**PCAST Meeting - July 18, 2013**

**Welcome from PCAST Co-Chairs**

>> John Holdren: It is a particular pleasure to welcome my colleagues on President Obama's Council of Advisors on Science and Technology. Our distinguished delegation representing our British Counterpart, the Prime Minister's Council on Science and Technology about which I'll say more in a moment.  And the members of the public and the wider Science and Technology community who are present here in the room, as well as watching on the web. This is really an extraordinary occasion.  We think all PCAST meetings are extraordinary occasions, but this is the first time that PCAST has met jointly with a counter-part group from any other country and it's particularly appropriate, given the special relationship that has long existed between the United States and the United Kingdom that this first joint meeting is with our colleagues from the U.K. The U.K. delegation is led by Sir Mark Walport, who is Chief Science Advisor to her Majesty's government, head of the government Office for Science and co-chair of the Prime Minister's Council on on Science and Technology.  His co-chair is Dame Nancy Rothwell, also here, who is Vice Chancellor of Manchester University, along with being a co-chair of the Prime Minister's Council on Science and Technology and I mention the parallel structure, there are many parallels in the ways our two Councils operate and one of those parallels is the co-chairmanship structure in which one co-chair is the Chief Science Advisor to the Government and the other co-chair comes from the members of the Council who as we say, keep their day jobs, but work energetically in the service of Science and Technology advice to their government.  I am going to suggest that we go very quickly around the table because of the unusual circumstance of having a mixed group of members of PCAST and the British Council for Science and Technology and then I will ask Sir Mark Walport and Dame Nancy Rothwell, to make a few observations, let's go around starting with Sir Mark.

>> I'm  Mark Walport and I've been introduced, I won't say anymore now.

>>  I'm Bill Press at University of Texas at Austin.

>>  Nancy Rothwell, you've just heard I'm co-chair of CST.

>>  I'm Knatokie Ford a AAAS fellow with PCAST.

>>  Sarah Mooney from the  British embassy.

>> Craig Mundy from Microsoft and PCAST.

>>  Paul Cannon from Kinetic and the University of Birmingham.

>>  Mario Molina from University of California San Diego, PCAST.

>>  Jim Gates, Regents Professor from University of Marylnd, theoretical physicist.

>>  Paul Boyle, Chief Executive the Economic and Social Research Council, United Kingdom and also President of Science Europe.

>>  Barbara Schaal, PCAST and Washington University St. Louis.

>>  Frank Kelly, mathematics, University of Cambridge, UK.

>>  Philip Rubin, Principal Assistant Director for Science,  OSTP.

>>  Chris Flemming from the UK Government Office for Science.

>>  Dick Garwin, consultant to OSTP.

>> John Holdren: I'm going to skip our two speakers because they will be introduced in a moment.  Well, actually we can't skip Sir Alan Wilson, he is a member of CST.

>>  Sir Alan Wilson: Let me just say I'm from University College of  London, thank you.

>>  Dan Schrag from Harvard University.

>>  Henry Kelly, Energy and Environment, OSTP.

>>  Clara Craig, Deputy Head, Government Office of Science.

>>  Pat Falcony, Associate Director of the Office of Science and Technology Policy.

>>  Mark Gorenberg, Hummer Windglide Venture Partners in  San Francisco.

>>  Christopher Chyba PCAST and astro physics at Princeton University.

>>  Ron Douglas, geographer by background and head of research at Willis Group, a large insurance and reinsurance broker.

>>  Shirley Ann Jackson, President of Rensalear Polytechnic Institute and a member of PCAST.

>>  Chad Mirkin Northwestern University, member of PCAST.

>>  Steve Kelly, UK Atomic Energy Authority, member of CST

>>  Ed Penhoet, Alca Partners in San Francisco.

>>  Marjory Blumenthal, executive director PCAST.

>>  Maxine Savitz, vice president National Academy of Engineering retired, Honeywell.

>> John Holdren: Thank you.  As one can see, this is a collection of extraordinary diversity, experience and stature and again, we're delighted to have such a distinguished group from the Council on Science and Technology

joining us.  Let me now ask Sir Mark Walport and Dame Nancy Rothwell for a few observations.

>> Sir Mark Walport: Thank you indeed, John.  We're delighted to be here and thank you for your hospitality. I'm tempted to use the word parallel but I was speaking to Rich Gohan earlier and he pointed out parallels never meet. The thing about this, we are meeting.  We do work in very similar ways from the co-chairmanship structure to the way we report to government to many of the ways in which we work.  And I think that this meeting is extraordinarily timely because it's going to touch on two issues of huge importance to both our countries, actually.  So dealing with secondary first, which is education in Science and Technology, Engineering and Mathematics, I think everyone agrees that this absolutely underpins our future skills base, educational base and ultimately prosperity, health and well being.  And mathematics education, of course, underpins so much of that.  So really good topic for us to be talking about.  Another activity that the Government Office of Science in UK has responsibility for is foresight scanning.  And we've identified over the years a number of similar topics to those you have identified such as advanced manufacturing.  Future cities is an area that we're starting work on at the moment.  So again, I'm looking forward to this session on the future cities.  So I hope these lines of the future no longer parallel, convergence is one that can continue.

>> John Holdren:  Dame Nancy.

>> Dame Nancy Rothwell: Thank you, just to add my thanks for hospitality we received here in Washington.  I'm hoping we can return that and you will come to the United Kingdom.  The only thing I would like to add, it is notable how many topics we're studying very, very similar, probably because they are global issues.  Science and technology is not confined by national boundaries and what we're all facing the same issues and therefore partnership and collaboration in tackling some of those global issues I think will be important in the future, and we'll certainly look forward to future interaction with PCAST.  Thank you.

**Big Data: Smart Cities**

>> John Holdren: Thank you very much.  Without further adieu, I want to turn it over to one of our Vice Chairs, Dr. Maxine Savitz, who will moderate the first session on big data to make cities smarter and we'll introduce the presenters.  Maxine.

>> Maxine Savitz: Thank you, John.  I'm really looking forward to this discussion on big data in relation to cities and how we'll make them even more efficient, more reliable and getting all the different people together, pleased to have with us Steven Koonin, who is the founding director of New York University Center for Urban Science and Progress, and he is professor of information, operation and management of science at NYU.  Prior to his joining NYU he wa the Undersecretary of science at Department of Energy,

prior to that strategic planning for British Petroleum and spent a good part of his life at Caltech, where he was professor and alsoprovost.  Followed by Sir Alan Wilson, who is the professor of Urban and Regional Systems in the Center for Advanced Spatial Analysis at University College London.  He previously was Vice Chancellor at the University of Leeds and he had many executive appointments varied from environmental studies to ministry of transport and also the institute of Economics and Statistics, very broad background.  So we are looking forward to it, we'll have each of you give your talks and then we'll open it up to discussion by the group.

>> Steven Koonin: (Away from mic) -- I'm pleased to be back in front of PCAST and eveb more so to be speaking to this joint U.S.-UK session.  I want to talk about urban informatics, which is the focus for the Center for Urban Science and Progress, or CUSP that I've been standing up at NYU for the past 15 months.  Because of the reader heads that have circulated I won't say too much about CUSP itself, but focus on the rationale for combining big cities and big data, talk about some of the issues as one tries to do this and then make some suggestions as how the government might help. Recent years have seen a convergence of two simple, but powerful trends.  The first of these is the rise in importance of cities to the national and global well being.  80% of the U.S. population lives in urban areas.

The 52 metropolitan statistical areas with populations of 1 million or more, contain 55% of the U.S. population and the 104 MSAs with half a million or more house two-thirds of the population.  Globally more than half of humanity now lives in urban areas and that number is expected to rise to 80% by mid-century.  After agriculture, cities are the most prominent manifestation of humanity on the planet.  They are where the people are, where resources are consumed, where economic activities happens and where innovation happens. Further work by Jeffrey West and others, another U.S. UK connection, by the way Jeffrey, has shown that large cities have economic and innovation impact disproportionate to their size.  In short, one could say plausibly the future of humanity is largely in its cities.

All cities need to be better for reasons of sustainability but any given city needs to be as good as it can be because we are in a global competition for talent, for capital and ideas.  Because city governments are mostly operational in contrast to the Federal government and there is greater commonality of interest within a city than within a nation, city governments are best equipped to address these matters.  But as 17% of Federal outlays, some 4% of U.S. GDP, are aid to state and local government to support activity such as education, housing, social services and transportation.  If there is clear Federal interest in understanding and optimizing our urban areas.  The second trend after cities is the rise in diffusion of information technologies that instrument society. Digital records, fixed and mobile in situ sensors and new sensor modalities.  There is also exponential growth in storage, processing and analytical capabilities, that let us deal with the torrent of data about urban infrastructure, urban environment, and the people in urban settings.  Through these data, we can now view a city with unprecedented coverage, granularity, variety and timeliness. It's not inappropriate to think about Galileo first turning the telescope to the heavens or Van Leeuwenhoek first looking at a living cell through a microscope. Taxi data are one example. First slide, please. No, that is the second there we go, great. The taxi and limousine commission in New York City compiles GPS start-stop locations, times, fares and tips for every one of the 170 million yellow cab rides in the city annually. NYU professors Claudio Silvs and Giuliano Farrar have been working to analyze three years of that data. It's extraordinarily rich, documenting mobility pattern, economic behavior and learning habit decisionmaking.

This chart shows one such analysis of the recovery of the city post Sandy where the taxi rides started, starting the Sunday before the storm and ending the Saturday after the storm and you can see clearly the lack of taxis in lower Manhattan and then things slowly returning. Another example is illustrated by this thermal image of lower Manhattan, it depicts heat rather than light. The building on the almost far left shows differences in heat escaping the individual suites because of thermostat settings or insulation or both. The peculiar pattern in the building in middle stems from the fact there is a data center there and the vents are on the roof. Let's see, that building on the right or cluster of buildings is city-owned housing for which you have the classic New York City situation of the heat turned up full blast and the apartment windows being open in order to control the temperature.

It is striking that a single nonintrusive sensor can reveal so much with persistence and granularity. It is not unreasonable to believe that the application of information technologies to urban matters will result in science of cities that will impact fundamental understanding and enable better government operations, planning and policy, improve the life of urban citizenry and enable the private sector to provide new products and services and foster revolution in the social sciences. Mobility, health safety, security, services delivered, infrastructure planning and emergency management are applications for the city that come to mind. It's a truism you can't improve anything that you can't measure and these technologies will let us do that. But it is also important to understand that the model since intervene paradigm of applied urban informatics is the fastest and cheapest route to improving cities because physical infrastructure changes over decades while IT can happen very quickly and relatively inexpensively.

The importance and potential of urban informatics is beginning to be recognized in various initiatives. CUSP has ambition to fully instrument New York City and exploit the data so derived. Other academic organizations are sprouting up in Chicago, Boston, the Bay area, London, Santander in Spain, Singapore and many others. There are private sector initiatives like IBM Smart Cities, Microsoft City Next or Cisco's Internet of things. Several city governments in the U.S., most notably New York, Chicago and Boston, have taken the lead to make their data available to the public and to breech the stove pipes in which it resides. We have early examples of wins including predictive policing, traffic management and building enforcement in New York City. The successes of big data in advertising, in political campaign and in the insurance industry also engender optimism that urban applications will be fruitful. But cities are unique in that their systems of systems with strongly interacting built environment and human components change on time scale ranging from seconds to decades. Some of the learnings in the first 15 months of CUSP are informative of what is takes to realize the potential of urban informatics.

Much of the work of urban informatics is in assembling diverse and often imperfect data and conditioning it for analysis, for example, some of those taxis rides I showed you when you look at the raw data originate in the middle of the east river, for example, clearly need to be thrown out. Analysis proceeds through outliers, machine learning, proxies, validated models and simulation. GIS and visualization are essential tools and there are promising opportunities to create new data streams. The informatics work must be informed by knowledge of city structure and operations and of the physical and human dimensions. So not only do we have to fuse status sets, we also have to fuse the informatics discipline with urban domains. Second point, urban informatics is big science with both basic and applied aspects. The work involves large complex technical tasks and is intensely interdisciplinary with multiple stakeholders.

I like to say in CUSP we're trying to assemble a team from sensors to sociologists to civil servants. If it is to have practical impact urban informatics need to happen at scale with schedules, budgets, timelines and there is important role for large team efforts perhaps in national lab-like entities and in fact four of the U.S. national labs are CUSP partners. Another point is that privacy and data, ownership, access use are big issues. Protection of critical infrastructure data is also an issue. CUSP has an experienced chief data officer to guide us as we work in these matters. In recruiting 25 students in our inaugural class, which will start in August, we've come to understand that urban informatics appeals to diverse students, particularly those with quantitative talents interested in having more immediate societal impact than ordinarily possible in technical fields. However, among the faculty, the interdisciplinary and mission driven aspets of urban informatics are uncomfortable in academic settings for reasons that I suspect are all too familiar to many of us. The private sector is also eager to engage as many of their business opportunities are in cities. CUSP's industrial partners are in the IT, utility and equipment sectors and we're in active discussions with large firms in the retail, banking, insurance, consumer goods and real estate sectosr and there is a vibrant pool of informatics oriented start-up companies that are eager to join in. I believe that the Federal government has an important role to play in realizing the potential of urban informatics, if only because few localities have capacity to pursue such innovation. A national program in the U.S. might have the following components. First, encouragement of data sharing. Urban data are in disperate hands, diverse city agencies and the private sector. The former are often reluctant to share, since within government data is power and analysis has potential to induce embarrassment and/or further regulation. The private sector often sees commercial value in their data.

Certainly there are Federal, state and local open government data initiatives, but much more work needs to be done, including finding ways to incentivize agencies to share data and to recognize those civil servants who help make data open.  A second thing the Federal government could do is define and promulgate data standards.  While I believe urban informatics is best practiced within a single city because of the synergies of multiple data sets comparison among cities are also important, as is the ease of technology transfer.  Examples in multiple cities sharing data and best practices in ways that purely corporate research would not.

Privacy research and regulation is another important area for the Federal government.  Privacy is to urban informatics as safety is to aviation. It is a license to operate and if we mess up, we'll be out of business.  Protection of the individual privacy is a complex subject with Federal interests on several fronts.  The government should seek expert advice on principles, policies and standards, building on the LC activity of the human genome project.  There is interest in research opportunity on how privacy can be preserved while turning data into information.  Funding for urban informatics research is on the agenda, as well.  Coordinated program of technology development, demonstration application and scientific studies using urban data would move things along.  Again there are certainly some Federal supported efforts underway, OSTP could dig in further and help knit together Federal effort at the intersection of urban informatics, NSF's social observatory effort and NTRD's broad effort in cyber physical systems.

A competitive set of testbed activities, much as U.K. has designated Glasgow, could assess the art of the possible at scale.  I think the government can also help by promoting cross-disciplinary undergraduate and graduate training.  As I've said several times now, urban informatics is interdisciplinary, educational support targeted in that direction would be useful, of course.  Encouraging academic industry government partnership is another step that could be taken if one is aiming for impact, not merely relevance in the work, it's important to bring these players together.

And finally, I cannot identify any place within the Federal government that is natural home or champion for urban informatics research, it would be good to know of one or perhaps create one.  So in closing as I hope I conveyed application of informatics to urban areas is particularly ripe activity. There's scientific discovery potential, there's significant technical challenges and there are intriguing societal applications.  The Federal Government could play an important role in moving this field along through policies, its bully pulpit and convening power and through funding.  With that, thank you for your attention, and after Sir Alan speaks, I'll look forward to your comments and questions, thank you.

>>  Maxine Savitz: Thank you, Steve, Sir Alan.

>> Sir Alan Wilson: Well, thank you again for the opportunity to come here to speak about cities and thanks to Steve for his paper on Big Data, which spelled out the agenda extremely well and what I'm going to do is to approach the big data in cities agenda rather more obliquely so in this sense we will

complement each other. So I have two separate aims. As Mark Walpert said earlier, there is a new cross-science project on the future of cities and I'm the Chair of the lead expert group for that project. The first thing that I want to do is give you some idea of what we will do and what we're aiming to do on that project. The second thing that I want to do is talk about the science of cities and regions and how this contributes, which seems to be entirely appropriate for CST-PCAST meeting. So where do I start? It's a very highly populated field, it's clearly interdisciplinary but rather fragmented. So bringing together concepts from the range of disciplines on the slide there. Mark's computes, physics and ecology, geography, economics through into social sciences and all the professional disciplines and the integration of all that is seriously challenging. Now in the future of cities project we have two systems of interest, if I could use the physics term. The first is to look at the whole U.K. system of cities and the second is to take some demonstrators and so I'll just give you a few illustrations to fix ideas as it were at the outset. I apologize to anybody in Scotland and Northern Ireland because the data I have is for England and Wales as you will immediately recognize. This begins to bear out the very obvious things you can start doing with good access to data and good computer visualization.

So this is data at the ward level for England and Wales and so hiring per capita in wards which are quite small space for units in red and through to blue and you see it very clearly the North-South divide, which is very well known in the U.K., except what you actually see from this map, it's actually southwest to northeast line and it's really either side of that line southeast-northwest divide, if you like, rather than pure north-South. That is same with city boundaries marked, that gives a bit more detail for the London region. Again, high income within all that. If I switch to the North, let's go back again. All that red in London, higher income, switch to the North, the red is in areas that Nany and I recognize - Leeds, Manchester, North Leeds, south Manchester, Western Sheffield, areas very different to the southeast. If I do employment and professional services, you get the same kinds of differences and again you see the spatial differences within Leeds, Manchester and Sheffield. I offer that as background in terms of the U.K. system of cities.

Then four more slides which you can tease out the data. This came from research project on higher education. Take students who live in London and in this case live in outer London. Whether they go to a university in the U.K. and yellow blocks are the larger numbers, you see scatter across the U.K.. If I do inner London, you find small numbers, which might expect maybe slightly smaller population, pretty widespread. I have a couple slides, I switch to geo-demographics and I will take what are called prospering suburbs in the geo-demographic jargon, and if I take the whole of London now, from prosperous wards, where the student go and how many, and it simply mirrors the original outer London slide. Then I'm going to switch to students who live in poor areas of London, all of London and ask the same question. That is what you get. One of the things I'm going to talk about is social exclusion, one of the most dramatic instances to me of how that works and how you immediately get a measure of the scale of the problem from good presentation of data. Let me go back to the future of cities and I'm going to talk about the questions that we're approaching. This slide is the agenda, I'm going to unpick each of these. What is the demographic drivers and what does that imply about city living? The urban economy, urban structure, specifically the density of different kinds of cities, future proof and again the end of the question, what makes a successful city? And we start with these kind of questions that policy makers at all sorts of different scales would be interested in, then we think about how to apply the science to those kinds of questions.

So the demographic drivers and people living in cities, aging, migration, social exclusion, rise in number of single-person households, if you put that wholle stack of factors together, which is part of the analysis challenge, the people demand jobs, hence income, and that is the root of many of the problems of -- we are identifying in the cities, housing, different kinds of services, education, health, retail, potentially a very long list. There is a group, expert group on this, we've been particularly interested in the disparities of various scales. What makes a strong urban economy? There is a huge literature on this. High levels of skill, high connectivity levels, that can be physical accessibility, it can be internet connectivity, clusters of economic activities, cultures that attract investment and migration and sustainability and future proofing. I'll say more about that in a minute. In terms of urban structures we do paramount regulation, either through this zoning in this country, things like Greenbelt and quite strong regulations in the U.K.

I just want to here show the interdependence questions, transport policy, for instance, is actually highly dependent on the density of suburbs. If you want to develop certain kinds of public transport systems, then you need high densities around public transport hubs and in many instances we don't have those. We find ourselves talking about possibilities in public transport policy that are not actually sustainable because analysis has not been joined up policy development and planning This shows connectivity, as I said, we have challenges of the decline in many cases of city centers for things like retail, if not offices, relative to out of town and a question which my colleagues on the group has put to the U.K. is we've been pretty good at physical regeneration, but not the social. The social disparities are actually still there.

The future proof and agenda means getting virtually all of that right. And we're obviously concerned with sustainability and resilience. If we ask the 64,000 dollar question, what makes a successful city? I anticipate the next slide, governance, institutions is probably the top of the list. So we're asking ourselves questions like: What are the best models of urban government? In the U.K., we have a pretty centralized finance system, that raises the question then how do you incentivize local government. Question is innovative finance high on the agenda. Impact of devaluation to Wales and northern Ireland and what does that imply? Neighboring cities, we set cities and local government into a framework where cities essentially compete for funding investment and so on on. And how do we strike perfect balance between cooperation and competition.

Again, back to sustainable and resillient economic growth. Then at the end of all this, number of people of my colleagues said and again it is evident in the literature, you can try to get all that right and ask the questions, but maybe what local government really needs is adaptive processes and I always have this favorite quote of mine from Darwin's origin of species, the species that survive are not the most intelligent or the most brave, but those that adapt most successfully to change. What does that mean for urban development and urban government? So I'm saying that probably tops the list, but economic theory of cities and investment, human capital, one economist recently said is the human capital argument is chicken or egg. Are successful cities successful in human capital because they attract people or did they have the people in the first place that made them successful. And you can see the list innovation, direct investment and so on. And the economicians have had a go at this and put in size, connectivity variables, response to industrialization, importance of universities, which always figure successful cities nearly always have universities. When they do analysis they never explain more than about half of the variants. So there is something else there to do with governance, culture, management, that lurks behind that kind of modeling. I'm not going through this list, but I want to note what I would call wicked problems, many people call these wicked problems. They have been with us for a long time. If we do analysis of challenges of urban policy and planning the list changes a bit, but there are are many problems on this list that have been with us for decades and I want to come back to right at the end is what is science going to tell us about wicked problems? So in terms of the project, we need some kind of baseline, we need a conceptual framework and we start looking at the science, can we develop a typology of cities for our systems, certainly have demonstraters, Steve mentioned Glasgow and ATSB demonstrators, London there is a big TSB investment and we'll link with those cities, we haven't yet chosen the cities that we'll use as our particular demonstrators. Then we need both information system, we need good indicators of issues and future development. We need to understand the historical context. We'll list drivers of change, most of which are mentioned, demography, economic, investments, technology, fairly obvious list. It is easier to have the list than it is to build it into models. Then at the end of the day, we hope we'll be able to say something about living in cities, who the winners, who are the losers, economies, structures, governance, and then say something about urban futures.

So that's two years down the line. We've just started this project. And what I wanted to do for today's purposes was then just spend three or four minutes talking about where we stand on the science and how that then relates to big data. So for this particular audience, what I put on this slide is actually totally obvious and that we want to build theories, often mathematical, we build models, we use those to test against emperical data, the computer modesl allow us to get right inside the theories, computer visualization enables us to see what is actually happening. So very familiar story physics chemistry, biology and so on. The point I want to make, that is much less developed in the social sciences and what I want to argue is that we now have an embryonic science of cities and regions and that has significant uses in policy development and planning and I want to see it as one of the major scientific challenges of this century. Steve has already said and I'm delighted that we're on the same side on this, that our fields ought to be big science, and you see a sermon I've been preaching for decades now urban science and urban regional science should be big science and because the challenges of that order and the scientific challenges are of that order, too.

So what are we trying to do? I want to relate just something about relating models to big data. And what we have to do is break down the city, the pink boxes on the left-hand side of the diagram represent the population in the city, somewhere to live, somewhere to work, use of services, those needs met by the economy, develop infrastructure, delivery in housing, jobs, products or services and all that linked through transport systems, telecom systems and so on. The city economy trade in, migration on the population side. So where are we now in terms of models of those kinds of -- those sub model? We have good demographic models, potentially have good input-output models from the economies tool kit of urban economies, but not normally developed for cities. Something we need to do.

Good space interaction model, good transport model, been used for decades effectively, one of the sectors where it's really worked. Similarly for retail, very good on the private sector, less good in the public sector in areas like health and education, but the models are there potentially for deployment. And residential location models, the end of this, notice in terms of the scientific challenge, all the previous bullet points and models are really about how cities work at a point in time. If you make changes, you can actually use these models to do pretty good short run forecasting. Doing long run forecasting takes it into more difficult territory because we're dealing with nonlinear, very complex systems and we then have urban versions of fields like developmental biology, whiich similarly has large challenges, but we are making progress with that and that leads us into a different kind of set of questions about the use of these things in planning.

And so these methods work when you can do some kind of statistic leverage and that is what works in transport and as I've said, the nonlinear dynamics end of this is challenging but more difficult. And I think this is my penultimate slide, one more to go after this. To show that if I -- if you take that system of sub models, stitch them all together for at least shortish run forecasting, these models exist. This circle delta model developed by David Simmons in Cambridge, I just use this as an example so as it were put on the table, that these things exist. Two slides to go. I said I was going to tackle big data, obliquely. I'm coming back to argue that we obviously have tremendous amounts of data available.

A colleague said to me recently that the U.K. government just released something like 7,000 new sources of data. We have to decide what of that is useful to us. What I want to argue is that there is a link between the science through modeling in my case, it can be broader than that. And to ink model-based thinking to provide the concepts that will allow us to design the architecture of the information system and which will join together what we need to know about cities to import the science into planning, so on this slide the usual data sensors geography, geometry but to link with the real time data coming from the big data initiatives on the left-hand side, combine all that into an information system, it's the cleaning up that Steve was talking about, it's wholly non trivial to develop that information system and to give it a good architecture. We have planning knowledge to feed into that, our control parameters, if you like.

Once we have that kind of information system, then we can do the modeling runs, we can get reports. In this case we were using from a project of mine using city engine and then feed that back to the planners and developers and policy makers. So this really is the final slide.

We have a huge challenge. I believe we can articulate the major questions. We can develop good information systems, but a lot of challenge is still given the advent of big data, the core science and potential for model building will help us to do that and the challenge for me is then to be able to deploy the science to get into the wicked problems agenda that so far commerce failed on. Thank you.

>> Maxine Savitz: I want to thank both of you for very interesting introduction to our public session and our meeting together across the ocean and complimentary of Steve collecting big data and your model which data will help to prove the models and make use of the model data. We will have for the discussion our usual way, where you put up your cards and we will call on you to come up. Mario, you are fooling with yours, I'll let you go first.

>> Mario Molina: Thank you very much for your nice presentations, very interesting stuff. My question has to do with you are talking about developing information systems. To what extent do you think it is feasible to do that internationally? Of course you're focusing on the U.S. and U.K. it's logical. But there is so much information out there in cities throughout the world with examples we can learn from that work and don't work, just briefly an example in Mexico City for transportation, we took advantage of the trans-millenial in Brazil and so on. Some of the things that have improved mobility have to do with examples of -- you get the idea, but the question is if it is feasible to have some organization to really try to gather this information in more systematic way, truly internationally?

>> Sir Alan Wilson: Let me just offer a very brief response in the way that, forgive me for putting this way, the way physics and chemistry and biology are universal internationally, the science of cities and regions ought to be universal internationally. So the models, the theories, the information systems and the concepts that hold information systems together should be universal. When they are applied in different parts of the world, the

results and models will actually look very different. But the underlying concepts ought to be the same. Our challenge is to develop a real science, not something which is specific to particular cities.

>> Steven Koonin: So certainly cities are global phenomenon and great value and intercomparison sharing of technologies and so on and like mentioned global cities indicator exercise that has run out of Toronto, by Pat Marconi, who is compiling statistics like 200 indicators of cities. For the work we're doing at the Center, we're a Greenfield center and one of the common ways that new initiatives fail is by trying to do too much and we, you know, you can sit down for half an hour, we can fill a blackboard with ideas of things to do, even within New York City. So we are concentrating on New York now, hopefully we'll learn things we can start to export to the rest of the world. But focus, focus, focus at the beginning is very important for us.

>> Maxine Savitz: Jim Gates.

>> Jim Gates: Thank you, thank you for the briefing Sir Alan, and Dr. Koonin. Very nice. When I went away to college back in the '60s, I remember learning about urban studies and it is clear that what seems to be occurring is natural evolution of how science works. You strudy a system and then you begin to understand its rules and then finally construct models and then use those models to get outcomes better the quality of life of human being. It is very exciting to see the evolution of urban science as opposed to urban study which many of us are familiar with. My question, which is actually related to both the comments both of you made, Sir Alan mentioned wicked problems and then you, Steve, just at the end of your dissertation said, in some sense, let's not bite off too much. So let me pose my question in the following way. In more mature parts of science, one of the ways we drive things, you are both familiar with, identify grand challenges and then identify some problem that has some scale to it, but that seems like it is within the reach of possible solution. Do you think such an approach would be useful in driving development of urban science and if so do you have a short list of things that might fit?

>> Steven Koonin: So I don't know how grand they are, but certainly if you live in cities they are important. Mobility, parking is vexing issue for many people in cities. Noise is the source of one-third of the complaints to the city. We measure, monitor, help with enforcement characterization of the noise. Energy efficiency. Can we identify the causes of energy and inefficiencies and start to put in place policy and regulations to drive that down? We are working on a project to characterize the urban metagenome. The city is one more environment, just like the middle of the ocean and we do genomics on bacteria samples, in sewers, subway poles or elevator swipes.

Finally, these are the interesting things we're doing, whether they are grand challenges or not, I don't know. How humans make decisions has been an interesting area for us to start talking with the decision scientists at NYU, larger urban data sets are examples of people making decision in real time.

To what extent can they inform us about the psychology, the biology of how people make decisions and conversely can we use that information in the kind of agent-based models that Sir Alan, I'm sure is very familiar. Those are, I don't know if they are grand challenges, but they are interesting.

>>Sir Alan Wilson: Let me make a brief observation, I think there are two kinds of grand challenges. There are policy and planning challenges that Steve has talked about. This is scientific challenge because I think you know, we're only as it were halfway there. I mean, I feel I appreciate what you are saying about the sixties. I have to learn about my urban science in the mid-1960s and I did that in visits to the United States because that is where it all happened in the urban cities department in places like Harvard. It's fluctuated since. It's not been sustained drive and I think what is terrific about this field now is the sustained drive is back.I think it is actually quite appropriate to try to define grand challenges and that is partly the science one. On the policy side, I agree with Steve's list, we can each have longer lists and this is actually one of the problems. I would like to see things joined up. We often say we have housing problems in poor areas of cities. The housing problems are not really housing problems, they are income problems. They are income problems for the population because employment problems. They are employment problems because there is skills problems. There is skills problems because of education problems. It is how we do joining up. How do you identify the change of causality and then say, we're not going to solve the housing problem, we're going to solve education and skills problem and then you have another challenge, that actually takes time. What you then do in the short run. It is those kinds of grand challenges that would be high on my policy list.

>> Maxine Savitz: Good things for us to think about. Mark Gorenberg.

>> Mark Gorenberg: Thank you for thought-provoking presentations. My question dovetails with Jim's, which is the cities have become a great renaissance Center for information technology entrepreneur, San Francisco now rivals Silicon Valley on the west coast in New York, flat Iron, Union Square, Soho, defines entrepreneurship centers. Is there a thought, the folks deal with the issues of the city every day, is there a thought to creating things like application program interfaces, opening this data up to the general citizenship to develop applications for themselves?

>> Steven Koonin: So absolutely. It is not an accident we're in downtown Brooklyn, another hotbed probably the fastest growing hotbed of this kind of activity. We -- one of the first things we'll be doing with the New York Cityidate, the open data is to clean it up and make it available publicly so that people, the kind you just described will be able to access it and presumably will do interesting things with it. The more closely held data is, of course, problematic, a different story.

>>Sir Alan Wilson: I think that is something we're probably all driving, the centers I work in, all information systems are web based at the end of the day and that will make the data publicly available. There is another question lurking underneath your question, which is can cities develop

clusters of things like IT activity?  In London, we have our version of Brooklyn in the east end of London.  Always seems that the cluster of activity form nodes that grow and then suddenly every city wants one of those and there is an issue as to whether that is feasible proposition.  There are lurking questions there, as well.  Open data, make it available to the the public, entrepreneurs to use it it, public to use it as part of the planning process, all great.

>> Maxine Savitz: Bill Press.

>> Bill Press: Obviously there are huge commonalities between cities whether it's a city in the U.S. or the U.K..  But what I think is fascinating is that there is a fundamental difference in how cities are governed and that could be a fascinating laboratory in the sense that I mean, I'll make up an example, if you could take matched cities that both have rapid changes in immigration of populations, how do the responses differ if they are American governed city with electorate and city council from if they are U.K. governed city with a more connection to central government in policies.  It seems to be in terms of transatlantic cooperation the fact that we're both similar and in this respect so different is a great opportunity.

>> Sir Alan Wilson:  I think I would just say very briefly, I said that in the U.K. we have a very centrally driven system in terms of finance, I don't think that is true in terms of local elections. If you took your example of immigration in local area, I suspect the fact there would be policy issues in different ways, but you know handled in the same way.  What we're concerned with in the U.K. is and this is the future of cities group. Whether it's possible looking at the different models of urban governance to develop any clues as to whether some are significant better than others and in particular in the U.S., of course typically narrow system locally which is still relatively unusual and has been voted down in most British cities for the preservation of traditional systems.  Now we'll look at that kind of question.

>> Steven Koonin: Even in the U.S. we have great diversity for governance situation, look at New York City, New York metropolitan area, relatively strong central city government, small outline.  Contrast that with Los Angeles, for example, which has got great number of more or less equally powerful governments throughout the whole basin.  So, yes, there are natural experiments, if you like, but presumably try to tease apart compounding variables and get at something.

>> Maxine Savitz: I think also in New York there is a different in Burroughs. Brooklyn and Manhattan are quite different and you have access to information from where you sit, which is interesting. Ronald Douglas.

>> Ronald Douglas:  Maxine, thank you.  Alan, I'd like to ask you a question about the remarkable potentially strategic opportunity for urban work to be a vehicle for interdisciplinary science, integration with public, private and academic sector.  We all know how important cities are going to be in terms of population assets here in the U.S., particularly in emerging markets.  And

I'm very focused on resilience and increasingly recognizing that actually the city is a key unit of resilience, perhaps beyond the nation, the cities have control over their space, they control planning laws, they set rules, they usually governed by governor or mayor and have control over the space, differences in UK U.S. over those rules of the game. And it is clear actually it could be unit of work for my industry and others and need to learn how to face up to this. Meanwhile, I look in sectors I need to worry about - demography infrastructure, the trends and I was going to have this long list share with my company about how do we need to face up to the future.

I have this list of issues and I was going to ask to have six or seven task groups and all the rest of it and then I realized frankly if you focus on cities, you actually are able to focus on all of this. And it is remarkable unit of scientific integration which is what we need at a scale we can manage. The other exciting thing is the city have convening power, and often control over not just the control but access to (inaudible), the public sector, utilities, they have relationships with population, quite often shared culture and identity within that city.So I see the cities work as being something that could allow us to do quite revolutionary into disciplinary science which have clear impact and probably a value far beyond simply the science of cities. I just want to get your sense of whether this is really the seedbed of something potentially much larger and a vehicle for something we all probably often dream about but never quite happens.

>>Sir Alan Wilson: Well, I'll go first, Steve will certainly want to come in. He's already talked about that, I quite like to question slightly more broadly. First saying, absolutely right. I mean, no question that if use an urban focus it would be possible to develop training from undergraduate level. There is argument about whether it should be just post-graduate because you have to start somewhere and indeed that is the general comment that I would want to make. I think while this is very powerful intellectual argument, most of us sitting around the table have worked in universities where disciplines are simply incredibly powerful. And to set up major interdisciplinary programs involve shifting resources within universities which I think has proved very difficult to do. If you forgive me, with one anecdote goes back to (inaudible) point about models in the U.S. in the 1960s. When I first came here, I talked to very distinguished economist who worked on cities, an American, and I said in my naive young way, delighted that there is this growth in urban economics and all part of this interdisciplinary endeavor and he looked at me very hard and he said, you have to realize Alan, putting the word before urban before economics is like putting the word horse before doctor. It wasn't a matter of contributing to interdisciplinarity, it wasn't fashionable within economics, there are some battles to be fought within disciplines. I'm picking out economics. But it's true of the -- partly true with Mathematics. It is not true in Frank's case, but the traditional subject matter applied Mathematics on the whole, doesn't include cities. You know, it's physics and engineering and so on, in terms of application. So I think Rowan's argument is entirely right, but there are huge battles to be fought.

>>Steven Koonin: I think what's changing the scene is the data. As it has in astronomy, in the earth sciences, in biology, we now have the capacity to go in with great granularity and coverage and timeliness and understand what's happening in the city. And that is attracting scientists of all sorts, economists, decision scientists, political scientists, etcetera, etcetera. That is where this will have the greatest impact. The physical sciences, probably not so much, but some is. It is in the social sciences where this is going to have the greatest impact, I believe, just because it is not very well developed.

>>Maxine Savitz: So it's also a chance for them to work together.

>>Steven Koonin: Of course. Exactly. They have to, right? I was thinking this morning, when we started planetary exploration, you had probably the astronomers and the engineers who have to build this thing, but then you have the geologists who really understand the subject matter and that fusion was probably a very interesting exercise in the '60s, '70s and '80s.

>> Shirley Ann Jackson: Yeah, I'm trying to learn about these things. I guess the question I had is not so global, how evolved are the actual analytic techniques in either their adaptation or migration to the urban science questions? I'm thinking by going from spatial visualization to knowledge framework, the use of artificial intelligence and machine learning or just the integration of data from different sources, not just conditioning the given data for other given type, people talk about tweets and analyze tweets to death, they talk about taxi rides, the question is if you are looking at tweets, insurance data, energy data, transportation data, how evolved are things with regard to really integration and conditioning relative to the questions asked?

>>Steven Koonin: It's not a science yet, it's a series of anecdotes. There's a lot of work to did there. With respect to the analytic tools as opposed to integration of the fusion, we have a big discussion about this within NYU. My own sense is that the data are so novel and unexplored that more or less conventional tools, appropriately scaled up like principle component analysis, clustering, etcetera, will skim a lot of the cream, but we're going to need new algorithms in order to get the last 50% out of the batter or something like that.

>>Sir Alan Wilson: I mean it wasn't an occasion today to have slides with equations on them, but I would say that you know, the underlying science for quite substantial chunks of this is actually well developed and it has been well developed for, you know, some of transport for instance, well developed for it since the 1950s, 1960s. And so we're not talking there about new models and Steve is right, the excitement of the new data really the 1960s it would have cost millions of dollars to get market research firms to do origin destination service to get the data to calibrate the models. Steve has this kind of data coming into him, I'm going to say for free. It's not quite free. But that makes a difference. What we have to learn is how to use different kind of data that within the models was previously understood. There are still areas we have to develop new models.

>> Steven Koonin: So just on the OD data, my understanding is say a decade ago you were lucky if you got survey every three years with a few thousand people in it. Now, although I didn't show it, we have charts, I can get almost real time OD data on half a million people at once. It really just changes everything.

>> Maxine Savitz: Sir Mark.

>> Sir Mark Walport: Thank you. Fantastic, interesting presentations about an important topic. I want to (inaudible) it seems the grand challenge is not dissimilar to trends of neuroscience, which is to understand cognition and there is individual people in cities or if you like the equivalent of the neurons. My question is a tractability one really. I was struck, I visited a tenement museum in New York recently and the most important thing that came out of that visit, I bought Jane Jacobs book about the Death and Life of Great American Cities from the 1960s," and an early chapter is what makes the sidewalk safe. She got there by basically sitting on the street and watching how those individual neurons, the people interacting with each other. I think my question is I'm sure with big data, I know this, it is well known, you can identify which streets are safe in different cities of the world. Of course, I suspect New York as a whole is safer than it was in Jane Jacob's day. Do you think you can answer the question what makes a sidewalk safe from big data?

>> Sir Alan Wilson: Well, we have -- let me have first go. I mean the scale issues are very important here. I think Jane Jacobs, I'm not sure how you put a label on Jane Jacobs, she's been an anthropologist or sociologist sitting on the sidewalk and whatever Steve and I are talking about in terms of looking at cities in rather comprehensive way, we still need anthropologists and sociologists to sit on sidewalks. It is complimentary at different scales. In terms of myself, Steve and I have a different answer to your question on big data.

You know, I think part of interdisciplinary is being able to function at all scales. If you go back to the start of your question, on individual people, as neurons in neuroscience metaphor, we get into interesting territory. Economists tend to believe we all have utility functions and behave rationally where as in fact there is much more variance than that and the economists have learned how to build in that kind of variance. I talked about statistic averaging. If you can actually for certain kinds of problem, you don't have to know how individuals making decisions because average across the data and building models that look like things out of statistical mechanics will give you very precise predictions. But if you go down a scale to a finer scale like sidewalks, you are in a different ballpark, if I can mix my metaphors. And then different skills are needed.

We need to combine all these and we need to be absolutely explicit about the scales that we're working at. The interaction between these scales, I think that is something we're not as good at as we ought to be.

>>Steven Koonin: So the facile answer is well, sure, we'll go out and do Jane Jacobs on steroids, watch the street 24/7, identify the walking patterns, how close is it to police, schools, so on, but I'm chasing by the example of genetics where when we started human genome project, it was going to be simple, right, genotype, phenotype connection will be there and we'll solve everything. It has turned out to be rarely the case, it's much more complicated and my guess is this will be more complicated also. At the individual level, though, as Alan said statistically, it's probably trackable.

>> Maxine Savitz: Paul Boyle.

>> Paul Boyle: Thank you. That follows up neatly to what I was going to say, following up from Mark and James' question, it seems the city is all encompassing and complex that simply to try and have the ambition of modeling that together is a challenge and I like the idea of addressing this either through grand challenges or perhaps Alan's list of wicked problem as approach. Let's try to identify what some of the big questions are and how do we gather whatever data is required to answer those rather than gathering data to begin with. It strikes me, we also need to think about those wicked problems as they move into the future. What do we need to prepare for? What do we know is going to change about cities in near to medium term that some modeling could help us understand better?

One area which overlaps with the other foresight areas that Mark set up is around demographic change and household living arrangements. If you think the cities the peak cities where young adults are finding it difficult to get in the housing market in the U.K at least., we're seeing growth of intergenerational household and need for housing that will accommodate intergenerational households in different ways. It strikes me this set of living arrangement is one example of something we can predict is about to come. What we need to know more about how the cities can adapt and deliver arrangement that will be valuable. Alan, when you said in your description of your report, you might have a chapter at the end on urban futures. I would encourage you to make sure there is a chapter on urban future and how we might adapt to some of those future scenarios.

>>Sir Alan Wilson: Brief comments on that from, it allows me to make a point which I realized when I did my slides that I ought to make but that I didn't make. Again, go back to my tutelage in the United States in the 1960s. Worked with somebody who became a very close friend, Briton Harris, University of Pennsylvania. Brit used to say, there are things to remember in the kind of work we are doing on cities -- policy, design and analysis. And he used to argue these involved different kinds of thinking and somehow have to get them together.

What I've been talking about is mainly analysis. I've been talking a bit about the use of analysis in planning and policy development. What I'm really missing now is design bit of the agenda and to answer Paul's question we have to be inventive and design in a very general sense, around inventing solutions to problems. And in the case of cities, analytical science won't do that, we actually need to work with, or ourselves take on the challenges of invention in terms of tackling some of the problems and then we could use the science to evaluate the alternative ways of solving problems.

>> Steven Koonin: Paul, the first couple sentences of your remarks touched upon the debate we have in CUSP and I thought I'd highlight that. It is fundamental question. It's tension between problem driven work and discovery work. And there are good reasons to focus on particular problems, it organizes the research and will give you tangible outcome and so on. But I think there is great potential for discovery just acquiring the data and messing around, if you like. I often ask the question, what problem was Galileo trying to solve when he started on the astronomy? The answer is sometimes, new data let's you discover things that would be great surprise is and of potentially fundamental importance. We need both, of course.

>> Maxine Savitz: Last question from Ed Penhoet.

>> Ed Penhoet: several parts of this conversation lead me to make a pitch for including epidemiology in the list of sciences that need to be in the forefront of your thinking. Ultimately you are trying to address the issue of cause and effect. One of the most challenging things in any big data is you got a lot of information, but you don't have enough information, you can draw erroneous conclusions from what you observe unless you get to root causes. It has a number of consequences down stream and the point oftentimes you see organizations, cities, counties, governments, trying to emulate the symptoms of the disease without understanding the cause. People would like -- everybody would like to have a silicon valley in their backyard. People would like to have these things. They don't get to the reason silicon valley is where it is and what it is. It is an important issue that you guys will certainly illuminate over time, which is to address the core competencies, if you will, or core aspects of this, which facilitate these things so that people don't waist huge amounts of money chasing the symptoms of good city rather than underlying causes of a good city. So I think to incorporate -- you almost have to set up experiments and in that way, Steve, I think just focusing on New York, you will miss an opportunity to do compare and contrast, you know, is it really this or that that drives the success --

>> Steven Koonin: There are, of course, natural experiments that all the time even within a given local, and you can use that. Sure, ultimately this is a global subject with different instances, all well functioning cities are alike, etcetera, and so yes.

>> Sir Alan Wilson: Yeah, I'm going to say yes, as well, on core competencies, I agree with that. In a sense, articulate it is about the education challenge and the depth of knowledge that ought to be there for people to draw on. We have pretty substantial depth of knowledge that will accelerate actually promoting that through the education system and into the public arena that is a big challenge. And then one final comment, if it is reassuring, the next time I do this I will have epidemiology on my list. But the serious point to make, again, I would guess about half the people in the room from different disciplinary perspectives work with Latka Volterra

equations and they are the core of what I do on urban dynamics and so in a sense it is not, you know. We need to learn how to plunder scientific tools from different discipines and draw them into this field. that is quite a serious challenge. But I do read that epidemiologist learn how to do things.

>>Maxine Savitz: Those last word really summarize what we heard, we look forward in a few years hearing the results where you both are as we come together. Thank our speakers very much and our panelists.

(applause)

>> Maxine Savitz: And there will be a 10-minute break.

>> John Holdren: Wait a minute, wait a minute. Just before we take the break, besides adding my thanks to the panelists, I wanted to note, the reason for the absence in the room of my PCAST co-chair Eric Lander, who very much wanted to be here is that Eric developed at the last minute, a back problem and was unable to travel, but he has been watching our event on the web and when he wishes he will weigh in by teleconnection. So with that, we will now break for 10 minutes, return at 10:30 for our session on Mathematics Education.

**Mathematics Education: Toward 2025**

>> John Holdren: Thank you, the second session this morning, devoted to Mathematics Education toward 2025, will be moderated by my colleague, Jim Gates, who will also introduce the panelists. Jim, the floor is yours.

>> Jim Gates: Thank you very much, John. This is, as you know, an occasion I have been working toward and looking forward to for some time. I am not a mathematician, I tell people I'm a fallen mathematician, that is mostly what United States physists are. When I was a kid, people used to say humans were the only species that created tools. Well, we know that is not true any more, are we the only species with language, that is not true, I think we are the only species with Mathematics. That may be our unique attribute, we create Mathematics. It is a very special language, specialized language, I like to say telepathic, you know more precisely what someone else is thinking when you do it mathematically than any other language I know.

As Charles Darwin said, with Mathematics it is as if one is endowed with a new sense, that is a way to sense the universe around us and we know from recent history that Mathematics is powerful enabling tool when it comes to the creation of new innovations and in Science and Technology so much so that Eugene Bigner wrote on unresonable effectiveness of Mathematics in the physical sciences. So all these things tell us, inform us that the Mathematics is incredible development perhaps species unique development that allows us to engage in scientific innovation. As you know, PCAST has written a number of reports on Stem education and our last one entitled Engage to Excel, had five major recommendations. The third of those recommendations was aimed specifically toward Mathematics, because recognizing that as we discuss the imaging, the stem ed pipeline in this country, we did not speak to the issue of the unique and special role of Mathematics, the other recommendations might well go to naught, so we did pay attention to it. So this brings me to welcoming our panel this morning. I'd like to make a brief introduction for each of them. We have David Bressoud, Wallace professor of Mathematics at Mcallister include, we have Eric Friedlander from Southern California, the Noyes professor of Mathematics at northwestern and professor of American mathematical society. We have Mark Green, distinguished research professor, department of Mathematics at UCLA. Mark and I have had various encounters in the past and he's one of the mathematicians forward leaning in the issue of preparing young people to teach Mathematics so people like me get a chance to have fun using it. And then we also have joining us from across the pond as some like to say, professor Frank Kelly, professor of Mathematics at University of Cambridge. We have additional observers in the audience, my colleague from University of Maryland, David Levermore and several other individuals to support our Mathematics panel as they step inside of the stadium where they are the Christians and we are the lions.

Let me also mention that for those viewers who might be watching online, that if you would like to tweet, it's #PCAST and some comments coming today might be read during the public session at the end of the meeting. This introduction, I'd like to introduce the nonfallen mathematicians.

>> Mark Green: That was such an introduction that as far as being forward leaning, I'm most concerned with leaning forward to the microphone at this point. Let us know if you can't okay. So So I was asked to talk about National Research Council and Mathematics doesn't do studies very often, the last one was about 15 years ago and we were asked to produce two reports. The one on the left, Fuelling Innovation and Discovery, this was intended to, we had a profession that was intended to give examples whether unexpected impact and uses of mathematics to be used on the hill, to be used even by to educate ourselves about what was done. So the underlying full report and that is what I'm here to talk about a piece of.

This full report covers all of the types of issues that might face mathematical sciences in becoming decade and we of course, we were commissioned by the division of mathematical sciences at NSF. As we proceeded, we found we had a lot to say to our own community and that is what I mainly want to talk to you about. So the only real thing to notice in the committee, I was vice chair of the committee. The chair Tom Everhart, an electrical engineer, a third of the committee was not in math or statistics. We had representation from mathematical sciences, but very much considered essential to have people from outside.

So I wanted to say a bit about myself, which I think will lead into what I want to talk about. So Jim was talking about being trained in the '60s. I also was trained in the '60s. I had what was then certainly as good a training as one could have and as you'll see, it did not include a lot of what I'm going to talk about in training the new generation. So I then have a kind of convergence experience to keep up Jim's metaphor, on I found myself directing a national Science Foundation National Institute whose focus was on interaction of mathematics in other field approximates and really connecting people from a broad range of other fields with mathematicians and likewise, educating mathematicians about what other fields needed. So it was interesting, I was sitting in on the urban informatics session and of course you notice that mathematics was listed as one of the things that was needed and modeling was a crucial element of that. And my experience directing the Institute was in seeing that in case after case and it completely changed my view of what mathematics is and what it should be.

So briefly the story is that the role and the impact of medical science on the field, over the 15 years since the last study, has expanded. There are all sorts of unexpected names that have been used and this of course has educational implications at all levels. You talk about how you educate someone in urban informatics, all of the subjects, you can ask what would you like to see people doing as undergraduates. What should they know and particularly what math would be useful.

The other part of the story is the business model of universities is changing. This is partly due to new technology and partly due to cost pressures and the combination of these things, the fact that well is a need actually for change and also that change is going to come really lights a great opportunity to do something important and positive. So the expanding role already this morning in, you know, many of these things eluded to, you know, although (inaudible) main concern with social sciences and even humanities are beginning to absorb new mathematical technique. My institute had a workshop that was actually funded by the national endowment for the humanities, networks in humanities. The for example, ran a workshop Shirley Ann Jackson brought up migration, one of the early attempts at understanding historical migration by (inaudible) who used GENetic markers to trace the movement of people sort of humanity expanded over the world and he produced, for example, the first principle component of his markers almost exactly match the spread of agriculture into Europe as determined archaeologists. so our curriculum has not kept pace with rapid change. And very much so and come to the conclusion, partnership with other discipline are quite important in the needs that dialogue about what they see as needed and even in teaching, things like that, could have a positive effect. And so I think Jim eluded to expanded role of Mathematics meaning that more possible careers needed also means potentially a barrier for growing with students. And (inaudible) students with stem cells that you really, this is the moment when they can acquire a lot of knowledge no matter what direction they go in.

So one key thing to motivate Mathematics by how it's used. And I'll come back to, this requires educating mathematical sciences about all of the things people are doing with mathematics. It needs to incorporate mathematical thinking, I'll talk more about this. Need to be a variety of entry points and pathways, what is appropriate for one field is not appropriate for another. Partnerships I mentioned, we recommend (inaudible) diversifying teaching methods and particularly importance of engage online education, which is going to have very broad impact.

So a lot of course very interesting individual efforts have occurred throughout our community. What has been missing is a community wide effort to bring successful experiment to scale and really to widespread change. This is something I'll again come back to, but we're trying to do. So there is research that shows if you motivate what things people were good for that it indeed helps me to learn it. Very interesting graph and gauge to Excel which divided up entry college students. A group of 27% had high math skills and low Stem interest. This was I know a group that you wanted to focus on attracting and of course motivating people by how it's used was a key way to do that. I think it also of course again you mentioned in your report, would impact drop off in stem ed of colleges. (Inaudible) graduates have to know how this is used and the training at a different level of k 12 teachers need to incorporate that. So this is not meant too literally, but just as a language for describing some of the different types of thinking that go on in mathematical sciences. So formal manipulation, I mean derivation of formulas, logical proof, of course the first two are what we have certainly in the '60s, we were teaching people. But modeling simulation has to be a part of this, you saw this morning that I'm sure countless examples of where modeling is that is the way in which Mathematics makes contact with the real world, it is also our version of critical thinking. If approximate you are going to teach critical think nothing Mathematics, modeling is where it happens.

Algorithms, I had to exemplary training, I did learn division algorithm, one division this, has to change. (inaudible) across the board. So the goals would be to expose students at all levels to a variety of modes in thinking and particularly to foster the ability to deal with problems that are not precisely formulated. Again this, is something we heard quite a lot from the people we talked to in like clustering, for example, it's not a precise problem, but crucial in genomics and many other areas. So we really felt that it wasn't so the needs span all of the different fields and it wasn't really enough to just kind of tinker slightly with courses that in order to have people get through it, they need to get through, need to redesign (inaudible) and create a variety of education pathways not all of them based on calculus people can get into mathematics and then get out into sciences and social sciences.So we called for community effort. Bioinformatics is a very different pathway than ecology, that one has to redesign the courses themselves and with abundance of experiments in our community that real community wide effort is needed.

We specifically recommended partnerships with other disciplines to create a compelling menu of courses. We highlighted the fact that mathematical sciences have critical role in educating a really broad range of students ranging from major, ranging from extremely gifted students, ranging from students who struggle with Mathematics, ranging from students who have a few things they need to learn. Again, partnerships will help.

Diversification of teaching methods, I know this is something that (inaudible) himself talked about. We've particularly felt that online education is rewriting the rules and that it is potential transformative, it really needs engagement of mathematical sciences to see that it is done well and to (inaudible) business model.

We did not have k 12 as part of our mandate accept as (inaudible) into the system. It's quite important to the success of secondary math education to have k 12 be successful and I think you all have studied this enough there is not much more to say except from our perspective, we do have the duty to train the teachers for k 12. This again requires substantial change in how it is done given the common core has come along. So we distinguish the problem of inadequate preparation versus how to best possible job of teaching and motivating the post secondary students who come in and start on Stem programs and also preparing k 12 teachers for the common core.

So the problem really is to bring reform to scale. And the stick is that change really is coming. The cost pressures, the technologies make the old way of doing business really something we can't continue and the carrot is really this is an opportunity to put Mathematics education on a sustainable and exciting course that would then probably serve us well for the next 15 years. And so we need to mobilize the stake holders, which includes both those within the mathematical sciences and those outside mathematical sciences and community wide effort and involve the experience in bringing successful reform efforts up to scale. So I don't need to say it's difficult and one difficulty is it really does involve culture change, it involves faculty of the comfort zone and it occurs and would be nice if this was occurring in the '60s where there was more money for universities. Instead reform has to take place in the face of intense cost pressures and just changing university landscape and it is really large scale and rapid change, it's one generation opportunity and I know that is kind of a catch phrase but I generally, I'm old enough if I say that, I know what I'm talking about, that I haven't seen an opportunity like this in the course of my entire career.

So what is going on so there are substantial follow up activities to math science 2025 underway, so there was a convening at the Carnegie Corporation of New York in February of this year Eric and I were both there, and a number of the correct players were there, Michelle Cagle, was one of the people who convened it.

The President's Committee of the National Academies was sufficiently interested in making sure the report got implemented, they provided funding to send the full report to every math and staff department, not just at universities, but throughout the community colleges, as well. And then a small group of us, Eric, some of you may know and (inaudible) a lot of expertise in reform at a division level and I. We've approached two foundations for funding to one meeting to launch a follow up to this. Of course this will just get us started, but I'm pretty optimistic that we can make a substantial difference. And I guess the discussion would be what (inaudible) like to play. So thank you very much.

>> Eric Friedlander: So I have to learn how to work this technology. Is this better? Good. So you can see my title is the three R's, the R's are maybe reading, writing and arithmetic, depending on your point of view. I want to give overview of what is happening in the mathematics community to address post secondary education and maybe very brief impression of the mathematics community in general, all of that in maybe 10 minutes. So let's see how it goes. So when I first learned about your report in February of 2012, engage to Excel, it was somewhat of a shock because I had no prepare it to indication it was coming and it was actually a very positive shock, I think that it had stirred up great deal of activity in the community and also an awareness that so much activity that is out there that has maybe not in coherrent form yet with PCAST and others and I'll mention a few other players, coming together, maybe we can put a framework on a lot of the activity that existed and certainly existed before February 2012. But your report is an important aspect of go to action. And I might say, it fit my agenda, one of my goals as President of American Mathematical Society was to shift the focus somewhat to post secondary education, I was really pleased to see your report and see the bright light shined on what we're doing and many of the things we're doing wrong. I am going to make some general comments that I hope is acceptable to you. My first general comment is that our community and maybe I'll say math trying to copy the British other than mathematical science community, math, is greatly interested in outcomes. There is interest almost all faculty, this is what we do and there is interest. It has to be shaped, we have to be guided, but there is interest and this is not something that's new, didn't happen after February 2012 or 2010, but things are slow to change and I think as Mark indicated, this is really an opportune moment for change. A lot of stars are aligning and may be able to move forward and work on on this issue, which I think is paramount importance to the nation and certainly a critical importance to the mathematics community.

So I'm a mathematician and flying in from Paris yesterday, I was working on a mathematics problem, that is what buzzes in my head most of the time. I just wanted to give you some comment that mathematics, mathematical research is really a thriving enterprise. Some of what I say won't be too interesting, I will give you two homework problems that were solved in the past couple months, both number theory, not my subject. One is that every odd prime number is sum of integers. So this is a long standing problem that was solved. You can think about about that.

Another problem is a very, very famous problem, the twin primes conjecture that there are many pairs consecutive integers that better be odd which are prime numbers. There has been tremendous advance of that and pleasing story of that event by mathematician base in the United States.

So Mathematics is thriving. Application to Mathematics are expanding all the time. I won't bother telling you about this, you have heard it and heard it today about urban informatics. It is interesting how the Mathematics applications have gone from hardware to software to gain theory networks, the types of Mathematics being used are often initiated by mathematicians or what we call curiosity driven and core of mathematics is absolutely important.

I view core of mathematics, the role to mathematics somewhat like the role of mathematics to all of the scientists. So another general comment I wish to make is that in your report you focused on stem students, very essential aspect of nation's future and the goal of producing 30% more Stem graduates, 1 million additional Stem graduates in the next 10 years.

We in Mathematics have many problems, that's only one of our problems. We face remediation, which is would come, growing issue and many efforts. We face the issue of trying to make the general college student enumerate, aware of probability statistics, what logical thinking is all about. We also have work with our math majors and advance science students and all of these levels of education require different approaches. There is no one size fits all, no magic bullet. And it requires a lot of activity bubbling up from the bottom. It's not going to be generated by a few people saying, do had, do that, or use this approach. A lot of activity, I'll mention some, is happening.

Another thing I wanted to make, point I wanted to make, I talk to a lot of mathematics departments and they all try to tailor their offerings to meet client departments. So nowadays, half the Mathematics departments do some special collaborative teaching. We make separate educational pathways for engineers. We do we're not just marching along as we have been all along and I'm going to address some of the problems that  Mark has addressed and I'm not saying things are good, but there is a background and a development and some things are happening and will be happening. And what is remarkable, how many local efforts there are to renew and improve delivery of Mathematics education. These efforts need more framework, they are bubbling up all the time. It's not that people are passively saying, well, I'm going to teach like Newton taught. I'm not sure Newton did teach and I doubt if he was a good teacher, maybe that is not a good statement to make.

So when we talk about improving mathematics education, what do we have in mind? Mark mentioned curricular reform. There are many aspects to curricular reform and one of them is hanging motivation and some of the explanations in mathematics, hanging that on applications and it's interweaving effect on other sciences and other disciplines.

Another reform that one your PCAST report mentioned several times is cooperation with other academic units and we do cooperate mathematics departments to the extent I represent mathematics with academics, about but more needs to be done.

Then we're teaching methodology and it is interesting that some people say, well, if you only used some simple techniques like clickers in the classroom or something like that, that would tremendously improve outcomes. We have studies that indicate basically my metaanalysis of the methodologies is that the best predictor of good learnings outcome is a very good teacher. Now there are a lot of teaching methodologies that we could develop, but maybe one of the most important things is to put an emphasis on good teaching and change the culture to encourage goodteaching of Mathematics. And then, Mark and Vihad many conversations about unlearn technology. I'm very optimistic that online technology can really help Mathematics education and education in the large. I think there will be so much feedback about what students get, what they have problems with, how they can acquire and how long is their attention span. Online technology is a great tool for our efforts to deliver mathematics education. On the other hand, a student isn't going to learn how to do Mathematics or how to manipulate formula or how to analyze a situation by watching an online course on this iPhone.

I think that almost all students need the personal aspect of education, be it a faculty member wandering from desk to desk or lecturing to the class and identifying students or getting them to speak. So I think that online technology will be an excellent compliment but not a replacement for standard methods of teaching. So what are the plans to develop and improve post secondary education? Well, I mention there are all these efforts bottling at the local level. One thing I mention is happening just at the moment across the river in Alexandria, some sort of workshop that has the title of ingenious being run by the MAA, and it's a very large self driven group of people who are thinking about how to improve education and direct impact on the work force. There are many activities like this and we need to put some sort of framework to organize these activities. Mathematics played a major role in the common core. I don't think any of us anticipate a common core for colleges and universities.

There are too many levels, too many different interests and too many pathways for students. We can establish some guidelines and these guidelines can be individualized for community colleges, for Harvard University, for whatever. We can develop a framework and that needs to be done to harness some of this bubbling of activity that's been going on, that is probably not the sum of its parts. American Math Society is preparing some online archives of best practices, of methodologies, of course materials or new assessment tools. These archives will be and this will happen very soon probably in the fall, supplemented by some sort of virtual meetings where people can interact and say their experiences. Already in Mathematics, we have online sites, for example, math overflow is a very good one. Research mathematicians post questions and other research mathematicians respond. Maybe graduate student posted questions. We don't have that yet in Mathematics education, that is something we need to develop and we are developing.

We need to develop interuniversity cooperation because resources are needed to cross boundaries and universities. I've had a little experience with this about how you get teaching credit from engineering school to teach school in mathematics or how to get mathematician to teaching biology classes to get credit. These are seemingly pretty, simple problems, but problems that aren't so easy to address. Universities are often as many of you know, conservative entities and we need to get leaders of universities to help with getting a broad involve management Mathematics education.

And then, many of us, several of us are involved in various programs I mentioned at Carnegie corporation and the other units, for example, American Association Universities has got a pilot program for first and second year universities that is going to highlight mathematics. Foundations such as the (inaudible) Foundation, the Gates Foundation, that are all interested in improving math outcomes. National Science Foundation has incentive, good program Transforming Undergraduate Education in Stem. These are resources that some of us are now tapping into to forward our goals to broaden what is happening on the local level to make an impact at the local level.

So I was told it wouldn't be and I'm always at my best behavior, I think my colleagues are really holding their breath at this moment. I'll just be gently provocative about the topics of discussion. First is the impact of online technology on disadvantaged students. You can ask about all students which is certainly important. I'm concerned if technology takes too much of a grip on our education, the disadvantaged students would fall further behind. You really have to address that.

There is an elephant that is in perhaps even this room. It's called the math wars or whatever, there is a disconnect between those of us who teach mathematics who get in front of the classroom and those of us who study Mathematics education and we have to bring these two communities together. There is much to learn from both. And I don't quite know how we're going to do this, but now is a very important moment to do it. So there is also not just the goal of improving the graduation rate or the through put of stem students, we need to improve skill level, we need to improve flexibility, we need to improve usefulness to society. After all, we're competing at a global level and part of our success in competing at a global level, we import educating students from afar. So I take it as major responsibility to the Mathematics community to improve quality of Mathematics education and not simply push through students from Mathematics so they can take other subjects.

And then I endorse what Mark's emphasis on applications, it's important hook and partly what Mathematics is doing now. But there is also some danger that our students who take Mathematics often need all of their focus to just be able to work with Mathematics we're asking them to do. We have to find some balance, so it can't be that we just throw out a few mathematical techniques or formulas and say let's see what this has to do with genomics, we have to find our way to this balance.

So I've lost track of time, which is typical for me. And so I'll leave the slide without saying anything, but my basic point of the slide is mathematicians cannot do this alone. We need PCAST, the government, academic leaders and also the business community to support us and goad us and push us into developing a better delivery system and a better success rate for post secondary mathematics. Thank you very much.

>>David Bressoud: I'd like to begin by thanking Dr. Holdren,for hosting us. I'm addressing my remarks to him, to Sir Walport, to members of PCAST, to members of the Council for Science and Technology. I'm going to be focusing my remarks on Calculus. Calculus traditionally is the single course, at least in the United States, that virtually all Stem majors have to pass through, their initiation right into the Stem disciplines. And we really haven't known a whole lot about what is really going on in the calculus classes nationally. I do want to talk a little bit about a study that I've been the project director on, sponsored by National Science Foundation, the Medical Association of America, characteristics of successful programs in college calculus. This was the very first large scale snapshot of what is actually happening within calculus across this country. We did a survey, it was conducted with both students and instructors from start to the end of the term. We surveyed 213 colleges and universities, we had over 500 instructors, we had 14,000 students responded to the survey. What we were marking as successful programs were those that encouraged the students, made the students want to continue on with their mathematics. We then followed up this past fall with case study visits to 16 of the colleges and universities that had successful programs as measured by our data in their calculus instruction.

I want to look at two trends that just snapshot gave us a cross section on and I think they are important trends because they are really influencing what is going on in calculus instruction today, in mathematics instruction generally and they're forcing fundamental changes in what is going on in colleges and universities. So this is a graph showing the high school calculus experience of students in research universities. And one of the things that I had suspected and our survey confirmed is that most of the students who are taking mainstream calculus 1 in the fall have already taken already completed a course of calculus while they were in high school.

If you look at the research universities, these are defined as universitys that offer doctorate in Mathematics, the research universities it is 70% of the students taking calculus one have completed a calculus course. In other words, they are repeating the course. Among the that 70% that remains, it's 29% took calculus in high school, but did not take advanced placement exam. There are number of ways they might have gotten some sort of accreditation for their calculus, but without the AP exam and it is 41% actual did take the AP exam, 15% earned less than 3 on the AB, or BC exam. A quarter of all students taking calculus in research universities not only took calculus in high school, they earned 3 or higher on the exam.

One of the things that this one of the effects of this is that most of the students entering major universities today who need to take calculus if they have not already taken calculus, they assume that they are at severe disadvantage and the fact is most of the other students in that class have already taken calculus. Now this is put against an incredible growth in the AP calculus program. This shows the green triangle shows how many students took the AP calculus exams, either AB, or BC, going back to 1980 when there were 28,000 students who took the exam. This past spring, 389,000 students took the AP calculus exam. Against that, to give you some idea of what the numbers look like, the blue diamond show the number of students enrolled in calculus one in the fall. In all four secondary programs, that's one between 200 and 250,000 students a year. The red square show the number of students taking calculus one in the fall term in two year colleges that, is running close to 50,000 students a year. What that means is that this past year more students took the AP calculus exam than took Calculus in the fall term in all of the colleges and universities in the United States and of course not every student who takes calculus in high school actually takes the AP calculus exam. From NCES data, about 55% of those take calculus in high school take the exam and so what that means is we're looking at almost 700,000 students who study calculus in high school in the U.S. this past year.

And we talked about this huge group of mathematically talented students who are not going on into Stem majors, huge group of students and we're taking calculus in high school as we see they are not going in large numbers to take calculus one in college. And they are not going in large numbers to take calculus two in the fall term either. Despite this growth in the number of students taking calculus in high school, the number of students taking calculus two in the fall term actually dropped from 1980 to 2005. The graph is interesting, you can see clearly from 2005 to 2010, there was dramatic increase in the number of students taking calculus 2 in the fall. We don't know anything about the students taking calculus two, except total numbers. I've got one guess about what might be going on here and a little bit of data I hope will illuminate the question. One guess is that back in 1980, 1985, if you were taking calculus two in the fall term, you were not the first year student. You were somebody who came in and had to take precalculus when you first entered and you were off the regular schedule.

What this graph suggests is that most of those students have been squeezed out of the system. If you come in and you are not ready for calculus when you enter, you probably are not going to make it to calculus two, so what we're seeing I'm guessing is squeezing out of those students who are not ready for calculus when they enter and being replaced by students who are are coming in and taking calculus two as first year students.

Something else has been interesting, that rise was 50% increase in calculus two enrollments. Calculus enrollments are driven by the intensions of entering students. And so this is based on the American freshman data from the higher education research institute at UCLA. The intended stem major of incoming students. One of the things that is interesting about this graph is that from 2005 to 2010, there was a 50% increase in the number of perspective stem majors. You talk about trying to get more students into the pipeline, well, that's happened and it's happened because of economics primarily.

The real growth spurt happens beginning in the fall of 2008 and one of the things that is interesting is to look at the line for engineering, dark blue curve across the top. I've done linear regression on the number of students coming into college with an interest in engineering and what I found is that there are two variables, the number of years since 1980 and the unemployment rate one year later, those two account for 70% of the varians in the number of students coming in who intend to major in engineering. Perspective engineers are very sensitive to the economic situation and one of the things you see in the engineering graph is the between fall 2011 and Fall 2012, as the unemployment situation has gotten better, suddenly we got a drop, very significant drop in the number of incoming students who continued to major in engineering. But the other dramatic thing in this graph is growth of students going into the biological sciences. You go back to  1980 and it was barely over 40,000 students. This past fall it was almost 200,000 students that will certainly surpass 200,000 this coming fall. What is happening is that incoming stem majors are more and more going into the biological sciences. And one of the things mathematical community has to do is to respond to this. So this is looking at a graph of the intended career of calculus one students at research universities, some of the data that came out of our study and it's the only such data that exists, but it shows clearly the research universities there are almost as many students in calculus one heading into the biological sciences as there are students going into engineering. If you look at all of the post secondary institutions, there are more students going into the biological sciences than going into engineering. The biological sciences are really dominating and beginning to dominate and I'm sure they will continue to grow in their influence on what the mathematics community has to supply. respiratory As Eric indicated, most universities now are very much aware of this, they are paying attention to the students in the biological sciences. They are developing special courses for them. This is a tremendous opportunity because as mathematicians get together with biologists and think about what the biology students really need, there's some very fundamental rethinking of what the calculus course should be. There is a lot more recognition of the importance of calculus as a tool for modeling dynamical systems. I'm very encouraged by this and I think it's got wonderful continuation, not just for biologist, but also for other fields. That is concludes the points that I wanted to make. I'm sure there will be opportunities for questions and discussion. Thank you.

>>Frank Kelly: So the major focus in the U.K. has not been on post secondary university 18 years plus education, it has over the last 10 or more years been on k 12 education. That perceived as a major problem. Many reports, many attempts to make progress with that. What I'm going to talk about, not especially that, I want to talk about what has been in the last year or two, focus of discussion between the Mathematics community and universities and public policy. And that is concerned with the government's growth agenda and the extent to which mathematics might or might not contribute to that. That provides framework with which to discuss things like k 12 education and university education, many points of conflict. The focus will be what I described is that.

So about two years ago, the EPRC, the main funding body for mathematics research commissioned report from independent report from (inaudible) measuring benefit of mathematical science in the (away from mic) now this produced quite a striking number, it came out with numbers which were huge, 10% of all jobs in the U.K., 16% of the total U.K. gross value added, and when I took back to the stemming group mathematicians, the early drafts of this report, they didn't believe the numbers. They went back to Deloitte, and they said that is interesting, what we are doing the report with the methodology with subject area and the numbers are always questions.

The Mathematics community is the first one that thinks the numbers are too big. (Laughter) It is quite interesting to work out why are they that big? If you look through the report, these are the top 20 sectors for direct employment, computer services, public administration, you see various things, banking and finance down there. That is direct employment, price value added, then banking and finance goes to the top, but there is widespread of different things.

Now as we discuss that, it became important to get narrative, story of why mathematics was important. Why are the numbers so big? Certainly something very suspect about the methodology, when you criticize all sorts of ways. In some sense, capturing something and using methodology the Treasury uses for other things and so it gets the subject on on to the agenda. In trying to explain why it is, what we did, we found seven people to tell their own story as to what mathematics had done for them. And four of them were entrepreneurs in the U.K. context, very successful entrepreneurs. And they came from areas such as finance, computing, data analysis, catography. A couple of them were not mathematicians, they were engineers. The people they recruited to their companies and worked on algorithms of one type or the other, they were big employers of high grade post doc PhD mathematicians.

The next two people were the directors of the major genomic institute and cancer research institute in Cambridge respectively. These are people with PhDs and applied probability, own specialty within mathematics. They gave convincing narrative as to why those areas need very strong mathematical and statistical input. That was complimented by a young epidemiologist, who discussed (inaudible) and also a couple people from the National Security establishment and attempt to describe what they think. All of these emphasized that it is quite hard to predict which mathematics you are going to need and importance of core mathematical training.

As new methods get developed, it is not obvious how they correlate with methods you might already know. So what consequence is this having on the choices of students? One thing that is quite clear is that if you have a degree and in particular if you have postgraduate qualification, you are in high demand in the market. This was data that went up to the reporting 2010 of Adrian Smith. The numbers continue in this way since. We don't admit the mathematic students to university by looking at their needer shipability, ability to form teams. We tend to do the math questions. And so they are in high demand out the other end of the degree pipeline is quite striking for the mathematician as much as anybody else. (Laughter)

What is going on here, various things, one thing is it is very hard, first of all, driven up the numbers doing Mathematics. The solid line there is first degree in Mathematics, the other two lines are physics and chemistry. Number of people in U.K. getting Mathematics degrees is now almost more than the number getting both physics and chemistry together. In the U.K., Mathematics tend to be broader church than in the U.S., so we have bits of applied math, rather than physics that are statistics taught within a math degree.

Despite that increase number of math graduates over the last 25 years, the number going into teaching is going is not being affected. This is cumulative deficit in 2008 and not got carried on down. You can see a story here, these people are in demand in the economy and there's in a language that gets resident of discussions a form of market failure here. There is the increased demand for mathematically trained people. Other than increase in supply of them, by taking people who might in other circumstances become teachers away from that protection, the supply is potentially decreasing, people mathematically talented and realizing they are. Quite thrifty for the Mathematics profession to work out how to get the message across. It isn't going to make sense to say come do mathematics because you know let's say the student the universe attract to the university degree in mathematics are ones that have aptitude for it. It is usual issue for mathematics, beautiful and useful. This is the style of the story that mathematics profession is trying to broadcast to young people.You kind of need attraction to the beauty of the subject. If you have that, it's likely you will find relatively rewarding to do it. And you shouldn't be put off by the fact it doesn't appear to be immediately vocational, it really is as Mark said to begin with,

Now what I want to talk about for the last few minutes of my talk is something which links between this and the topics earlier in the day. When history, I (inaudible) Mathematics networks, cues, applications, those sorts of things, communication work like telephony and (inaudible) department of transport in the U.K., different kind of network, but of course one is interested in the all range of scientific challenges there. Now one thing we did in transport, one thing we did about 10 years ago, made a (inaudible) to put data out there, to have data on real time information to make to put it out there. We thought things would happen. Many obstacles, mainly commercial contractual, lots of reasons. Gradually, you take barriers down and put the data out there. You can see things begin to happen. You couldn't predict what was happen. We were talking 10 years ago about PDA, personal assistance, this kind of thing. IPhone didn't come along until 2007. By the time it did come along, the apps for transporting cities were beginning to appear and now they are there, you see them all over the place. Look on your Apple map on iPhone and ask are if the public transport option within a city, it will give a list of app that compete to do it in the city you are in.

The innovation that goes on in different cities, Left hand on tremendously good application enhoned in London, the small team that have done that are looking to repeat that in other cities, local information on that. The rate of innovation and provision is quite striking. Bits of traditional maps could be way in there. One thing I was involved with at the Department of Transport was constructing as illustration of how to use data, constructing isoprones that black dot is where I work in Cambridge,and those contours show you where you could live if you wanted to travel by public transport within 20 minutes, 30 minutes, 40 minutes or whatever. Actually you see the things that represent not just major transport, public transport routes of buses or trains, but represents frequency of the journey on the routes and the technology mathematical technology for doing that isoprones dates from the end of the 19th century, Frances Gordon developed that as one of the early applications of what we call dynamic programming. It is nontrivial algorithm to do that. It is well known and taught in undergraduate courses. Now one of the things that will be important is becoming important for the applications, transport is good thing to put out data develop open data, put data out there and use it. It is one of the straight forward applications because privacy isn't such a big issue, it doesn't look like it is used for private data. It is some level. If for example you think of an app, someone phones me in London and we both realize we are in London and want to meet at a restaurant easy for us to both get to, halfway between us, the app that delivers that has to know various things, it has to not just know how to locations, it has to know that A, is willing for B, to have partial information about these locations and similarly for B about A. The development of those information structures is conceptually pretty. I dare with modern sensibility about sexism describe a story of salt an and 40 unfaithful wives, but those that know that know if you describe a structure of privacy it is not enough to say, well, a bit of data is either public or only known to the owner of it. What I know about what you know is information. What A, knows about B, knows about C, knows about D, is information.

That recursive data structure conveys information and can be used to extract further information. And describing that recursive data structure, mathematical induction, definition of common knowledge, that is a difficult logical philosophical mathematical challenge to describe what it means, there is something that is common knowledge. That requires kind of level of conceptual ability to analyze that, that tends to be in the people have gone through mathematics degree and lots of our discussion of privacy are going to move to that highly articulated area. When to use things like Google Plus in different circles, that is the sort of thing with Google Plus or successes, linked to these apps that require multiple bits of information about multiple people. There are issues concern with privacy about reciprocity, for example, the way in which if you put in northern countries, data on income is off in the public domain. Data on health records may be, too. Also in the public domain will be those that make access to it. So openness is double edged. If it if you are insurance company and want to look at medical records, that will be C. If you spoof it, that is breaking social norm and liable to society penalties for that. And what I think will happen with privacy is what happened with various other technologies, when the first introduced sense technology will police itself within itself. Got introduce, people walk in front of it, limited to (inaudible). Gradually over time one recognizes one has to police mechanisms like responsible driving, speed limit, law, prosecuting people who break the social norms. And I think that the debate on privacy will at one level become something highly mathematical. The abstract structure about who knows what about what, and another level involves social science. The what we mean by social norm.

I'll just finish with a final remark about big data as opposed to open data or two things overlap. Big data currently I would say one of the very major challenges for mathematical sciences. With a huge opportunity for integration between the different parts, supplied map, statistics, those sorts of areas. Compressed sensing, recovery of large data matrixes, from incomplete set of entry. So the specific example of this, the NetFlix prize, matrix, the rows of people, the columns are films and entry in the matrix telling you how much that person liked that film. Now in one sense that looks like a lot of data. In another sense, matrix is very sparse, most of the matrix is missing and so the challenge, which is of interest to people across the entire spectrum of mathematical sciences is how do you use, how do you try to estimate the entries in that huge matrix that are missing. It is not at all obvious from the work that has been done so far where which bit of mathematical science will have the key to unlock that and probably integration between all of them. The one often has comment that there is too much data, not able to process it. Well, that is indication that the scarce resource is no longer the data. The scarce resource of the data analysts, the people to analyze it and five or six years ago, Alvarrion, chief economist at Google said (inaudible) will be the sexy subject. When people were not curious, he said, look, who would have guessed in the 1990s computer engineering would be glamorous subject to be in and everything was seen so far with what is happening with big data and with open data indicates that that is probably right. And seems to me big opportunity for the mathematical sciences to use that as something that unifies and communicate out as talks indicated data looks exciting.

The method to analyze it might be an old one, isoprones or new one, ways of dealing with (inaudible) and large matrixes.It gets the attention of people because the application through the data is so clear. I'll stop there. Thank you very much.

>> Jim Gates: Well, first of all, I would like to thank the panel for a range of presentations from the rich data and PCAST is not a body that shies away from data, we appreciated that. On the other hand, well was a pull back to the applications, which Frank actually gave us a wonderful rundown in the context of the experience in the U.K.. And then finally, the sort of metaphilosophical ideas about how mathematics in the context as we practice it here could be made more effective as a tool for engendering increased interest among our young people to continue into stem field. I truly appreciate the presentation. John, would you like to take the helm again or what?

>> John Holdren: We have interesting situation, we have just about come to the end of allotted time, I think we don't need as much time for the public session as originally anticipated because the number of commenters is smaller than anticipated.  So I think we can spend at least the next seven minutes with discussion from the PCAST members and CST members, questions, comments or cries of outrage. Anybody who has either a question or comment or a cry of outrage is invited to raise their flag and I'll start with Craig Mundie.

>> Craig Mundie: To Eric, several times when you talked about emergence of the online teaching environment, you sort of stated a big concern this was in the case of disadvantage would be a problem potentially and that it wasn't really a substitute for the classical laying on of hands by the professor so to speak. I'm just curious, why you think that. I mean, so little data, it's rapidly evolving field and there are certainly many people who argue exactly the opposite is true. And given your role in the community I'm concerned and why you think that.

>> Eric Friedlander: Well, I think if a large part is motivation that so far mukes have been very successful for some people, perhaps in India, China really want to learn the material and are going to after a hard day of working will be at night facing their computer monitor and studying. But a lot of the problems we face, especially in remediation are students who are very undermotivated and undirected in their involvements in education generally, but especially in mathematics and have some sort of adverse reaction perhaps to it. If they are told to simply turn on some device and look at that and digest the material, that is not successful. At least that is certainly my intuition and the studies I've seen one program is extremely successful. Program at the University of Michigan in which they provide much, much personal attention to their obligating students and this sort of involvement and personal attention seems to succeed in getting people to be motivated and to understand. I don't see that you can learn mathematics just by seeing across the screen. So I agree somewhat it is intuitional. It is impressions I hear from others. We shall see. The huge advantage of nukes or online technology is the feedback mechanism and is the also we can take our best teachers and put them forward and we can put tremendous efforts on individual class preparation, all those are positives, but I don't think those are sufficient. I think they will work well with some groups, but I worry about the disadvantaged.

>> John Holdren: Jim gates.

>> Jim Gates: Thank you, John. Can I defer to Bill and

>>John Holdren: Absolutely.

>> Bill Press: Yeah, I want to pick up on the slide that said, beautiful and useful. And I think none of us at this table or in this room doubt the beautiful part. I mean, I became a scientist first fall nothing love with the beauty of Mathematics and only much later discovering the much Messier beauty of data. My question and I guess to David Bressoud, about the data you have on on calculus students. Do we have any data at the end on how many students picked up on the beauty as opposed to the utility? Because maybe in the interest of efficient teaching with better outcomes, as wonderful as the beauty is, it isn't something we should try to teach, we should just get to work on trying to teach the utility.

>> David Bressoud:  It's great because one when I said we were looking for successful programs in terms of desire to continue, we're actually looking at three markers measured at start and end of the term. One was intension to continue to calculus two. One of which was confidence in mathematical ability and the third was enjoyment of mathematics. So that is something we were really tracking as important in helping to decide whether students would go on. It's one of the interesting things about the study perhaps not surprisingly is the taking calculus in your first term of college destroys the constant mathematical confidence of many students. Fortunately enjoyment doesn't go down quite as much and intension to continue doesn't go down quite as much. But I think there's some parallelism between enjoyment and seeing the beauty and that is something we were looking at.

>> John Holdren: Steven Cauley.

>> Steven Cauley: One piece of data really, in hard economic times, students moving to mathematics, we get more stem trained people and isn't that a piece of data which we ought to follow up on in the sense of now in better economic times we don't want the numbers to go down again?

>>David Bressoud: Exactly. That will be a real challenge. The challenge of the profession.

>> Yes, yeah.

>> John Holdren: The last comment will be from Jim Gates.

>> Jim Gates: Thank you, John. Once again, I would like to thank the panel this, is a very important exchange for PCAST and entirety to hear from representatives of your career. I'm encouraged by the fact that a, our call to you elicited such an informed, impassioned response about what is going on in your community and you also outlined the challenges in particular the fact that many good things seem to be out there, but not quite brought to scale. I have a couple specific questions. One is are your slides available to either to members of PCAST or to the public? I very much would like to actually have all the presentations for various things that I'm involved in. The second is and personal one or two of the slides, indications about continued interest in having PCAST in dialogue with you in particular or other groups in your community. I can't speak for the entirety of PCAST this, is John's call. I think many of us around the table would be eager and anxious to continue this dialogue for the benefit for the country in terms of what mathematics can do for what I like to think of as reigniting the American dream. I want to end the presentation by thanking you for that and turning the mic back to John.

>> John Holdren: I can assure you that the slides of at least the first three presentations are in our books. So that is easily answered and I think we would be interested in continuing the dialogue. So let me add my thanks to the panel that was terrific set of presentations. We'll now turn to the public session. Before I turn it over to PCAST vice chair Bill Press for the details, I do want to recognize that we have a group here today in the audience from the net work of educators in science and technology from the

George Washington MIT stem policy institute. I think we probably owe in part the attractions of this great panel for bringing an entire delegation to the public meeting, so we're grateful to the panel for that convening power and grateful to the folks from the net work of educators in Science and Technology for joining us. Bill Press, the floor is yours.

**Public Comment**

>> Bill Press: Thanks, John. Well, we've heard about statistical and problemistic thinking and I'm afraid we have a negative statistical fluctuation in that we don't have people who have signed up to make oral public comments. Is Bridgette Hunley here? Mrs. Hunley was the only person to sign up and hasn't registered. She's not here. So I think all I can do is one additional call out is there has been a lively set of tweets in real time about the last session by Karen King. So I wanted to call out Karen, we're glad you are out there and helping to spread the word about PCAST. Karen's public Twitter profile says that she is math educator, she's in the DC here both as native and as a resident and she describes herself as political junkie. So I would just add that PCAST needs more such political junkies. Our hashtag is #PCAST and our next meeting is September 12th. So I hope that before that meeting we have more people signing up who can make it here to make public oral comments and in addition more peep toll get online and tweet or e mail to us during the meeting. I'm afraid that is all we have for a public session.

>> John Holdren: Well, with that, it only remains for me to thank once again the members of the delegation from the Prime Minister Council on Science and Technology, my colleagues, Sir Mark Walport, Dame Nancy Rothwell, and all of the terrific delegation that made the trip across the ocean. My thanks to the PCAST members, my thanks to all of our panelists in both sessions and of course to the members of the lighter science and technology community who joined us in person and on air, we are now adjourned.