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The value of innovation

The Hinton Lecture

Throughout history, extraordinary periods of achievement have been sparked by the appearance of a single invention – the printing press, the telephone, the aeroplane, the transistor, the Internet. There are countless examples. But it is rarely the invention itself that creates the revolution. It is the pervasive application of the invention that makes the difference.

Introduction

Presented by Lord Broers FREng FRS

President of The Royal Academy of Engineering

I am President of The Royal Academy of Engineering, and it is my very pleasant task to welcome you to this 2004 Christopher Hinton Lecture. The lecture is named after our first President, Lord Hinton of Bankside, who was first President of the Fellowship of Engineering, as it was then. It later became The Royal Academy of Engineering, as we know it today. Lord Hinton was the first Chairman of the Central Electricity Generating Board.

The Hinton Lecture is our premier lecture and the speaker is always a global leader in engineering, someone who is truly driving technological progress. Tonight's speaker is all that and more. As Senior Vice President for Technology & Manufacturing, Nick Donofrio leads IBM's global innovation strategy and its community of 190 000 engineers, scientists and technical professionals. Over his 37-year IBM career, he has held numerous technical management and executive positions and has led many of IBM's major development and manufacturing teams: from semiconductors and storage technology, to microprocessors and personal computers, to IBM's entire family of server systems. He is also a foreign member of this Academy, and about to become an international fellow.

He is a champion for education, vigorously promoting mathematics and science as the keys to economic competitiveness, and he is passionate about the integration of diverse cultures and ideas in both technical education and the technical professions. He was Chairman of the National Action Council for Minorities in Engineering for five years until 2002, and in 2003 he received the Rodney D. Chipp Memorial Award from the US Society of Women Engineers for his outstanding contributions to the advancement of women in the engineering field. Nick also devotes considerable personal time to America's schoolchildren through a US programme called National Engineers Week. It is an initiative designed to expose young men and women to the rewards of science and engineering through hands-on experiments and the sharing of real-life experiences. It is also an opportune time for Nick to speak to us, as IBM UK won this year's MacRobert Award for the WebSphere suite of programs which have enabled e-commerce and saved business billions of dollars.

If I do nothing else in this lecture, I want to leave you with three thoughts. Number one: technology will never let us down; the base is secure. Number two: value is migrating. What people perceive they want to spend their money on in the twenty-first century is entirely different from what they spent their money on in the twentieth century. Number three: it is always about people, it has always been about people and it will be about people going forward. People and culture are both needed, along with technology, along with value migration, to understand innovation in the twenty-first century.

In many ways, I feel intimidated being here. The topic that I am talking about is something that the Academy does better than we do in the United States. I am not saying that I borrowed the whole idea of innovation from the Royal Academy, but I do read the reports that I receive from the Royal Academy and I noticed right from the beginning that everything was discussed in terms of innovation. In fact, it is the value of innovation that headlines most of the topics that I read. Therefore, I probably shall not tell you anything that you do not already know, but I hope at least to give you another perspective.

Accelerating advances in technology

Many of you have seen the graph in Figure 1. This is Kurzweil's graph (Kurzweil is a famous computer scientist from MIT). It is a semi-logarithmic plot, which literally plots, for a fixed amount of money, the number of calculations per second for well over 100 years. If you did the inverse of this, you would find the cost of a transaction per second. It does not matter which way you look at it, it is an impressive curve and says that for 100 years, the number of calculations you could get for a fixed amount of money per second went up 15 orders of magnitude.

If you study it even further, you will notice that the back end of the curve is a steeper slope than the front end of the curve, because in the last 30 years we probably have more than six orders of magnitude improvement – all because of physical science and physical engineering, and all the substitutions that have occurred.

I have lived through many of these substitutions. When I started with IBM, one of my very first jobs was working with vacuum tubes and ferrite cores, and most people know very little about either of those in today's technological arena. If you look at the curve a little further, you see that the hope for the future is something we call nanotechnology because, in the end, everything comes to some form of an end. This is likely to happen at some point in time for semiconductors, but I remain optimistic for the next 20 to 50 years. Technology will be there, and we will be able to deliver what we need to deliver to continue to drive the IT industry.

Innovation at the nano scale

I shall not take you through all of the nanotechnologies of the world, but I want to highlight for you four of them [see boxes], mainly because they are probably more or less the key technologies to drive the next 15 orders of magnitude improvement. So smaller, faster, better will all continue to happen.

Of course, all of these technologies are at different stages. The Millipede is ready to be commercialised right now. The carbon nanotube field-effect transistor is something that needs a little more work, the molecular cascade even more work and spintronics even more work. However, there is great

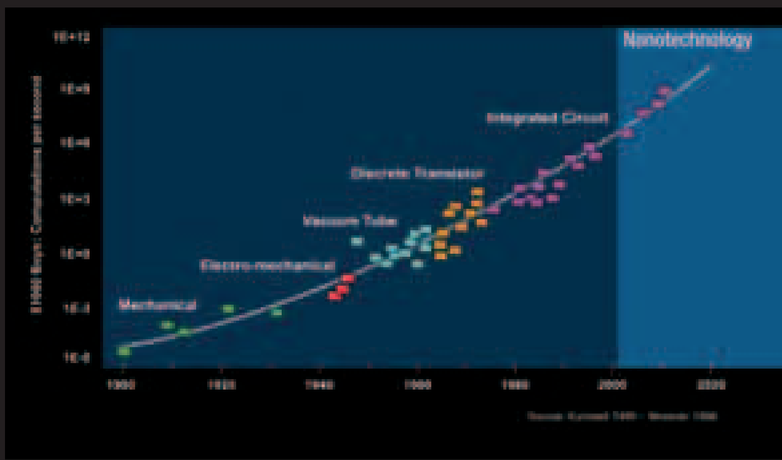

Figure 1

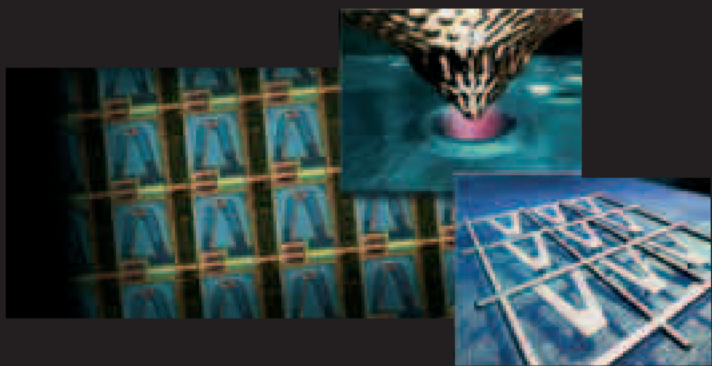

Figure 2

'Millipede' storage

The Millipede comes out of our Zurich research lab and was built off the Nobel Prize that we won for the atomic-force microscope. As a result of that, the engineers and scientists there have developed something that is almost an order of magnitude denser than the densest hard disk drive, with the added features of being not only non-volatile but also random access. This technology in its fullest form exists, and we are trying to work out right now how to commercialise it.

You can see what is going on in Figure 2: it looks like a little electro-mechanical fulcrum that dimples the substrate or does not dimple the substrate, so the substrate is one source of information and, of course, the X/Y matrix is another source of addressing information. You either heat the substrate, leave a dimple, in which case we could call it a 1, or not leave a dimple, in which case we could call it a 0. It is a very clever piece of nanotechnology that's right around the corner, and could drive the next one if not two orders of magnitude improvement.

Carbon nanotubes

Some of you are probably experts in carbon nanotubes. We happen to have one of the best and brightest people in the world working in our Watson research lab, Phaedon Avouris, who has done an incredible amount of work on taking carbon nanotube structures and embedding them in semiconductor structures, and getting phenomenal results: low power, high density and – if we could figure out how to manufacture it in large scale – perhaps even something that is cost-affordable in the industry. This technology may give semiconductors the kick-start that they need, and keep semiconductors viable for the next 15 orders of magnitude.

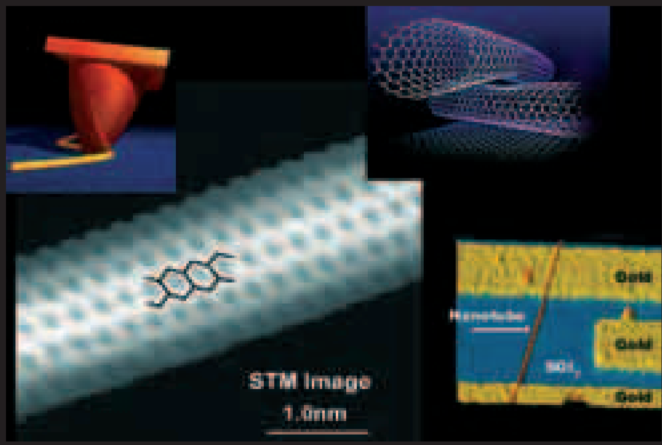

Figure 3

hope and logic here, and that we can do even more to convince you that the base is secure.

The other point I should make is that, although I am talking about physical sciences and physical engineering feats that will allow us to make the structure on which to build things, technology in software and services is every bit as important.

Many of these are technologies that we practise in IBM research laboratories around the world, but they are found in other people's labs as well, and there are people who are just as scholarly and just as capable in these technologies as we are.

Technology leadership is the core

None of these technologies by themselves will have the capability to drive the industry the way that the transistor did, or the hard disk drive. We are way beyond that and, in fact, the technology leadership we just spoke about is still fundamental and key, and will always be fundamental and key. We need to keep doing it, we need to keep practising it, we need to keep finding it, but value continues to migrate, and it will not do it by itself as we want to go forward. Therefore invention needs to move to the next level, which we call innovation. True innovation is a little elusive, it is in front of us, we believe that it is more business-minded than it is simply technology-minded. We believe that it is less push and more pull. We believe it is more to do with the issues of businesses, governments, academe and societies which we deal with around the world, and less to do with the next big idea.

You will see IBM continue to invest in all of the technologies, in all of the

Molecular cascade

Again, we used the atomic-force microscope to create a cascade of molecules – specific molecules on a specific substrate. This, too, comes out of one of our research facilities, this time the Almaden Research Center. Don Eigler has been able to prove that he can actually build the primitives of a computer. He can build an 'and' circuit, he can build an 'or' circuit and he can build an inverter. Of course, the equipment to do it would consume this entire room, so it is unlikely to end up being your laptop, but at least the beginnings are there and you know how it all works.

Initially, the equipment is huge and mammoth, but eventually people figure out what is critical because it can potentially provide us with at least the next six orders of magnitude improvement in density, if indeed we can do it in a cost-affordable fashion. Density will not be an issue. Performance is something that Don Eigler has to continue to work on.

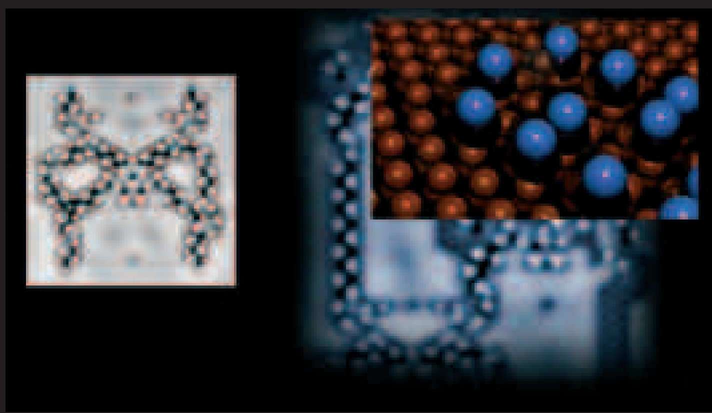

Figure 4

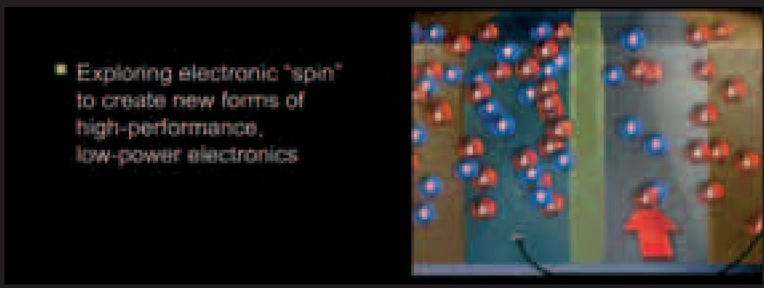

Figure 5

Spintronics

Spintronics is a very exciting area for IBM. It is another area where exploring base-level material and capitalising on a quantum property of electrons, namely its spin, can give huge benefits in terms of power and density. We think so highly of spintronics that, as most of you probably know, we are no longer in the hard disk drive business. Our researchers on the West Coast in Almaden have tremendous capacity and capability. In fact, Dr Stuart Parkin from the UK is leading this effort, along with Stanford University. As I said, this alone promises another six orders of magnitude.

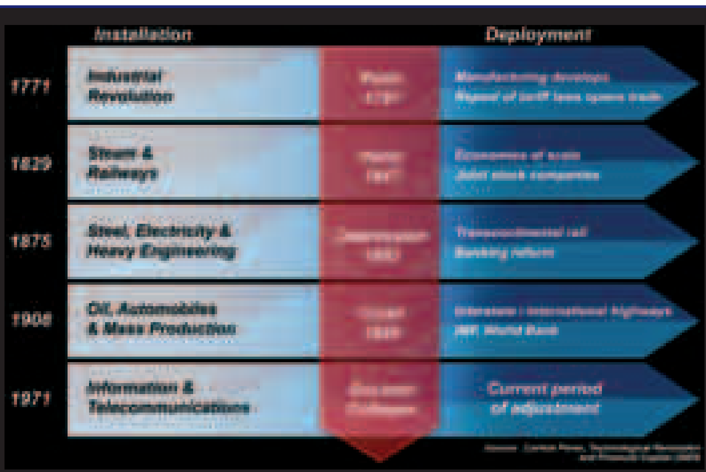

Figure 6

engineering and all of the science required, but that is simply not enough.

Historic junctures

It is not the first time that we in the modern world have been faced with this type of problem. I am not trying to present the conclusive thesis on this topic, but Figure 6 is interesting. It is a chart by Carlota Perez, from a piece of work called The Technological Revolutions and Financial Capital 2002. The chart is very straightforward and simply says that during modern history an interesting number of transitions have occurred. Good ideas come along – the Industrial Revolution was a terrific idea – everything gets going, everybody becomes excited, everybody starts to invest, but they go a little over the top in terms of their investments. Something occurs such as a crash or a panic, or a major event, but that does not mean it is the end. It means that the heavy lifting now has to happen; the really hard work has to occur. Real value has to be generated, and usually for the next 25 to 30 years real value is generated, along with real wealth and leadership. Then you proceed down the chart through all of the things that are listed in Figure 6.

It is very interesting, when you put it into this context, that we have gone through these major dislocations in the past. We made everyone excited and everyone wanted to invest, something happened and then a correction occurred, and I would postulate that we are in a correction at the moment as a result of the dot.com bubble bursting. IBM has pushed a lot of things at their customers and clients around the world: if you liked 500 kHz, you will like 750 kHz; if you liked 750 kHz, you will like 900 kHz; if you are going to like 900 kHz, you will like 1.2 MHz. Why? If everyone else has it, don't you want it too? What is the value? Did people's fingers get faster? We give you a better, clearer screen, we put a lot more data on it – are people's eyes getting any better? I have often said that, as I get older, you should be going the other way; you should slow it down for me and present fewer data because I cannot see them anyway! That is what I mean when I talk about the correction that has occurred. There is a lot of value now that needs to be generated, so we believe that this has some merit in our thinking about innovation in the twenty-first century.

The value of innovation

There are many examples that I could give of a brilliant idea, either an invention or a discovery – I understand that engineers proudly say they invent things and scientists proudly say they discover things, at least that is what they do in the United States, but perhaps you do not suffer from this in England. The automobile is a very good example. No-one would argue it is not a great idea, a wonderful invention, but is it the automobile itself that is of value, or the invention generated? We could argue, if we were to look at Figure 6, that it is the value generated that is important; it is the things that came 50 years after – the way we live, and the urbanisation/sub-urbanisation that occurred because of the automobile. It is refrigerated trucks, it is distribution, it is the hotel industry. That is where real value is; this is what fuelled an incredible driving economy for a very long period of time.

Something I've been involved with since close to its beginning is the transistor. What a powerful idea compared to a vacuum tube! Light weight and low power; soon numerous appliances started to appear such as the portable radio – you were nobody if you did not have 10 or 12 portable radios, and you counted their success by the number of transistors they had. I had a four-transistor; I never knew what all those transistors did but I knew that four were better than two or one. I still do not know what they all do! Digital watches, other appliances – the transistor was a wonderful thing but, in the end, it is not the transistor that is of value. It is everything that happened, it is our whole way of life, it is everything about us that the transistor enabled. We could not do many of the things in this room without the value that has been created by the transistor: a PA system, a speech system, a video system. An incredible value ecosystem has been generated.

Here, too, value migrated. It migrated away from the people who made the transistors, towards the people who made the things with the transistors that made something of value in the marketplace, where people were willing to spend their money. At IBM, we went through a bad period when we became irrelevant because we did not understand where value was in the marketplace. We thought that value was what we had, what we were selling versus what customers wanted to buy. The whole world spun by us, so now we are very sensitive to these issues, perhaps more so than other companies, either in the information technology industry or outside it.

Figure 7

Systems and storage – evolution of the computing model to deliver business value

Figure 7 moves value up a little, away from the physical technology that I have been talking about so far, towards a different form of technology, and how things have changed the systems, software and services industry as part of IT. We have to keep reminding ourselves that technology is running through all of these from a systems perspective. Originally, people made systems that simply grew upon themselves; they grew in a vertical fashion. They made single processing units that became bigger and bigger and when they could not do that any more they made more processing units that behaved like that single processing unit. That is called the scale-up theory of computing.

However, in the future it is not just a scale-up theory of computing; it is a scale-up and scale-out theory of computing. It involves hundreds of thousands of processors working together on a common set of problems. It lets you do many things differently to satisfy your clients' needs. It lets you step back as an engineer and scientist and innovate a little, think about what technologies you really need in order to do something. Do you need the latest and greatest, do you need the bleeding edge, do you need to die for some period of time on the bleeding edge before it pays off?

As most of you know, IBM is building the world's largest computer: a petaflop computer. We are building it out in stages and are well on our way to completion. What is very interesting is not that it is a petaflop – 10 to the 15th floating points operations per second, which is close to the compute capacity of human brains (not thinking capacity) – but that we are doing it with mediocre 700 MHz technology (state of the art is 2–2.5 GHz). Yet here we are building the world's largest computer, which we hope to have finished in the next two years. Why? Because our engineers and scientists stepped back, and looked at value in a different way and at technology in a different way. They liked the scale-out idea because it allowed them to do all kinds of things by moving things around and doing them differently. They can create value in a different way.

Software – evolution of the programming model

The best thing you can say about software, to use a phrase of Fred Brooks, author of *The Mythical Man-Month*, is don't write it, re-use it. When

Figure 8

you examine the evolution of the programming model, what transpires is that things that were so tightly bound, things we called operating systems, these services and capabilities, have moved out into the application layer – the middleware layer. They are reusable components against an open set of standards, against a services-oriented architecture that allows people to decompose their installed software so that they can recompose it in a fashion that allows them to be able to plug and play, plug and unplug, and do something with the legacy that they have. They can move it forward and then continue against this enterprise service bus approach with the tools of the twenty-first century in an open environment, never losing control of what logic they were originally wanting to implement. This is an incredible transformation of the software programming model.

Services – evolution of business synergies

The last point I want to make is that this is the services business, and even services value has migrated. Nobody wanted to pay for services before, but now they are what people want to pay for; they want to pay for individual service offerings. We are getting to the point where we are finally starting to bring women into the services business, into the technology area, as we talk about value-added services, transformational services, or the highly innovative adjacent space to the information technology industry.

This is a trillion dollar industry growing, arguably, 3% or 4% a year on a global basis which has found another half a trillion dollars in this adjacent space where people are willing to outsource all kinds of things that relate to their information technology. Where is the science here, where is the engineering here? What are we doing to prepare ourselves for this type of opportunity?

The nature of innovation is changing

It should be clear to you now that I feel strongly about the statement that the nature of innovation is changing. Technology is required, it is there, it is critical, it is not good enough by itself. Value is migrating and therefore, by definition, the nature of innovation is changing in the twenty-first century. There are a few attributes that I can talk about with respect to the changing nature of innovation. The most powerful is that this cultural diversity will turn out to be exceedingly important in the final analysis. Multinational competitors see exactly the same thing as we see; they see it better than we see it. I met with several of the people from the DTI today and my compliments to all of you here for your view, your persistence, your initiative and leadership on this issue of innovation in the twenty-first century.

National Innovation Initiative

We have an initiative in the United States which is later than yours and is called the National Innovation Initiative. I shall explain a little about what it is and what it does. It is sponsored by the Council on Competitiveness, and our Chairman, Sam Palmisano, and the President of Georgia Tech, Wayne Clough, co-chair it. It has been running

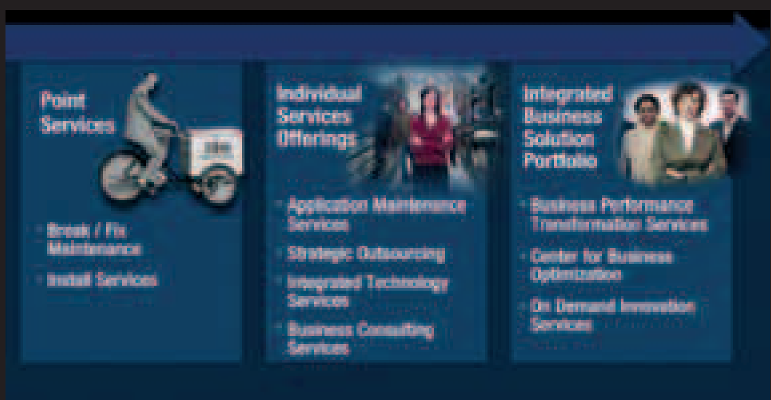

Figure 9

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Figure 10

for almost a year, and we had a final report scheduled to be ready for release soon after Election Day on 2 November; we plan a big summit in Washington on 15 December where we will hear it, talk about it and go through a series of plenary sessions to listen to what people think about it. Our real goal, of course, is to get the NII into a position where we can execute and not just 'elocute'. We believe that this is critical as a national priority.

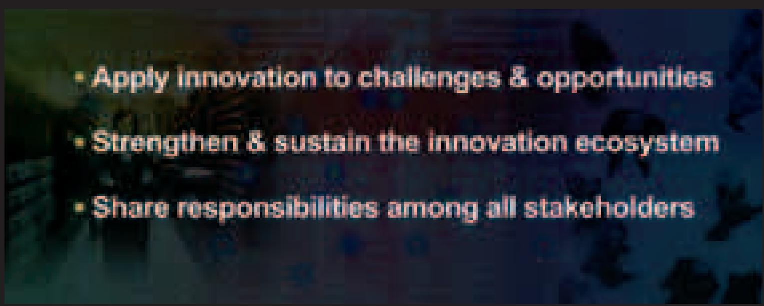

Figure 11

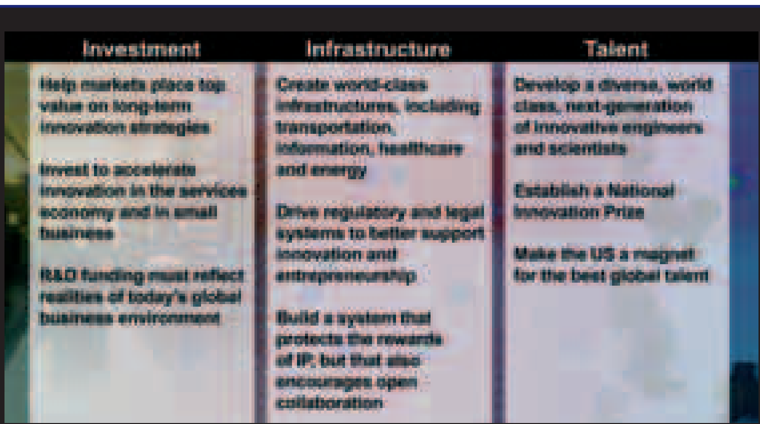

Figure 12

It is an industry-led initiative and may be a little different from how things started in England, but we are capable of involving the government, and we have briefed both political parties. We briefed President Bush and we briefed Senator Kerry as well. The three thoughts in Figure 11 summarise the NII, which involves many academics and business people, labour is part of it as well although not not-for-profit businesses.

The first two points are quite straightforward. We need to find ways and places to apply it and we need to be able to strengthen this and stay in the innovation system, but we are also confident that, in the end, it will be a shared responsibility among all stakeholders. The interim report is out and what I am talking to you about is completely well known, so I am not leaking any information to you. I work on this, and I am the chair of one of the committees that feed into its whole infrastructure.

Figure 12 shows the way in which we summarise our thinking. We think about it in terms of investments, infrastructure and talent. I shall not take you through all of these as time does not allow it, but I want to talk to you about three of them, one from each category.

This whole issue of R&D funding, at least in the United States, does not reflect today's global environment. In the United States, we have moved all of the government-supported funding from physical sciences to life sciences, so we have over-compensated for the lack of investment over the years in life sciences, understandably so, but we have left our flanks uncovered on the physical sciences. Therefore something needs to be done to cover that back up again and to reinstitute people to think about the things I discussed with you at the beginning.

Secondly, we need to do a better job of surrounding a cluster of good ideas. We do not do that very well. We will fund a piece or two out of three pieces of something, or we will fund three out of four pieces, and we will leave a piece out. Then we wonder why nothing really comes of it in the final analysis. We also do not believe that this is just under the aegis of government. It is also partly dependent on business. We have to find a way to stimulate business investment. It is not a very pleasant thought when you think about the fact that IBM is one of the few private industries that still has a pure research division to look after these things in the US. If not IBM, we go back to the universities or, in our case, we go back to the national labs. Therefore we have to put more money into R&D and, yes, it has to be able to return, and we need the government to help us to move in that direction.

Infrastructure is a little controversial and we are struggling to keep this into the final report, as you can imagine. We have many life sciences people on this board of advisors who are happy with the intellectual property structure the way it is, but we are not so sure. We need to be able to do two things: to protect research and development investments with IP; and to do something about building standards, building a common platform, adapting some form of an open-source model for all industries in order for the common base to become secure faster, so that people can build value on top of it.

At one time, and this bothers me a great deal, Alec [Broers] said I ran a lot of the hardware businesses, but I was also responsible for generating one of our very earliest versions of AIX, which is IBM's Unix. It bothers me greatly when we keep thinking that value remains in those things in which it used to reside in the past, and this is a very good example.

It is absolutely clear to me that things like operating systems are not all that critical going forward. They are close to the system, they are close to the metal, they are very critical in all of that, but in the case of Unix, and you know this in England, which has been a hotbed of Unix for years, when Thompson and Ritchie from Bell Labs invented it, it was a single thing that they invented. We screwed it up, we split it, we divided it. When I think about Linux and say perhaps we can get it all back together again, that is not a bad idea. There are many things to work on, and this does not necessarily have to be one of them. There is a greater set of value, and we learned this lesson in IBM with something we used to call S&A and Token-Ring versus TCP/IP and Ethernet. Arguably, we had the better technology but nobody cared and nobody would give you anything for it. There was no value in it. The value was in coming together with something common so that everything could move forward faster.

This is not just a US statement because we will not change something unilaterally in the United States if we do not rationalise it globally. I know that here in Europe you are already working on it between the upper house and lower house in the EU, for which I applaud you. We just have to get into gear with you and then work out how to move the rest of the world in that direction as well.

The other issue that I want to say something about is developing a diverse set of scientists and engineers. I tempted you earlier with this. What are we doing to broaden the range of engineers and scientists? What curriculum needs to be changed? What is the nurturing system that we need to put in place? We are a services-led economy, everyone says, at least in the United States, and you would probably say the same thing here in England. Do you hire anyone who has a Batchelor of Science in services or a graduate degree in services? Do we even think that way, do we think about what that means? There are many issues here and we will talk a little further about them. Of course, metrics are very important and here you have a great start. We have a terrible set of metrics in the US and are arguably still in the industrial age. We have a manufacturing-based set of metrics to measure productivity and innovation, and here we are in a services-led economy.

We have already agreed that value is migrating away from manufacturing and we have no clue about what we are doing. We have a services definition that is big in the United States. Services represent around 70% of our economy but the problem is that in that services definition we have hamburger flippers and we have business transformation giants and everything in between, all categorised together. So we do not do a very good job of focusing on metrics. I know that does not get people excited and, as an engineer, it used not to get me excited, so I know I must be getting old as it excites me now. Therefore, I can tell that something is happening to me.

Developing the next generation

I want to bring this lecture to a close by talking a little about developing the next generation. There is no doubt that we are in times of intense transition and change. If you listened to what I have been saying, technology is changing

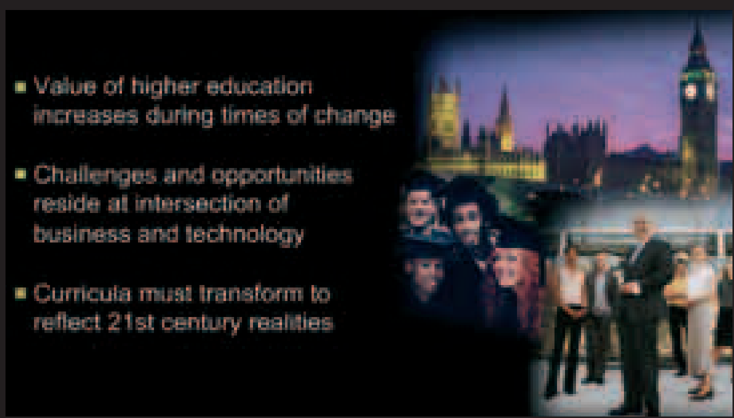

Figure 13

and moving all over the place, and value is moving right along with it. These are not new ideas. They may be brought together at one point in time because of the incredible characteristics of the time that we live in, but now, more than ever, the value of higher education is clearly the path forward. We have to find a way to deal with this intersection of business problems and technology better than we have ever done in the past. There are examples, and we have to learn from them.

One of the things that worries me most is that I frequently speak with colleges and universities and, when they start by saying we have the answer for you, it is one of two answers that they give me. One answer is: 'Two million bucks and I'll give you the answer!' I am not interested in that. The second answer is: 'my engineers in my business school' or 'my scientists in my business school are the best combination'. We cannot wait for that to occur. We have to do something intrinsic to the engineering and science disciplines, the curricula.

There is a great deal of study going on of something called problem-based learning, and perhaps you know more about this than I do, as I am just scratching the surface. There is a lot of merit to this idea. There is also a lot of merit to asking the question: how is it that in the United States our high school or secondary school children do not test well in maths and science compared with the rest of the world, and yet that does not seem to hurt us in the final analysis? So what is going on here, and what do we do other than teach them? You need to know maths and science; you will never get me to say you don't need to understand maths and science.

Should we be chasing China, should we be chasing Japan, should we be chasing India? Should we be saying, if they go to school seven days a week, you have to go to school seven days a week? If they can multiply faster, you have to multiply faster. If they can do integrals in the fourth grade, you have to do integrals in the fourth grade. I honestly do not know. I have this

Figure 14

compassion for a different form of curricular reform, the idea of working on problems. Know the basics, but how about teaching problems at an earlier stage?

I am not so sure that our engineers and scientists who graduate from college and university know about that either. Therefore, as you can tell, I am a big fan of some form of curricular reform. Whether it is because the services industry is leading, or whether it is because innovation is shifting, we need people who are capable of multiple disciplines; that should be clear. We need to find a collaboration dimension to people. Invent, discover in isolation – that will be true, but for a decreasing number of people going forward, handfuls of people. Most people will be required to work in some form of collaborative fashion, and that is where the true genius of invention will be found.

Innovation stewardship

When all is said and done, it is our stewardship that will make a difference. It has been and always will be about people; it will be our ability to change industry, government, the academics, the not-for-profits, labour; our ability to put our cultural differences aside; our ability to give something up in order to get something, in order to start to make the progress that needs to be made in order to promote an era of true innovation in the twenty-first century.

I am not trying to lecture you on this topic; the Chinese are studying this topic, the Japanese are studying this topic, India is studying this topic. It is not that we are working on it in secret and no-one will know about it until we are finished and are able to unleash it. Everyone is aware of it, and everyone is excited about the opportunities for their country to get ahead; for their country literally to leap-frog into the leadership position. That, coupled with the buying clout of some of the Asian growth companies, is an awesome formula for either success or worse. However, I am the optimist in the final analysis, I believe it will all work out correctly because, in the end, engineers solve problems and this is nothing more than just another problem. ■

Nick Donofrio is the leader of IBM's global innovation strategy and is responsible for the career development of IBM's 190 000 engineers, scientists and technical professionals. Over his 37-year IBM career he has held numerous technical management and executive positions and has led many of IBM's major development and manufacturing teams. He is a champion for education and is passionate about the integration of diverse cultures and ideas in both technical education and the technical professions.