could just learn and do interesting things on one's own, even if one didn't have formal training in those areas. I think this is something which kids in today's highly structured world of study and organized play are missing. So, with that background to my views, here are three aspects of preparing students for interdisciplinary work which are applicable at the K–12 level.

The first is depth, breadth, and cross-cutting perspectives. There is no substitute for solid grounding in the basic scientific disciplines and in the nature of scientific inquiry. However, these deep underpinnings must be supplemented with a breadth of exposures coupled with an educational context which calls out the cross-cutting ideas, as well as differences of approach and terminology between disciplines. One way to do this is simply to point out relevant examples of the integrated nature of science in the course of teaching standard material. A more specific approach is to teach subject matter which is selected for its ability to convey this broader view of science. Comprehensive overviews of such subjects as the nature of life on earth or the functioning of the human body provide opportunities to present a panorama of science in action across multiple disciplines. Another useful approach is to include material about systems and systems thinking in the curriculum. Computer modeling and robotics are two powerful, hands-on educational tools which can also help build the interdisciplinary skills of open-ended problem solving and systems thinking, even starting in elementary school.

The second attribute is playing well with others. Being able to work effectively in interdisciplinary teams is an important aspect of doing interdisciplinary science, and

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learning how to play well with others is certainly one of the fundamental objectives of early education, or at least it should be. This includes developing the requisite interpersonal leadership and communication skills. When, later in life, students deal with interdisciplinary teams, they will hopefully by then have acquired a real ability to deal with often difficult cultural differences, such as those between theorists and experimentalists. Note: maybe I'm kidding, or maybe I'm not, about that particular remark.

The third, and perhaps one of the most important points I wanted to make, is about problem solving outside of the comfort zone, which I alluded to before. There is no more essential skill for interdisciplinary work than the ability to enthusiastically and effectively solve problems outside the comfort zone of one's prior training and experience. This is the sort of thing which is learned by doing, not by lecture. The basic approach is to direct students to a diverse range of open-ended projects. By this, I mean projects where the requirements are specified, along with some additional background information and guidance, but which do not come with a specific detailed list of instructions for completion. Such projects should require that the students learn new content and skills as the need for them is recognized by the student during the course of the project.

Let me turn now to another very important issue in all this, which is implementation. There are a lot of issues and challenges associated with doing much of anything in K–12, and this sort of material is no different. Making all of this happen won't be easy. To start with, we need to figure out how to get students more interested in science in any form. It also must be regrettably observed that as a society, we are not doing well even with the simpler task of effectively conveying the basics, much less dealing with material that requires more advanced pedagogical approaches. But those issues aside for the moment, let's consider some more specific problems directly related to implementation of the sorts of ideas that I mentioned here.

One problem is simply that the school day is finite, so adding any new material inevitably impacts the rest of the curriculum. Another issue is that close mentoring of students doing project-based open-ended learning does not necessarily scale up well to teaching large numbers of students. Present-day assessment requirements and methodologies present another challenge. Proper assessment of the value and effectiveness of any new teaching modality is, of course, essential. But overly rigid or inappropriate assessment requirements can be a roadblock to implementation of new educational approaches such as those described here.

Now, I must quickly emphasize that I am not proposing a lessening of standards. I am just observing that there are skills and knowledge which are less than straightforwardly amenable to simple, quantitative assessment. For example, testing an ability to carry out effective, free-form problem solving in domains outside of one's prior experience is something that does not, regrettably, lend itself to a multiple-choice exam. The simple and challenging bottom line on assessment is this: in the end, everyone teaches to the test, so if you want to be sure that something is well taught, you'd better come up with a good way to test it.

I will close with a few words on a subject near to my heart: the special role of community-based informal science education—meaning science museums, science centers, and other such community-based learning resources and programs outside of the schools. This important facet of science education has much to offer as a complementary path to what can be done in the schools. And it can strongly support the educational goals that I described here.

Thank you.

Goodman:

Thank you, Russell. This subject is a very important one. As a person that runs a futuristic institute that combines biological scientists with chemists, physicists, mathematicians, nanotechnologists, engineers, and computer scientists—working on biomedical problems, one of the biggest issues relates to differences both in vocabulary and concepts between the various disciplines. And we all, at our age, are learning on the go. It would be far better if the process started earlier in our education in terms of synthesizing different disciplines. And that's really what this question is all about. Now, are there any comments from anybody else on the platform on this particular subject?

If not, I turn to the audience. Are there any questions or comments that the audience has in relation to the presentation that was just made?

Dr. Francine Anderson: Virginia College of Osteopathic Medicine:

I have an interest in outreach using the anatomy course for helping kids K–12 be stimulated, not only in the anatomical sciences, but hopefully with the idea that anatomy, being so basic to all of us, can be the tool to allow these young people to show interest in the sciences. My concern is with school administrations buying into it throughout the academic year, and not just in a summer program that a kid who has opportunity can apply to and be accepted into. So, do you have any ideas that may help stimulate outreach using anatomy throughout the academic year for these kids? We have kids coming to our institution throughout the year, but we also go out and solicit, if you will, some of the interest. There are kids who love this kind of thing. They just need a place to go, and someone to take them there.

Goodman:

So, in a bigger context, your question to the panel is how to get buy-in from the administrations in K–12 to really get involved in this type of program. The question could be applied to your program specifically or interdisciplinary research and training in general.

Hulse:

That's a very good question, and one that bedevils most people who are trying to do outreach. Part of the answer is to look at it from the school administrator's and teacher's point of view, and to realize that, as I noted in my talk, their day is basically very full. They also have a lot of pressure these days to teach to the test—standardized testing—and to teach the standard curriculum that they're supposed to follow. So one strategy is to, as best you can, find ways that the material that you have to offer can be folded into the regular, standards-driven curriculum. In that way, it's not something extra; it is something which they can use to better convey material that they already need to teach. And that will make an easier go of your attempts to work with the schools. Another thing I want to say is to re-emphasize that you shouldn't forget how important the sort of direct outreach that you can do is. Doing things through the school system is wonderful, but, for various reasons, including the constraints just mentioned, there is a limit to what you can do within the structure of the school system. And that's one of the big reasons that I'm so enthusiastic about what I like to call community-based science education, running programs where you bring the kids in and you show them things and you inspire them. I think that inspiration is an important word—it's the inspirational aspect that you can provide outside of the school. The school's main job is to follow a curriculum and build structured knowledge. Those of us outside the K–12 system have the primary task, I think, as practicing scientists to bring inspiration and new knowledge and fascinating facts to kids in a way which the schools can't. And that's why it's a nice complement to what the schools can do.

Dr. David B. Burr, Indiana University School of Medicine:

It seems to me that before any of the ideas that you've suggested can be implemented, we have to effect some sort of political and societal change. Because in a world in which we live with the No Child Left Behind approach, I just don't think teachers are going to buy into this sort of thing. They're going to be assessed not by the kinds of interdisciplinary thought that you're talking about developing, but by what the kids know about the basics. And so I wonder if you have considered how you effect that kind of change. I mean, as Nobel laureates, it seems as though you would be able to have more influence than any of the rest of us in effecting changes to existing law. So my first question is: "Have you considered working along those lines—even before you work directly with school administration and teachers?" My second question is: "As far as community-based programs are concerned, many students don't have access to those. And the problems are somewhat large. For instance, students that live in small communities don't have access to museums and so forth. And those that live in larger communities can't afford to go to the museums. And so that has to be changed. If we're going to charge to go to museums, then we're going to effectively eliminate portions of the population from having access to those. So how do you change that?

Hulse:

Those are two very good questions. Trying to effect systemic change, as it's called in the educational system, is very, very difficult. This is a huge, well-established bureaucracy, among other things, and it also has a lot of inertia for good reasons—because it has a very important responsibility. And it can't afford to make mistakes by trying something which just doesn't work out. That said, that's one of the reasons why I brought up assessment. Because the U.S. is, for better or for worse, increasing its emphasis on standards-based testing, I think there are better and worse aspects of this push towards standards-based assessment. It is important that if there are things you want to teach and get across, you'd better have some sort of believable way of quantitatively assessing that you got that information across. Otherwise, you're not going to be able to get into the system. To put it another way, my feeling is that if we, as a scientific community, say "here are some important things that you need to have in the curriculum that you don't currently have"—AND, here's a way to effectively teach it, AND, here's a way to effectively assess it—then we've got the complete case with which we can go to the educational system and, with persistence, actually get it implemented. But unless we have our complete act together, right through to assessment, it isn't going to happen—it's just going to bounce off.

Your other question about informal science is an excellent one—and we're thinking alike along these lines. Just quickly, my sound bite about the four critical requirements for informal education is as follows. First, you need to get real engagement. You need continuity, meaning that once you've got the kid interested, there's something that they can follow up on. You need family and social context, because a lot of this is about providing that sort of supportive context to enjoy learning about and doing science; and the final and really big one, which you picked up on, is dissemination. Big, centralized science centers are wonderful things, but they have the issues that you just raised. Mainly that not every kid can get to them, many can't get to them that often, and it costs money. One of the things that I've been working on in response to these needs, particularly the dissemination issue, is a program called Contact Science. The idea is to put small science center–style exhibits and associated mentored activity programs in public libraries, and use the great community access that public libraries afford to have a science presence in the community, for free, all the time. We've piloted it in New Jersey, with a colleague of mine, Jinny Baeckler, who is the director of the local library in the town where I live. It works very well, and if you know anybody who'd like to fund something like that, we're trying to get it going in Dallas. And one of the other nice things about Contact Science is that as we develop the program, it really is something that is scalable to a nationwide program by its very nature. So, we're working on it.

Goodman:

I'd like to limit this particular question to the three folks who are at the microphone, and then I'll move on to the next question.

Dr. Stephen W. Carmichael, Mayo Clinic:

As you know, Russell, when Bruce Alberts was President of the National Academy of Science, K–12 outreach was a major priority of his. In fact, he spoke with this group in December of '98. And as you just brought up, funding was a major issue that he also raised. Where's the money going to come from? But the question that I want to ask you, Russell, is: do you think that Bruce was very effective in pushing his program while he was President of the National Academy of Science?

Hulse:

That's an interesting question, and one that I'm going to have to pass on. I haven't really sifted out what things he did, relative to what other things happened back in that period. But, needless to say, having leadership at that sort of high level that focuses on the importance of these issues is critical. And we have another example of such leadership in the recent National Academy report entitled "Rising Above the Gathering Storm." This report is focused on the future of American competitiveness, but, not surprisingly, a lot of it ends up being about improving K–12 education. In discussions that I've had with people about that report, some think that it didn't go as far or wasn't as innovative as it could have been, but then of course the committee only had a very limited amount of time to put it together, so that's perfectly understandable in that regard. But one has to remember that in a lot of this, especially in the political realm, it isn't nitpicking about exactly what should or shouldn't have been in such a report that is important. It's merely—I shouldn't even say merely—it is the critical fact that such a high-profile group gets out such a high-profile report, and thereby gets the legislators talking about it. It gets people talking about it. And that's one of the things that we need to do as a community is to support those sorts of high-profile efforts that will make an impact in the political world.

Goodman:

OK, Sally, please ask the next question for our panel.

Dr. Sally S. Atherton, Medical College of Georgia:

One of the things that strikes me with K–12 education is that we somehow need to have better-educated, more scientifically literate teachers—or people that will really buy into science in a broad context. Have you given any thought to how to get people that are well educated in science, even at the Ph.D. level, to be involved? It's sort of the unpopular thing to do, to teach at that level. Many scientific trainees think that you have to go into industry or into a university situation. I think that's one of the things we may need to think about. How do we get really very well qualified individuals, in all the sciences, involved at the K–12 level?

Hulse:

You're absolutely right on that. One needs to be a little delicate about this because one doesn't want to inadvertently insult all those wonderful science teachers that are out there. But the truth remains that we need a much larger number of very highly qualified and motivated teachers. And not just in science, but also elementary school teachers and such. One of the big problems is that, for instance even at the elementary school level, the teachers who are teaching that level of general science are too often simply not comfortable with it. And this has, I think, a profound impact because the kids pick up on that fact. They can tell what subjects the teacher thinks are interesting and gets enthused about, and what subjects are just being gone through because they have to be gotten through. And that's a very big factor. One of the things that I worked on for a few years was to get involved with a school of education, because there you have the high leverage of getting the teachers of tomorrow more interested in understanding, enjoying, and having a higher comfort level with doing science. So that's another approach.

One of the recommendations that was in the National Academy report I referred to earlier, which directly addresses your issue, is this notion that there should be college scholarships in science, engineering, and math for students who would agree to become certified and teach K–12 for a certain number of years after graduation. I think that idea has a lot of merit to it. The caveat I would add is that taking these bright, enthusiastic, technically trained students and putting them in K–12 systems which are, let's say, refractory to their good intentions, is just going to wear them out. So you need to address that side of the equation too. What school environment are these new scientifically trained and enthusiastic teachers going to be put into?

One sort of off-the-wall idea is that you also have this notion of charter schools, which have greater or lesser success in different areas for a whole variety of reasons. But it occurred to me that you might marry the two and essentially have charter schools which are taught by students who came through these sorts of scholarship programs. This would give them much more of a hand-selected environment where they could prosper, and potentially these might be good experimental test-beds for trying to come up with new curricula in a way that would be more effective than trying to do it in the regular school system.

Goodman:

Jim, you have the last question.

Dr. James R. West, Texas A&M University System Health Science Center:

I'd like to go back to focus on Russell's first point of engagement. One of the facts of life in the United States today, and we see the results of it in graduate schools where we more and more have to try and recruit foreign students, is that our boys and girls are turned off, not only to science but to intellectual activities in general. What can we do to keep stimulating that natural curiosity that kids have at a very young age, so that we're not eliminating a lot of possible excellent scientists very early on?

Hulse:

That's an excellent point, and what you're talking about is one of the motivations for the work that I've been trying to do in informal science education. I think that addressing some of those issues really is an area where science museums, science centers, and other community programs like the Contact Science program I mentioned can really make a big difference. And the four points that I mentioned are at least my current take on the package required to make that work. You picked up on the engagement part, which is certainly important—that's why it is first. You need to do things that make science cool, to use that phrase. Well, OK—there are ways of doing that, there are activities, there are exhibits, there are various sorts of things that you can do to grab kids' attention. Once you grab their attention, then how do you pick up on that and keep the attention going? That's the reason why family and social context is on my list. That's the way you keep it being cool; by having it not be that the family and friends of the kid think that being a scientist is this nerdy, uncool thing. You have to build some cadre of friends and a support network for the kids so that their interest is nurtured rather than crushed. And then you get down to the final issue. How do you get it out there and make it accessible to everyone? And in that spirit, I would encourage all of you to think about what sort of outreach programs you can do. If you do them already, more power to you, that's great. And think about the four essential points. I don't pretend to have a lock on exactly what's required here, but you might want to think about those four precepts that I mentioned in terms of what outreach programs you have or you might plan. See what you can do to flesh them out. This business of inspiring kids to really enjoy science and incorporate it into their lives is something that we all have a responsibility to get involved with.

Goodman:

To keep us on schedule, I'm going to move to the next question, which will be addressed to Aaron Ciechanover. The second question is, "How will graduate and medical education need to change to reflect the interdisciplinary nature of research in the post-human genome world?"

Dr. Aaron J. Ciechanover:

Well, I've undergone those two melting pots, initially through medical school and then through graduate school, so I think that I can offer some insight. And you forgot one more class in between, and that's the class of the M.D./Ph.D. students, which is a very particular but excellent class of students that we are putting a lot of effort into educating. I'll relate to them later. I think that we are talking about two completely different education systems. Medical education is very different. The basics should always be there. You know, when we are educating a physician, we are producing a product—a general practitioner who does certain tasks. There would be no way in the world that we should not teach him anatomy. He needs to know that the femur is linked to the tibia and to the fibula, and then the humerus to the ulna to the radius and to the muscles. And then he needs to know basic biochemistry—how energy is produced. He needs to know what a tumor tissue looks like and what the difference is between a benign tumor and a malignant tumor. He needs to learn how to listen to the heart using a stethoscope, to interpret an ECG and ultrasound, and yes, also to be able to talk to the patients and their families. All these limit our flexibility to a large extent. There is very little leeway left in medical education for other things, and we don't teach them medical ethics at all. We don't do it in medical schools—we don't have time to do it. In the United States, it's even worse. In Israel, we adopted the European system, so we teach medical students six years. We take them either from high school or after the army. In America, you take them after undergraduate studies, and you have merely four years for the entire task. So with medical education I am less optimistic about highlighting to them the complexities of nature, via active research projects, and it should be more passive. We should teach them, however, more modern technologies. I doubt if most medical students know the difference between MRI and CAT scan. And they don't know what a radioimmunoassay is and how it is being carried out. We should teach them a little more of technological developments, but in a passive way. We should train them in important technologies. Graduate school is a totally different ballgame. In graduate school, we can afford to be more flexible. We don't have to teach them every brick of the building. We can teach them milestones. We can teach them methods. We can teach them metaphors and ways of thinking, of problem solving, then let them do the rest. And therefore we can be much more flexible. Now, I am a little bit worried about the word interdisciplinary. Because I now have the task, and I started to go into it, to establish kind of an interdisciplinary program in our school. Our university, which is basically a technical university, doesn't have liberal arts, but has very good schools of sciences and engineering on one hand, and departments of biology, biomedical engineering, and medical school on the other. And the question is, how do they talk to one another? And we should be very careful about jumping into buzzwords like systems biology and what to do with it. Don't forget we are now moving from the genome era, as Steve mentioned, to the proteome era. And the proteome era is promising to be much longer and much more complicated than the genome era. It's very easy to understand the genome. It's a linear library of information that doesn't basically tell us anything. It only tells us how proteins look linearly. But in the end, proteins are not linear structures. We need to know the three-dimensional structure. We need to know how each of them looks. We need to design drugs into the appropriate active pockets. So the proteome era is going to be much longer. And actually, this is the future of the drug companies, and this is the future of medicine—the proteome era. And here we are really lacking a lot of tools. We are lacking, as Russell mentioned, modeling—computer modeling. We need to teach the students, first of all, basic bioinformatics. And it is not just bioinformatics to find the sequence of a protein. It's the bioinformatics to play with it, to find homologies, to find inter-species relationships. And then, from the bioinformatics, we have to jump to three-dimensional modeling. And then we have to teach them very good chemistry. Because we are lacking completely a whole discipline that only drug companies are lucky enough to have—medicinal chemistry. Medicinal chemists will know how to take these pockets, how to take these proteins and fit into them small molecules that will act as either activators or inhibitors of these proteins. So in graduate schools, we really have to shuffle. But we have to do it very carefully. In the word interdisciplinary, we have to be careful. We have to define what we are really missing. What are we really going to miss in the future? And we are going to miss the fields of bioinformatics, modeling, medicinal chemistry, chemistry of reactions, energetics for biologists. We should target the graduate students within the university to graduate courses in those fields so we shall be able to educate the right people who have the appropriate talents to go into the industry. Mass spectrometry or microanalysis of proteins is another field. People think that mass spectrometry is a shelf technology. It's not a shelf technology. There are only a few people in the world that know how to master it. If you want to give a femtomole of a protein to a mass spectrometrist, you will find a handful of experts in the entire world who know how to analyze. We need also to educate people in this direction because these techniques are in huge demand. And we know that this is the future. The future is the future of proteins. And we have to direct our graduate students into the disciplines of this future. So as we can see, we are still missing people in discrete technologies, and the march into interdisciplinarity should be a careful one; we still have large holes in the network of understanding single proteins. I have one more word before concluding about the M.D./Ph.D.s. For me, this is a dear class of students. I know that this is true for many of you—because they constitute the bridge. These are the people that can see the problem from the very basic science all the way to the patient bed. And therefore we should pay very special attention to those students. We should develop extensive programs, heavily funded in medical schools, to foster them. Obviously we are fighting private practice. We are fighting changes in the health insurance system in the United States that lure people out from this track rather than luring them into it. When a colleague of mine, Professor Michael Fry, built the M.D./Ph.D. program in our medical school, he used the U.S. model in several medical schools, like Washington University in St. Louis. We are enjoying excellent graduates. And it doesn't matter what they do. If they go into science, they make excellent scientists, they can see the hospital via the laboratory's window, and they know how to relate the question to clinical medicine. If they go into medicine, they are excellent physicians because they are more humble, they know the limits, they appreciate the complexity of the physiology and the pathology. They know the complexity of the system that they are dealing with. They know what they can do and what they cannot do. And these students need an integrated program. We have to educate them to both modern worlds—that of science and that of medicine. And this is, as a matter of fact, the real challenge. How to take a kid and in less than ten years make him an M.D./Ph.D., and a very good one. Special attention should be paid to this class of students.

Goodman:

Thank you very much, Aaron. First, are there any responses from the panel before I hand it over to the audience?

Hulse:

I'm fascinated by your remarks because I've thought along much the same lines. I was very interested to learn just today that you are an M.D./Ph.D. Let me just tell you briefly a couple of personal anecdotes. One is that there is a colleague of mine who was a physicist at Princeton who went and got an M.D. And not by any special M.D. program, he just went and took the whole nine yards of a standard M.D. program. And I always love talking with him because he has such a special view of medicine and medical practice. And to my mind, I think that, as you emphasized so well, there's an enormous virtue to that combination of training. Coupled with that, is that there is a very, very bright young graduate student in physics at Princeton who came to me at one point discussing that she thought she might actually want to get an M.D. degree. Part of making any of these decisions of course has to do with the individual's personality and interests. I thought that she'd be wonderful. And so, in the response to her question, I said that I think there are programs out there which are customized to taking Ph.D.s and training them to be M.D.s. And I went and looked on the web quickly, and the answer is—there aren't. And I was frankly appalled. And just for the sort of reasons that you're saying. Look, here you've got somebody who would be an enormous asset to our society in being dual—not interdisciplinary—let's call it dual-trained. You would need to go through two different formal programs that have important overlap and synergy. And there was no supportive program out there designed to help her to do it. And just as you said, I was thinking my goodness, there should be a world out there begging for these students that express an interest in doing this. And instead there wasn't anything really for her to do. But one thing I'll say that there was—she did go to some conference—and I forget who sponsored it—but it was designed to get young physical scientists interested in the modern biological sciences. She did go to that and found it somewhat informative. But again, that was a little off the beam of her initial interest in an M.D. What was really needed was an M.D. program which would recognize and build off her physics Ph.D. experience.

Goodman:

I'm going to hand it over to the audience. The conflict that I see, and maybe some of you can comment on it, is that the science that we do is changing very rapidly, but our medical curriculums and even graduate curriculums tend to change slowly. That's where the rub lies.

Dr. Peter J. Stambrook, University of Cincinnati College of Medicine:

I want to address this to Aaron. Two issues: First of all, I agree with you that M.D./Ph.D.s can be a very special class of very bright people. The first comment is—I'm concerned about the Ph.D. training. They're usually very restricted in time—usually only three years. And the concern is that sometimes the Ph.D. is watered down just to get those individuals through in that time frame. That's not always the case, but that's a concern. The second is—what happens to a lot of the M.D./Ph.D.s once they get into the real world? In other words, they go to a medical center and there are economic pressures for them to, and I know this is true in Israel as well as the U.S., see patients, and they don't have sufficient protected time to carry out their research. I just want to know your comments on that.

Ciechanover:

Well, let me first relate to the last one about the time allocated to these people. In the big powerhouses in the United States, such as Harvard or U.T. Southwestern or Washington University, these physician-scientists enjoy a large proportion of protected time, but after completing their residency, as fellows and then as young assistant professors. Then they spend only one day a week or so in the clinic and then maybe one month a year. So I think that it's again a matter of convincing presidents of universities and deans of medical schools that clinician-scientists, graduates of the M.D./Ph.D. programs, are the best asset that they can ever imagine. Not only do they generate grant funds, but they also bring in clinical money. They also recruit better graduate students and therefore improve their institute. They generate an entire momentum. They increase the professional level and the research level of the institute. From our experience, these are the best. Being lured by private practice and the changing atmosphere dictated by medical insurance companies and the way medical schools are run these days obviously pose a problem. We are living in a dynamic economy. Israel suffers the same. I have several M.D./Ph.D.s that have gone through my laboratory, and I believe in role modeling. I try to convince them, to talk to them, to direct them, to think of their career. It is very personal, but the role model played by the mentor plays a critical role in carving their future career, even in this era of economical pressures. I cannot compete with private practice. There is no way I can do it. But that role modeling here is very, very important.

Goodman:

Mike, please make your comment.

Dr. Michael D. Gershon, Columbia University:

I would like to say just one thing about the need for political involvement in outreach. We're living through what has been, if I can use the title of a book, "The Republican War on Science," in which the public needs to become educated as to what science is. And until that happens, a great deal of what we do in terms of curricula and trying to direct people within science is lost—we're fiddling with detail when the world is burning around us. We have a government that doesn't know the difference between intelligent design and evolution. Until we get people to understand what science is, its value, and how it relates to society, nothing of what we do is going to be useful. And so intelligent involvement of scientists with the general public is critical. I mean, just think of the massive movements against vaccines that we have, in which witchcraft substitutes for vaccination to prevent disease. We've got to get the public behind the science or science won't progress from K to 12 and then beyond.

Ciechanover:

You're 100% right. I was lucky to get the easy question about graduate education and medical school. Russell had to deal with the more difficult one. Those that come to graduate school or to medical school are already convinced that they are on the right track. But you are absolutely right. I mean, I just cosigned—I don't know if Russell signed it—a petition to the Board of Education of Kansas about intelligent design. It didn't help. But on the other hand, the judge in Pennsylvania ruled against intelligent design. You're right, you know—it starts at home. And we are not at the homes of these kids. You start at home, you start at elementary school, and it's pathetic that we still have to convince people that science is the ultimate truth. And maybe cases like the one that has happened in Korea and another one announced yesterday on fraudulence in Norway, undermine our efforts. Because people think that maybe we are a bunch of liars and that we are interested in our own promotion. Also, people are kind of disappointed that science does not provide a cure for all their troubles, poverty, abuse, and diseases, so they look for solutions in higher spheres of belief and religions. They don't understand. They don't make the distinction between the absolute truth of science, its objective limits, and then the few rotten seeds in this big field. But you are absolutely right. It has to go to elementary school and into kindergarten. Graduate school is already a done story. There is no problem in graduate school. You are absolutely right. It's a problem in the United States and in Israel too. Our government doesn't understand the essence of basic science.

Goodman:

Russell Hulse also has a response to your question. And after this question, I'll take two more and then we'll move on.

Hulse:

There's a point here that I'd like to comment on a little more. This is all another reason why I'm enthusiastic about science museums and informal science. You're certainly right that we as individual scientists need to do what we can, but the question is what's the mechanism for our successful involvement? Especially to compete with people who have much more media exposure than we'll ever get. This relates to one of the interesting concepts that I've heard from a couple of science museum and science center directors who are groping with the question of what should science museums and science centers really be focusing on going forward into the future. What should they look like? What role should they play in our society? One of the interesting points that comes up is that maybe they should be the place where a real dialog with the public occurs about science—in part because there is no other place for it to occur. At least one science museum in Minnesota has programs where they brought in experts in an open public forum. People come in and just have an open discussion about issues of current importance in the news that concerns science. And I think that's a very interesting additional role that museums and science centers can play—to act as the forum for that sort of discussion.

Gershon:

I would certainly support that. The Museum of Natural History has a phenomenal show on Charles Darwin, and if you see the mobs of people fighting to get into that and standing stuck at the television with shows of debates on intelligent design versus real evolution—you just see science winning.

Ciechanover:

One more comment. It's not only science museums. I think that we as scientists also have a role in this game. Many of us feel we don't owe the public anything. We do our research and ask the public to trust us, we are good. But we have a moral obligation to the public, the money of which we use to carry out our research, we have to promote the "case" of science. It's our role—and I'm doing it in Israel in one way, which is my own personal way, but it isn't necessarily the best one—in the last 16 months, I estimate I addressed approximately 10,000 students on more than 20 different occasions. In large auditoriums or small teaching classes, I addressed high school biology students and undergraduates in universities. I bring them my own example, and I bring them the system that we work with, but only as an example. And then we start a conversation. And we talk about science and about bioethics, and choice of a career. And I think that it's our role to educate the public. We have to reach out. We cannot just sit in our laboratories. We have to reach out to the public because in the end it is not only morally right, but it is in our best interest. We are using public taxpayer money. I mean all the NIH money is coming from the public. Everything is coming from the public. We owe the public an explanation of what we are doing, and what science is all about. We have to use all means, personal lectures, the media, talking to politicians. Construction of museums of science is also one way to educate the public. It's certainly a very useful tool. But if we, as life scientists, would come out and keep on explaining—not just a one-time event, it will be an extremely powerful tool.

Gershon:

Amen.

Goodman:

Before you go on, we have one more comment on that. Steve Fluckiger.

Dr. Stephen Fluckiger:

I just noticed this morning that the National Nanotechnology Initiative and the National Science Foundation funded one of the largest grants for science museums to address the issue of nanotechnology and its effect on society. So I know the government is also aware of this need of educating the public, and I was interested in that particular angle.

Dr. John I. Clark, University of Washington School of Medicine:

So, this is a little bit of a combination question. Because two of the problems that I would say more than 50% of our graduate students and medical students have are writing and experience with math. I'm from a biological background. Our graduate students a lot of times have difficulty writing, and they have a lot of difficulty understanding mathematical approaches to pattern recognition or systems biology. Are there any recommendations in those areas?

Hulse:

That is another good question on a difficult subject. I think that part of it is that—and this is a view of a physicist, of course, not a biologist—but that the field of biology is still in the process of redefining itself. And that process inevitably takes a while. And a lot of that redefinition is integrating more of the quantitative sciences into what biology is really all about. And I'm not involved with it, but I think that, if I understand correctly, Princeton is doing an interesting thing along these lines. They sort of have two tracks, or at least they're talking about that. One is more along the lines of conventional biology, if you will, less quantitative, and the other is more "modern biology"—with a much more mathematically based approach. And I don't know how much that's done elsewhere, but you can see the transition in progress. And I think it's a generational timescale of change, unless you really force it hard—for a field to change its mind as to what it really needs to teach its students, what it expected of its students, what kind of students will it admit, with what skills, and that sort of thing.

Dr. Vytas A. Bankaitis, University of North Carolina, Chapel Hill:

So, more of a comment that might elicit other comments: going to the point of our professional responsibilities. I've been around, I think, enough to at least make a fairly reasonable comment on this. There are plenty of young scientists who come into graduate school who really are quite motivated. And I think what happens is they become demotivated—they're not motivated to do better. Motivation is lost. And I would suggest that part of the reason for that is because we live on a very nice edge between enterprise and training. And many faculty that I see actually are well over the line on the enterprise side, and just the whole culture of big science. You have an array facility that can do something and a mass spec facility that may be able to do something. OK, how many of us actually ask our students to learn the technology? Very few, I would suggest. And most of them use it—they don't understand it—but they can crunch the numbers. For example, we have a structural core. I actually ask my students—you know, to do the hanging drops—that's pipetting—you know, it's not rocket science. Purify your proteins. Have it mounted. Be there. Start doing some of the refining. That's actually not unreachable. And I think once students do that—they have ownership of their problem—they become interdisciplinary because they follow the problem, and then you don't have issues necessarily of motivation. And I think that as faculty members, we need to pay attention to that part of it. Telling good people what to do and saying "Somebody else will do this for you; you just sort of crunch the data and give it to me" is I think a big failure of our profession.

Goodman:

I'm the moderator, but I'm actually going to respond to what you're saying. Right now I'm trying very hard to push a Ph.D. in Biotechnology at UT Dallas, and it's for the exact reasons that you've just described. Many of our students basically learn that you take a sample and you send it to a core facility. I would prefer having students who actually have hands-on understanding of the technology. Then they can use it well in the experiments that they're doing. So I agree totally with what you just said, and now I'm going to hand it over to anybody else on the panel that wants to make a comment.

Hulse:

Yes, there's something that I would like to add. Let me observe there's an overarching issue in many of these considerations that we've been discussing, which is the concept of teaching to the test, now using that in the broadest sense. Kids, in my impression, certainly the kids nowadays, certainly are very, very sensitive to where the real career prospects are and what's the most efficient prescribed route to get there. And no matter what we do, unless a student feels that learning a certain thing is going to be of fairly direct benefit to their career, or to put it another way, they can get a job knowing that—all the rest is for naught. Another interesting question arises from one of Aaron's comments—consider that you have these M.D./Ph.D.s, that is, let's say, biologists who also understand how the mass spec works, etc., etc. Are there real career paths for a large cohort of students along those lines? Unfortunately, the answer may be that we sit here and think there certainly should be career paths for those students, but the reality is, the marketplace doesn't really have them or doesn't make them obvious. And if that's the case, you're in a lot of trouble, because the kids won't pay attention to what you're trying to tell them.

Goodman:

I'm going to move to the next question. And this question will be addressed to Da Hsuan Feng. And the question is: "How can university administrations nurture both interdisciplinary and interinstitutional collaboration and cooperation?" I chose the words carefully. I used the word nurture because I think really very few administrators understand that concept. Da Hsuan Feng is one who does, which is why I'm addressing the question to him.

Dr. Da Hsuan Feng:

Thank you, Steve. Actually, this discussion on mathematics and medical doctrine reminded me that every time I go to see a doctor, which I hope is not very often, they always ask me "what is your profession?" I always say I'm a physicist. And you all know how difficult it is to get into medical school—the idea is that you have to have a 4.0 to get into a medical school. The doctor always will say "you're a physicist—ugh, that's the toughest subject I ever had in college" and I always wanted to ask well, how did you get an A? Anyway, thank you very much, Steve, for giving me this very interesting question. I will try to give you my view. Any errors that occurred in coming to the view that I have are entirely mine. So I would appreciate very much that you criticize my ideas if you wish. But for sure this is certainly one of the most important issues confronting 21st-century research universities. Since most of you are department chairs, and a few are administrators, you probably deal with these issues on a day-to-day basis. However, what I am about to say I hope will give you some food for thought.

I do believe that the proper execution of this for all research universities not only can and will have profound ramifications for the universities, but also for humanity in general. If I may be so bold, universities, especially research universities, which we all come from, in the 21st century are at a very interesting but precarious position in the societies they serve, in the nations they belong to, and in the world. The topic, or should I say the challenge, is indeed timely. It is part of a much bigger challenge. There are truly serious global, grand challenges that are confronting humanity—such as looming pandemics that we hear about often now, the energy-shortage challenge that we also hear about often, the ignorance and severe poverty even in the first world, and the lack of tolerance and hatred of fellow human beings—just to name a few. Solutions to these grand challenges from a research university administration point of view certainly must come from nontraditional, non-silo thinkers with bold visions and innovative skills. Indeed, some would say that research universities are probably lighthouses dotting this turbulent landscape, or turbulent sea. Is this not the mission of research universities around the globe—to nurture such individuals, as the word nurture was used earlier?

Now, in my mind, research universities need to respond to what Thomas Friedman called the flat world. I would say that the flat world is due to two very different speeds. The first is, of course, the speed of light. As everyone knows, almost to the point of being cliché, the internet, by exploiting the speed of light, has altered the way mankind thinks and operates. However, there is another speed which I think is just as important. It is the speed of moving large objects like you and me.

Here, I actually have a more personal anecdote. As recently as the early '60s, students going from Asia to the

United States for higher education usually took a boat which took three weeks to arrive. You can imagine that in the mind of a student making that trip—they felt they may never see their families again, and may never see their homeland again. That's in the mind of the student making the trip. And that's also the reason that you would see tears at the docks. Because the parents think that that's the last time I'm going to see my kid. And it's almost like a funeral. And compare to the transportation of today—it takes 10 to 12 hours to fly from one point to the next. And believe me, this is a factor of 40-fold increase in speed. So the tears are certainly gone. You don't see that anymore in airports. And in fact the parents, whether you want them to or not, will be seeing you very soon. So what does it all mean? Well, there is an old Chinese saying that studying 10,000 books is not as fruitful as traveling 10,000 miles. It means that human beings are going to go to all corners of the globe. Intellectual and economic developments, achievements, and for that matter failures, are no longer regionally confined. The success or failures of a region or a nation, one may argue to a large extent, will depend on how globally enlightened its citizens are and how often and how high a percentage of its citizens travels to all corners of the globe. Indeed, the global grand challenges I mentioned earlier are now the responsibilities of all, especially research universities, not just a few.

From an individual research university's point of view, it can no longer serve merely a local region, catering to regional needs. I firmly believe that as we move more and more into the 21st century, there will be more and more melting of intellectual international boundaries because of these two speeds that I mentioned earlier. Research universities are entities that are almost forced into catering to a wider region, if not globally. As such, they will overlap, if not geographically, surely internet-wise and people-wise, with other universities. Embedded in this two-speed paradigm, I think as never before university administrators in the United States and elsewhere—Israel and elsewhere—need to be cognizant of the global issues that I mentioned earlier. The ultimate is of course to benefit humanity. And whatever we discuss here will hopefully have some of that implication. I should stress, however, that this is not to say that one should not carry out research that is based on curiosity. Indeed, I am quite sure that it was entirely based on the curiosity of Watson and Crick that DNA was discovered. I'm quite certain that IP was not on their mind. I seriously doubt we would even have this conference here today if Watson and Crick hadn't accomplished what they did. I'm sure someone else might have discovered it, but they didn't. And so if people need to travel or if people use high-speed computers, then these barriers will be lowered—whatever barriers we have—and that is the critical part of a research university's mission in the 21st century. Therefore, research administrators like me should be fully alert about the fast transformation of the research landscape and encourage researchers to pursue what the late Alan Bromley referred to as grand challenges.

Research administrators within the university should and must create a comfortable environment whereby working on such grand-challenge problems, from funding to infrastructure to seamless communications with other researchers as well as other research administrators in other institutions, is highly encouraged. Funding, of course, as you have heard already, is a very important issue. I have a favorite statement about funding—and that is, "vision without funding is hallucination." So when I entered graduate school in physics, I had to select, from this thing called physics, a spectrum of physics problems to make contributions to. While most of those problems were exciting and unsolved, their scopes could be considered as rather limited and would not fall into the definition of a grand challenge. I am sure that my biology friends, my chemistry friends, my mathematics friends, my civil engineering friends, or whatever fields one happens to select, have to make analogous choices. While this paradigm is still quite prevalent in the silo structures of universities, more often than not one now is asking questions that are much more within the definition of grand challenge. Let me give you one example that is totally out of your area, and the question is the following: How can we ensure that transportation of grain in the United States is secure and seamless? Think about this question. Obviously, a plethora of knowledge is going to be needed to deal with this problem. From agriculture to economics to network security to human behavioral sciences to rail scheduling on a massive scale, and so on and so on and so on. What is also clear is that problems of this nature can be tackled only because of the interplay of the two speeds that I mentioned earlier. Research of this nature will require individuals possessing very different skill sets, probably distributed in different institutions. So the issue that we are confronted with here is both profound and deep. It is interesting how speed seems to alter human behaviors. Indeed, it was the speed of the Zero fighter plane in World War Two that was the determining factor in why Japan attacked Pearl Harbor and not San Francisco. Now it is the two speeds for the internet and the speed of light, and a travel speed for physical objects—which seems to be more or less stored at the speed of Mach 1, the speed of sound—that are changing human behavior today. Research universities and their administrators must be very cognizant of this changing global landscape. I know for sure that I am merely touching the tip of the iceberg here. However, it is nevertheless a very serious problem and I urge all of you to give all you have—your wisdom and your knowledge—to provide the best answer to this problem. Our nation, that is the United States, indeed humanity in general, will depend upon our coming up with the most appropriate solution. Thank you.

Goodman:

Thank you, Da Hsuan. Anybody on the panel want to respond? OK, let me throw it out to the audience. Are there any questions or comments from the audience?

Dr. Robert D. Goldman, Northwestern University:

Not that anybody in the room can do anything about it, but with respect to international collaboration and communication, the government now is our worst enemy. If you try to bring in a postdoc or a graduate student from another country, you have to go through a most difficult process. And you have to pay a lot of money to lawyers. So the government I think now is the biggest obstacle to international collaboration and communication.

Goodman:

Da Hsuan.

Feng:

Your comment, of course, implies that the United States is the center of the universe. And for the entire 20th century, that probably was the case. But I think that the world is shifting already. Government, of course, will respond to economic pressure. When real economic pressure starts to be placed on the United States, I believe that things will certainly change. Let me give you my pet theory. In the first half of the 20th century, the Atlantic Ocean and the Pacific Ocean essentially provided a moat for the castle called the United States. And because of that moat, the land of the United States was essentially free from the world wars. And as I mentioned earlier, the reason the Zeros didn't attack San Francisco is not because San Francisco is not a good target, it's simply because they couldn't fly that far with a speed of about 350 miles an hour. However, during the second half of the 20th century, there was essentially no real conflict on a global scale. So many other countries started to grow economically and intellectually. And that is what we hear about the flat world. Students may not want to come here even if we open up our doors further than we have up to now. So that is a challenge, I think, for American research universities: to rethink how they could be embedded in a flat world, and not as the center of the world.

Goodman:

Any other question from the audience on this? Michael.

Dr. Michael T. Shipley, University of Maryland School of Medicine:

So my question kind of goes to the general issue of interdisciplinary training and education. To say that we think it's important is almost trivial. We all know it's important, and we're all struggling with it. And in that struggle, I think that many of us are finding that the devil's in the details. So it's really a question of implementation. So how do we avoid educating a cadre of graduate students and postdocs who know this much [lots] about this much [little], without giving them really solid grounding in depth in a discipline so that they can in fact make use of the breadth of knowledge and the accelerated pace of knowledge. And this segues into a second concern, which is one of the ways that people are trying to implement it, which is to try to gear graduate education around technologies. And I'd like to know what people think about that, because technologies, as we know, change very rapidly. So the broader question is: how do we meet the challenge of preparing our students, preparing our young faculty for a interdisciplinary world, while at the same time preserving what is the core value of science, which is the depth of knowledge and the focus and the intensity necessary in order to really make a difference in science?

Goodman:

Mike, I guess I'll start and then I'll throw it out to the others. I think that anybody who is truly involved in interdisciplinary education knows that the very first step is that the students have to be well grounded in the discipline. So that is step number one, and I doubt that anybody in the room would argue with that concept. But one has to then, I know from personal experience, go beyond that. Because when you try to get together people of diverse disciplines, they speak different languages, they use different jargons; they have different ways to think about concepts. And so, while they all need to be grounded within disciplines, there needs to be a second step. And it's that second step that I think many universities and medical schools have not come to grips with, but will need to come to grips with very, very quickly. Now I'll hand it over to the other people on the platform.

Hulse:

This depth and breadth question, you may have noticed, was one of the first things on my list. This particular question, where we're discussing how university administrations can deal with this issue, is very important. Because again it gets back to one of my mantras, which is that you have to remember that people will teach to the test or the career equivalent. You want to drive the right behavior. Just setting up interdisciplinary centers at universities doesn't get you where you want to go if you haven't changed the reward system. One of my favorite points about this whole issue is that you have to ask "Can an assistant professor get tenured doing this?" because if the answer is no, then you've got yourself a problem. And this is, of course, an area where administrations can play a big role by changing what the reward system is in a university. One other quick comment is that when you are talking about depth versus breadth, it is helpful to remember that it isn't necessarily the case that any given person may go in either of these two different directions. Some people are intrinsically better equipped for discipline-focused work and others for interdisciplinary efforts. I like to make an analogy based on the old saying about "not being able to see the forest for the trees"—to oversimplify, and not to make any value judgments at all, there are tree people and there are forest people. And part of this interdisciplinary team aspect is that you need to combine together some appropriate mix of what I call "tree people," meaning people who are very discipline-oriented and have very deep skills, and "forest people," the people who can look around and broadly see and put things together that the tree people wouldn't have noticed as they focus on the individual trees. How you nurture all this depends to an important degree on having differing reward systems tailored for those two different types of people, so they can all coexist and prosper at what they each do best.

Goodman:

It's very interesting that Russell just raised the issues of promotion and tenure. Because, had Alan MacDiarmid been here with us, and by the way, he wanted to very badly before he broke his hip, his question dealt exactly with those issues of how tenure and promotion were going to have to change. That's something that I think we'll need to discuss informally during the meeting. But the last question that we will discuss formally will be addressed to Steve Fluckiger. Also a very important question: "How will the interaction between academics and industry need to change in response to the movement towards large interdisciplinary and inter-institutional research?"

Fluckiger:

Dr. Goodman in his welcome message on the internet to this conference mentioned the NIH roadmap announcement and the series of awards to foster interdisciplinary research. While the roadmap does have an initiative for public and private partnerships, it does not really address in detail the question that Dr. Goodman just asked: How will the interaction between academic and industry need to change in response to the movement towards large interdisciplinary research? From the perspective of an attorney whose practice has focused in the life science for a little more than a decade, I know that it's fair to say that industry in general believes there are pretty high barriers that exist in terms of particularly transferring technology from the university to industry. Just as an anecdotal example, I polled a number of my partners in our 130-strong global life science practice on that precise question. I think it's fair to say that the typical response that I received was that it is very difficult and very slow to transport technology in the traditional model, which is coming from a single researcher or single laboratory. That is greatly compounded when you're dealing with multiple institutions in an interdisciplinary type of research project. The good news, however, is that a consortium of federal agencies, including the NIH, has combined in the National Nanotechnology Initiative and has specifically addressed this question and has also over a period of years now implemented a number of strategies that are worthy of emulation in the biomedical research field. And so what I've done is I've taken about 14 of these different strategies and ranked them, if you will, in a wish list of strategies that biomedical researchers like yourselves, and government agencies that fund this research, might be well advised to consider in terms of how to approach inter-institutional biomedical research centers. And, of course, like every good scientist, I've come up with an acronym for that type of center, an MDRC, Multi-Disciplinary Biomedical Research Center.

My first suggestion would be that funding agencies dedicate a significant percentage of their budget to multi-disciplinary research. It's interesting that the National Nanotechnology Initiative currently has set aside at least 20% of its funding for these types of initiatives. And the overall funding for nanotechnology in 2004 exceeded $8 billion. Of course, that included industry and venture capital funding as well. My second suggestion would be to set up a program to fund the creation of these multidisciplinary inter-institutional biomedical research centers, or MDRCs, patterned after the nanoscale science and engineering centers that the National Science Foundation has funded. There are 16 of these centers now, to the tune of about $2 million a year over a period of about five years, which are dedicated to this type of multidisciplinary research. An example of one of these is the one at Northwestern. The integrated-out patterning and detection technologies center is a collaboration with not only includes Northwestern, but also University of Illinois at Champaign-Urbana, University of Chicago, Argonne National Laboratory, Lawrence Livermore National Laboratory, NASA, Dupont, Exxon/Mobil, Rohm and Haas, Motorola, IBM, and Unilever. The third suggestion would be to award the federal research funding described in the second bullet to the director of the center rather than to individual investigators. This is the pattern that the NSCEs follow, and this allows the centers much bigger flexibility in terms of organizing themselves and determining their priorities and how to allocate those resources. Something that I'm sure that Dr. Goodman with his institute would welcome.

Number four, I would require as a condition to receiving federal funding that each MDRC include industry partners, as the NSCEs are all required to do. Number five, I would also require as a condition to receiving federal funding that each MDRC have multi-investigator research teams composed of investigators from different members of the center. Number six, I would adopt simplified or uniform technologies transfer procedures, including possibly the pooling of intellectual property. And if we had sufficient time to get into the U.S. intellectual property law ramifications of joint research where you have multiple investigators, that would facilitate transfer and licensing of intellectual property and also a mechanism for determining the patentability and licensability of IP generated by the center. Number seven, I would facilitate the transition of IP developed at these types of centers to the private sector by creating internal programs designed to allow industry to communicate its needs at an early stage, thereby enhancing the likelihood that new ideas would ultimately be developed and commercialized. Number eight, I would encourage industry partners in these centers to make unrestricted gifts at various levels, depending on their desired level of involvement. This is followed in a number of these NSCEs, including Northwestern, and later, as the particular or potential relevance of the research to a company's specific objectives becomes clear, allow these companies to enter into funded responsive research agreements with the center to support a specific project. Number nine, I would permit IP developed under a responsive research agreement to be owned and protected by the private company sponsoring the research, provided it refunds the universities for any associated costs. Number ten, I would adopt programs designed to enable the spinout of companies through the creation of internal platforms for assessing market factors, drafting business plans, and attracting B.C. investors. I think it's interesting that Northwestern has spun out, I think, four companies over the last several years through these types of efforts that have gone on to commercialize some of the intellectual property developed. Number eleven, I would encourage the exchange of researchers between universities and industry, to allow university personnel to spend time in industry labs and vice versa. Number twelve, I would establish industry liaison groups with various commercial sectors to promote exchange of information on research programs and industry needs. Number thirteen, I would support meetings at which researchers from academia and government and industry exchange information and results and possible applications, and finally, I would foster the establishment of user facilities that are available to research from public and private sectors. My experience, and just observing this as an outsider working with venture capitalists and startup companies in the biomedical field, is that inter-institutional research and the movement towards greater inter-institutional and multidisciplinary research is going to prompt these changes, and that this is already occurring. We're seeing already the impact of this in the marketplace, and a core corollary is that medical schools and universities that are in the forefront of these types of changes will get a disproportionate share of the shrinking federal research funding budget.

Goodman:

Thank you, Steve. And so the issue here, before I address it to the panel and anybody in the audience, is that as we become more interdisciplinary as well as inter-institutional in the work that we do, and then we're interested in dealing with industry, it presents new unique issues. Industry doesn't want to deal with ten universities when they're dealing with a product. They would prefer dealing with one office, and yet you may have ten universities involved in the discovery. And so these are unique issues that were never on the table before. They relate to both interdisciplinary and inter-institutional research. I guess first I'll ask if there are other people on the panel that would like to comment. Let's hand it over to the audience. Anybody in the audience that would like to comment? Yes, Peter.

Stambrook:

Unless I misunderstood you, the way you describe the interaction between academia and industry and the NSF model is that it is almost like an engineering project—it is task-oriented. And I'd like to ask you—how do you see individual innovative science fit into this large pattern? Most basic advances in biology have not come from task-oriented types of projects but rather have emerged as a consequence of individual curiosity, and from that curiosity have emerged large fields of the sort of thing that Aaron talked about earlier today. So how does that individual innovation fit into the large-scale picture that you just described?

Goodman:

So before Steven comments—I know he wants to—I think we have to just think a little bit differently today about individual innovation. For example, a basic research project, many times hypothesis-driven, might involve ten scientists in the project instead of one and remain highly innovative.

Stambrook:

I would argue that most innovation comes from surprise, the sorts of things that are not task-oriented.

Goodman:

Steve.

Fluckiger:

Another way to look at the question is why would industry be interested in these types of basic research? The Nanotechnology Initiative is interesting, and of course it includes nanobiology, so there's some direct application there. In some of these centers industry is interested because (a) they gave shrinking research budgets, and (b) they recognize that a lot of the product development down the road is going to arise from this basic research. So they are willing to participate in a general way, sort of like the example of the companies that at the very early stage grant or fund basic research, but as that develops and there are products on the horizons or specific applications, then they have the opportunity to identify that and say we would like to pursue that and add a specific application and fund specifically the project. So, I believe there is interest in industry in basic research as well.

Goodman:

I'll take one more, and we're actually going to finish on time.

Bankaitis:

At the beginning we talked about how we keep students motivated, you know, how do we set up these interdisciplinary situations. Anything that is big is going to be fundamentally more inflexible, more conservative. Momentum is going to take longer to build, and it's going to take longer to slow down. I would have loved to have seen how one would convince somebody that the death of proteins is interesting, you know, back in the '70s. I mean, most people really didn't find that very interesting then, as I recall. I think the other issue is that conotoxins, which are going to have huge pharmacological interest, came from a guy who essentially was taking cone snail toxic fractions, injecting them into rats, and doing Michaelis-Menten kinetics on how quickly they dropped off of a hanging position. I don't think that the roadmap is the way to go, or it's a good model for academic science—not this guy.

Goodman:

I think that perhaps we're confusing two issues, and I'd like to try to clarify those issues. One issue deals with basic research. I think everybody here would agree that basic research can be done in a single lab or basic research can be done in cooperation amongst several labs. I hope that there are not people in the audience who are against the concept of team research, because much of what we need to accomplish in biomedical research today requires teams. But then there's a second issue, and I think it's the one that Steve was responding to. Let's say that you do the basic research and now you have something that's worth turning into a product. How do you handle that situation if the product is coming not from the research of a single laboratory, but the research of multiple laboratories at multiple institutions? No one has suggested that fundamental basic research should be somehow lost in all of this. The question is what happens after it's done and it leads to something that could be a valuable product.

Dr. Scott T. Brady, University of Illinois at Chicago:

I think one point that should be made here is that I don't think anybody objects to team science. But the problem is whether you're doing top-down science or the teams are emerging naturally. And the model that was presented essentially is a model that comes out of industry. It basically is also not so very different from many of the European models of how research is done. And it reminds me a little bit of the new Coke phenomenon, where the number one soft drink company in the world decided to model themselves on the number two.

This is not really denigrating European science, but the kind of top-down organization that is being talked about here. It's perfectly good for delivering things, after all, that's what big pharma has been doing for a long time. But the problem that's faced by big pharma, and the problem that's faced by this whole enterprise, is the fact that it does in fact limit innovation. It essentially ties up resources and it creates a great infrastructure. And I think that's something that we're going to have to come to terms with. And that's what hasn't come out in the proposals that Stephen Fluckiger is making. Because, in fact, that's the way NIH is going right now, and I think that it's going to tie up a lot of resources. And given the current funding situation, I think it's quite understandable that we're worried.

Goodman:

Thank you. Mike, please state your comment or question.

Gershon:

Well, I think the argument that we've been dealing with now is confusing the issue of research and development. Research and basic research are the natural province of universities and individual scientists. And that's very well handled, and has been with the great explosion of knowledge since the Second World War, through the mechanism and support of science that evolved in that period. We are now changing and moving into a developmental model in which we are starving the support of real science and research and pushing instead to have industry models develop and do it from the top. And this movement is, I think, threatening to choke off innovation and new development and new progress in science in the United States. If it does that, we are going to lose our initiative to those other centers of the world that are now emerging and understanding where science is really going and how to support it, such as India and China.

Goodman:

I agree with some of what you said, but it raises an interesting problem. As the NIH monies shrink, as we all talked about in Salt Lake City, we're going to have to broaden our portfolio. And one part of broadening our portfolio is that we're going to have to become more reliant on private money. Some of that private money is going to come from industry. And so it's going to raise issues which are we are addressing in this discussion.

Gershon:

Well, even giving industry its due, they need new ideas and new development. And industry, at least the industry that I've been dealing with, has been moving to support some of that. I think development is best left to the industries that use it and the NIH ought to be supporting new ideas. Development has been well handled by industry. We don't need to have individual scientists or universities doing development. That should be left to the people who use the products. We should be giving new ideas to those people to use.

Goodman:

Russell.

Hulse:

I was just going to add that one facet of this discussion is how you deal with the fact that when a discovery or innovation of some sort really takes off, the application-oriented approach tends to take over and in the end forces out continuing innovation. This is a very real problem. I've seen it, having worked for many years in the "big science" world of the fusion program. The big project, no matter what people say, tends to dominate and draw funds and resources from everything else. The answer to this is in large part that it's a management responsibility. For example, there's a management solution which you even see some enlightened industries using, which is that you make sure that you establish some separate entity, often called a skunk-works, where people get to have more freedom to do what they really want to do, based on their own judgment as to what's important. And you isolate it and buffer it in a way that this entity cannot get subsumed into or starved by the larger, big projects. The other side of the coin is, how do you make sure the skunk-works doesn't just wander off in some completely irrelevant direction? There are various solutions to that, one of which in my experience seems to work pretty well, namely that the deal that you have for the "innovators" in the "skunk-works" is that they get to spend most of their time in whatever curiosity drives them to do, but they do have a routine obligation to help out or even rotate into the regular production or "big project" side when their skills are really needed. And that helps both sides, because it helps keep the skunk-works people on track and it also brings in fresh insights and innovations into the "development process," which might not have occurred otherwise.

Goodman:

I just want to say one more thing and then we really are going to have to end this interesting discussion. I want to remind you all of a little bit of history that wasn't that long ago. And that's when it was proposed that the NIH was going to fund the human genome project. And you might recall that there was a substantial outcry, perhaps some of you were involved in that outcry, against using NIH funds towards the human genome project because it would draw money away from other things like investigator-led independent research. And probably people in this group were split on the question of whether that was a worthwhile investment that NIH was making in the human genome project. I would imagine that if I asked the same question today of whether that expenditure was a worthwhile investment, I doubt that there would be anybody who would say that it wasn't. The point is that it may take several years or even decades to evaluate the current NIH roadmap initiative.

I want to thank everybody on the panel and the audience. This has been a wonderful discussion on a series of important questions related to interdisciplinary research and training.