THE ROYAL SOCIETY

Making Science Work

Academicians, fellow scientists, honoured guests; it is a real pleasure to be speaking at the University of the Chinese Academy of Sciences. This is an intellectual powerhouse, training tens of thousands of graduate students across all areas of science and engineering. A symbol of the importance China attaches to science and what it can contribute to the advancement of world civilisation and the benefit of humankind. It was this University that was the first to graduate China's first doctoral students in science and engineering, and also the first female doctoral student. Perhaps there is a future Nobel Prize winner sitting in this room today.

This is my first visit to mainland China. As an active research scientist and as President of the Royal Society, I am here today to celebrate the collaborations and contacts between Chinese and UK scientists, particularly those of the Chinese Academy of Sciences and the Royal Society, the UK's science academy. The Royal Society was founded in 1660 and is the oldest science academy in the world. I am here to learn and to be inspired by the opportunities that working together presents to both our nations. It was in 1962 that the Royal Society sent its first official delegation to China and to the Chinese Academy of Sciences. That is close enough for me, not being a mathematician, to say that the present delegation from the Royal Society should be seen as the 50th year anniversary of that 1962 visit.

The Royal Society has been connected to Chinese science for much of its history. Among the earliest specimens that the Royal Society received was an annotated catalogue of Chinese plants, sent in 1748 complete with packets of seeds and recommendations for their medicinal and culinary use.

Further exchanges and contacts were made throughout the eighteenth and nineteenth centuries. These covered topics such as medicines, acupuncture, animals, plants, books, surgical equipment, porcelain, silk and the Chinese language. A good example of these exchanges is this key to Chinese chronology published in 1729 in the Royal Society's scientific journal "Philosophical Transactions".

But it was the English biochemist Joseph Needham and Fellow of the Royal Society who was the first UK scientist to fully appreciate the scientific and technological advances of Chinese civilisation. From the 1940s onward he visited and studied in China, publishing many volumes on "Science and Civilisation in China", describing the Chinese discoveries of printing, the magnetic compass and gunpowder for example. It was also Joseph Needham who introduced me personally to Chinese science when I heard him lecture as a student in the 1970s.

Chinese and UK science contacts continue to be strong, and will get stronger in the future. The UK is already China's largest collaborator in Europe, co-authoring more scientific research papers than any other country in the world except the US and Japan. And these collaborations are increasing. The Royal Society runs an international exchanges programme with China, and Chinese scientists make up the largest numbers in our highly competitive Newton Fellowships scheme. In 2008 our History of Science centre developed an exhibition "China and the Royal Society: A history of mutual respect" based on the Royal Society archives. More recently we have run joint projects with the Chinese Academy of Sciences on synthetic biology, research evaluation, evidence-based policy making, and Frontiers of Science. I thank our colleagues at the Chinese Academy of Sciences and Ambassador Liu and his staff in the Chinese Embassy in London for their hard work and continued commitment to making our relationship a success.

The Society is also developing strong science publishing links with China. Chinese representation on Royal Society journal editorial boards is increasing and Chinese scientists are encouraged to submit research papers to our Journals. The forthcoming Theme issues of our journal Philosophical Transactions "Molecular nanostructure and nanotechnology", has Professors Bai Chunli and Chen Wang as Guest Editors.

In 2015 we will mark the 350th anniversary of the launch of Philosophical Transactions. This was the first scientific journal in the world and introduced the concepts of scientific priority and peer review. The anniversary programme including activities in China is currently under review.

A recent innovation in our joint working is hosting secondments from the Academic Division of the Chinese Academy of Sciences. We are enjoying hosting Mr Wang Zhenyu at our science policy centre at the Royal Society, and hope the good links and understanding we are building will be helpful to both our organisations in the future.

The Society has Chinese Foreign Members, including Professor Chen Zhu, elected this year, a former Vice President of the Chinese Academy of Sciences, and I hope to see more and more Chinese scientists elected as Foreign Members in the future.

There are many opportunities for Science, as well as high expectations, for what science can do for society. It is right, that we as scientists should reflect on how and why we do what we do. So in my lecture today I want to talk about the values of good science and how to support high quality discovery scientific research. Then I will consider in outline some of the great challenges facing humankind that can be addressed by science and technology, and finally will argue that science across the world should be more co-operative and collaborative, making a specific case for greater contacts between Chinese and UK scientists.

"Good" science carried out properly and openly is a reliable way of generating knowledge because of the way that it is done. It is based on reproducible observation and experiment, taking account of all evidence and not cherry picking data. Scientific issues are settled by the overall strength of that evidence combined with rational, consistent and objective argument. Central to science is the ability to prove that something is not true, an attribute which distinguishes science from beliefs based on religions and ideologies, which place more emphasis on faith, tradition and opinion. Good scientists are inherently sceptical. If an observation or an experimental result does not support a specific idea, then the idea has to be rejected or modified and then tested again. It is important to recognise that sometimes scientific knowledge is quite tentative especially at early stages of investigation, and it is only after repeated successful testing that knowledge becomes more secure and reliable. It is failure to fully understand this process of science that can lead to problems when scientists are called upon to give scientific advice on policy issues because sometimes the science is not certain.

What factors have to be considered when deciding which scientific research should be supported? Several are important but the one I think is crucial is the scientist carrying out the research. Major discoveries in science are usually associated with highly talented scientists who combine a number of qualities: they should have in-depth knowledge, be creative, understand the values of science and how research is done, be well motivated, and be effective in achieving what they set out to do. In-depth knowledge of an area of science is essential but this needs to be combined with 'peripheral vision', an understanding and openness to what other sciences can contribute.

Carrying out good scientific research is a creative activity and scientists have more similarities than might be imagined with those pursuing other creative activities such as the arts, writing and the media. Like other creative workers scientists thrive on freedom and organising them is like 'herding cats'. Freedom of thought, to pursue a line of investigation wherever it may lead and to uncover uncomfortable truths, are all crucial to an effective scientific endeavour. A scientist whose thoughts are restrained, who is too strongly directed, or who is unable to freely exchange ideas will not be an effective scientist. Similarly, societies that are not free and do not encourage the free exchange of ideas or respect the values of science are unlikely to be leading scientific powers, because that freedom is closely connected with the creativity required for good science.

Scientists need to embrace the values of science, to have a sceptical approach which challenges orthodoxy and the ideas, both of themselves and those of their senior colleagues. Scientific research is hard and to be effective research scientists need to be highly motivated. Often this motivation is provided by a passionate curiosity about the natural world, a desire to know how things work or how they can be directed to achieve particular outcomes. That is the case for me for example. But other motivations are also important, a desire to undertake public good through the eradication of disease for example, to make something useful, to create economic wealth, or to become famous. But whatever the motivation, it needs to be strong because the pursuit of research is long and difficult. So in deciding what research should be supported, much attention should be paid to the scientists carrying out the work, and as far as possible decisions about research projects should be closely associated with quality assessments of the individuals proposing the projects.

Given this emphasis on the primacy of the people carrying out the research, decisions should be guided by the effectiveness of the researchers making the research proposal. The most useful criterion for effectiveness is immediate past progress. Those that have recently carried out high quality research are most likely to continue to do so. In coming to research funding decisions the objective is not to simply support those that write good quality grant proposals or simply publish in high profile journals. The objective is to support good quality research.

Such an emphasis needs to be tempered for those who have only a limited recent past record, such as early career researchers. In these cases making more use of face-to-face interviews away from their supervisors can be very helpful in determining the quality of the researcher making the application.

A difficult question is how prescriptive research funding agencies should be in determining what research areas should be supported. This recurring issue arises because of the tensions between scientists wanting the freedom to decide what projects they should pursue and society which supports science not simply as a cultural activity increasing knowledge, but also as an activity aimed at improving the lot of humankind through achieving specific useful objectives.

My view is that those leading research funding bodies should focus their attention on high level priorities avoiding the temptation to become too prescriptive and finely grained in recommendations concerning what areas should be funded. The point I am making here can be illustrated by a metaphor derived from geographical exploration. In the nineteenth century a Geographical Society based in London for example, might have decided that it wants to sponsor exploration of the Amazon basin, the source of the Nile, or the Antarctic. But it would have been ill advised to be too fine grained in its deliberations, for example, to specify which Amazon tributary or African lake or South Polar glacier should be the focus of attention. That should be left to the explorer on the ground, not those in London. The funder's role should be to define the general geographical region of interest, identify the best explorer and then properly equip that explorer so they can be most effective in the field. Research funders should behave in the same way. They should put their trust most in the explorer scientist carrying out the research rather than in a committee.

However, this approach needs modification when a research programme is directed at achieving specific goals or applications. This does require a more prescriptive behaviour. It is necessary and valuable to identify sectors which are close to application as being areas that are worth supporting. However, identification of sectors worthy of support should be broadly scoped and involve both those carrying out the research and those who want to use outcomes of the research being supported.

Are there any other special features concerning decision making with respect to science closer to application? Work closer to application is more likely to be multi-disciplinary and may well require greater team work, not only covering more scientific disciplines but also activities outside science including finance, market analysis and the law for example. It requires effort to get individuals from such diverse backgrounds to work well together and attention needs to be paid to encouraging mutual respect and to breaking down barriers between them. This would be encouraged if there was much greater permeability between sectors encouraging the transfer of both ideas and people more freely.

One of the problems is that increasing knowledge has led to specialisation, making interactions between different scientists, industry, the public services and other professions more difficult. It was easier to make such contacts in the less complex society at the time of the industrial revolution. Take the Lunar Society for example, which met in the eighteenth century in England. It was made up of chemists, biologists, doctors, industrialists, engineers and social reformers. The group included James Watt, the Scottish inventor and mechanical engineer whose improvements to the steam engine were central to the industrial revolution; Josiah Wedgewood, the famous

English potter; and Erasmus Darwin, English Physician, inventor and poet, and grandfather to Charles Darwin. It was in this atmosphere of free exchange of ideas that the industrial revolution was born and we still need it today. This is a key message, the promotion of translation and innovation requires good permeability across the sectors.

What is science for, what can it achieve for humankind? First I should emphasise that scientific knowledge leads to a better understanding of ourselves and of the natural world, which is an essential aspect of civilisation and culture. It is revolutionary in character giving rise to major shifts in our views of the world. It was science that moved the earth from being the centre of the universe to a planet circling the sun. A sun which is only one of billions of stars in our galaxy, a galaxy which is only one of billions of galaxies in the universe. It was also science that moved humankind from being specially created to being related to all living organisms on the earth.

As well as enhancing our understanding and culture, science from its very beginnings has helped improve the way humankind lives. Robert Hooke at the birth of the Royal society emphasised how "scientific discoveries concerning motion, light, gravity, magnetism and the heavens help to improve shipping, watches, optics and engines for trade and carriage." Robert Boyle at the same time speculated how science might "Prolong life, lead to flying, to travel under water, to make an unsinkable ship, to accelerate seed germination." Science is crucial for the innovation needed to bring about the applications that drive economic growth and bring benefits for humankind.

There is a continuum from discovery science acquiring new knowledge, through research aimed at translating scientific knowledge for innovation and applications. This spectrum should be considered as an interactive system, with knowledge generated at different places within the continuum influencing both upstream in the creation of new discoveries and downstream in the production of new applications. An historic example of how investigations downstream can influence research upstream was work on improving the steam engine which greatly informed the subsequent formulation of thermodynamics. It is important to emphasise this continuum of science spanning discovery through translation to innovation. We should reject attempts to place artificial barriers in the continuum and those who argue that different parts are superior to other parts. Science throughout the continuum shares the same values, skill sets and methodologies, although there can be differences in emphasis in how research is carried out.

Today science touches nearly every aspect of our lives. Modern agriculture, healthcare, information technologies, telecommunications and transport have all been developed by scientific research. The food we eat, the planes which allow us to travel the globe, the vaccine which protect us from disease, and the computers and telephones which keep us in touch with each other, are all products of the global scientific enterprise. Our everyday lives, society, industry and economy have all been impacted by science and will continue to be so in the future.

And there is no doubt that we will increasingly need science in the future to help us tackle the significant challenges to humankind in the coming decades. For example, by 2030 we can expect a billion more people to be on the planet, world food requirements will rise by 38%, world water demand will exceed supply by a gap of 40%, and world energy consumption is forecast to increase by 54%. These together amount to a "Perfect storm" and the power of science will have to be very effectively harnessed if we are to understand and reduce the impact of this storm. I want to consider two of these challenges in more detail, climate change and food security.

Climate change is happening. There is scientific consensus that temperatures increased around 0.7 – 0.8oC during the last century and that these changes are likely to be the result of human activity, including the effect of increased carbon dioxide concentration in the atmosphere. This warming is accompanied by increasing variability in weather patterns with greater chances of extreme weather taking place. Modelling of the earth's climate system is complex and difficult, but models have been developed which explain past changes of global temperature as a consequence of both human activity and natural variations. These models predict that global temperatures could rise by several degrees more over the next century if emissions of carbon dioxide due to human activity are not curbed.

Such temperature rises would have significant impact on the globe and human activity. Sea level rise, as a result of thermal expansion of the ocean, melting of ice caps and glaciers, would have serious effects on cities and populations around the world. Warming could lead to more floods, droughts, storms and changed seasonal growing conditions, all of which can affect agricultural productivity. Human, agricultural, animal and crop plant infectious diseases can also be expected to change. Air pollution is another factor particularly important in urban environments, which will be influenced by climate change.

These scenarios have major implications for science. Firstly, it is important to get the science of climate change right, particularly because this is an area of science which is experiencing very considerable political pressure. Views range from those that dismiss the problem to others that over-estimate the problem. There are supporters of both these extreme positions in the public sphere but it is the former arguments that have gained more traction. A feature of this controversy is that those who deny that there is a problem often seem to have political or ideological views that lead them to be unhappy with the actions to limit if global warming. These actions are likely to include measures such as greater concerted world action, curtailing the freedoms of individuals, companies and nations, and curbing some kinds of industrial activity, potentially risking economic growth. What appears to be happening is that the concerns of those worried about these types of action, have taken extreme scientific positions not supported by the majority of climate scientists.

Several other features have complicated the situation. One has been earlier failures of some climate scientists to be as open as they should in making all their data available. This has led some who deny there is a problem to claim that the climate scientists' data is wrong or has been manipulated. Another feature is the complexity of climate science which leads to uncertainties. In a world where people often want simple answers, uncertainty does not appeal. This allows space for poorly evidenced but confidently stated opinions, which are sometimes mixed with personal attacks and misrepresentations to attract public and political attention.

What can be learnt from the climate science and global warming controversy about giving scientific advice to society? It reinforces the importance of relying on the consensus view of expert scientists and the need to avoid the cherry picking of data and argument. But it also emphasises the need to keep the science as far as is possible from political, ideological and religious influence. I know that can be difficult, as after all, scientists are only human, but that is what good scientific analysis needs.

So what should scientists in China and the UK be doing about climate change? First we must support the highest quality research to understand climate better, continue to monitor the climate, deploy new technologies in monitoring, and develop better models for predicting future climate change and the impacts that will have on all aspects of human activity. Second we need research and innovation that will lead to technologies that can generate energy with less greenhouse gas production and can ameliorate the effects of climate change. This will require technological solutions to generate energy efficiently from renewable sources such as wind and solar, and from nuclear reactors, as well as carbon capture procedures. Third, it requires expert scientists to engage with the public and politicians about issues around climate change so the best scientific advice can be given, not tainted by those over influenced by political or ideological considerations.

Both the scientific and political contexts in China and the UK are encouraging for properly tackling climate change. There has been significant investment in climate change research in the last Chinese 5 year plan and there are a number of Chinese Academy of Science Institutes, Meteorological Administration Institutes and Universities carrying out relevant research. Similarly in the UK, the Hadley Centre at the Met Office and several universities and research centres are very active in climate science. In addition there are a number of formal partnerships between China and the UK, including intergovernmental projects on Adapting to Climate Change as well as collaborations between meteorological research organisations on extreme weather.

This year the Royal Society is initiating a policy project on ecosystem-based approaches to build resilience to climate change, and is preparing a joint statement on climate science with the US National Academy of Sciences, as well as a joint report with the same Academy on Integrated Assessment Models.

Politically the UK passed in 2008 an Act committing to cutting greenhouse gas emissions by 80% by 2050 and is developing new policies to encourage investment in decarbonisation. UK scientists were heavily involved in the IPCC's 5th Working Group 1 Assessment Report to be released later this year. China's current 5 year plan has a guiding philosophy of "Ecological Civilisation" which is influencing efforts to develop sustainably with due consideration of the environmental effects of growth. There is a joint 2013 statement between China and the EU on dialogue and co-operation on environmental policy and green growth, and a joint China-USA statement noting the "overwhelming scientific consensus about anthropogenic climate change and the need for large-scale co-operative action to contain climate change".

I personally strongly support these statements and the level of political commitment it implies. I also encourage closer working between the Chinese Academy of Sciences and the Royal Society in pursuit of the agenda of climate science. Our differing perspectives will help provide a broader view of this extremely important global challenge.

The second challenge I want to consider is Food Security. China currently has to feed 22% of the world's population and has just 9% of total arable land in the world, whilst the UK has to feed 0.9% of the population and has just 0.4% of the land. Therefore agricultural productivity in both our nations has to be efficient. Productivity needs to increase to feed the world's growing population and China has its own specific goal of increasing yields by 30-50% in the next 20 years. These hikes in productivity should be achieved whilst limiting environmental damage by not destroying natural habitats or depleting soils, and by controlling pollution of air and water. The situation is made more complex by climate change resulting in changed seasonal growing conditions, more extreme and variable weather, and changes in plants and animal pathogens, as well as by the greater demands being put on the world's water supply.

Dealing with this problem requires an integrated multi-faceted approach using sophisticated modelling to analyse agriculture as a complex ecosystem. The inputs and outputs of nutrients and water need to be well understood to optimise irrigation, drainage, and fertiliser use for example. New crop varieties and hybrids need to be developed to improve productivity, to reduce losses due to pathogens and to be able to utilise better more marginal agricultural land. These developments have to use all approaches possible, deploying new crop plants, improving crops used both locally as well as globally, using conventional plant breeding supplemented by new molecular biology techniques as well as transgenic genetic modifications.

The generation of genetically modified foods by the introduction of genes by genetic engineering has been controversial in some countries around the world, including in the UK. The consensus view of the majority of expert plant scientists is that in principle this is a safe approach and can lead to considerable benefits. These scientists would argue that precautionary checks need to focus on the trait introduced rather than the method by which it was introduced. New traits should be assessed on a case by case basis to determine safety and effectiveness, whether they were introduced by conventional breeding or by one of the increasing range of new techniques available.

In my view the key features of this controversy that need to be considered are peoples' sensitivities about what they eat, concerns about scientists manipulating nature, and worries about the influence of over bearing commercial interests. These have converged to generate deep suspicion amongst some of the public about GM foods.

Human beings have a tendency to be conservative, even fearful, about what their food contains. One anxiety frequently expressed during public consultation exercises over GM crops was a concern at "eating food containing genes". This was an issue a scientist was unlikely to have considered but was a perfectly reasonable one for a member of the public to express. This concern was exacerbated by newspaper headlines calling GM crops "Frankenstein Foods", conjuring up images of white coated scientists tampering with the purity of food. Another feature is that often those who object to GM have political or ideological opinions disliking the power wielded by powerful commercial corporations behind the manufacture of certain GM crops. These anti GM opinions have been adopted by some environmental NGOs who campaign against the issue of GM crops, even when their use is aimed at serving the public good such as reducing vitamin deficiency in children for example. For example, only recently golden rice trials have been trashed in the Philippines.

What can be learnt from the public debate concerning the use of GM crops? First, it is clear that there is a need to engage the public properly. Scientists have to listen to the public to be completely aware of their concerns and of the questions they want answered by the scientific advice. Scientists and single interest pressure groups are not always the best individuals to frame these questions. Second, is the need for high quality debate in the mass media. Scientists need to be part of this debate from the very beginning to ensure that it is based on evidence and rational argument rather than ideology or politics. Third, scientific advice is best delivered by scientists who are impartial, rather than those who may have other motives. This can be the case for a company trying to promote use of GM, or NGOs attacking GM crops who rely on the support of individuals ideologically opposed to such technologies.

China has been leading the way with integrated approaches to agricultural productivity and has increased cereal production by 32% between 2003 – 2011, more than double the world average. The Chinese government has recently tripled its investment in agricultural research involving 50 universities, 300 institutes and 200 companies, with research supported by the Chinese Academy of Sciences and the Ministry of Science and Technology. Some GM plants are already grown commercially in China, mostly Bt cotton. The UK has a long tradition of plant research, for example through the Botanic Gardens at Kew, the Institutes at Rothamsted and the John Innes at Norwich, and Universities such as Oxford, Cambridge and Nottingham. However, GM plants have not been introduced into agriculture despite the research strengths in this area in the UK.

Collaboration between China and the UK in the plant sciences and agriculture is good. The John Innes has over 100 alumni in China including academicians of the Chinese Academy of Sciences and these contacts are being further developed in the future with a planned joint Chinese Academy of Sciences – John Inness Centre of Excellence in China. Other linkages between Chinese and UK universities are currently being formed.

The Chinese Ministry of Science and Technology and UK Research Councils are also developing a number of joint collaborative projects. These contacts are to be greatly welcomed because we have much to learn from each other.

I want to finish my lecture where I began, to celebrate the collaborations between Chinese and UK scientists and to develop these in the future. I will shortly be meeting with President Bai, and hope to sign a joint statement about working together to advance science and to identify sustainable solutions to the world's problems. And we need to work with the public and policy makers too. By working together we bring together different skills, knowledge and perspectives and we will be more effective and efficient as a consequence.

I have already mentioned that the Royal Society has been working with China for much of its history from the eighteenth century onwards. On this 50th Anniversary trip of the Royal Society to China we should celebrate all that has been achieved already.

But we cannot rest on our laurels. When Premier Wen visited the Royal Society in London in 2011, he closed his speech "the Path to China's future" with a quote from Francis Bacon: "A wise man will make more opportunities than he finds." As the Premier said, "the Chinese and British people, with vision and creativity, can certainly create more opportunities and lift our cooperation to a new level."

I hope we can find new ways and support for closer working between Chinese and UK scientists. We need to up our tempo to persuade our governments to increase their funding for closer working. We need to have more young Chinese researchers working in the UK and more young UK researchers working in China.

We need to promote collaborations not only academic ones but with industry too. We need to build trust and mutual respect between our scientists and our two nations. There is much more we can do.

Let us build on our mutual proud heritages in science and work together to advance science and the contributions science can make to our cultures and civilisation and to improving the lot of humankind not only in our two countries but throughout the world.