HOUSE OF COMMONS

Science and Technology Committee

Oral evidence: My Science Inquiry, HC 859

Wednesday 1 February 2017

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Watch the meeting

Members present: Stephen Metcalfe (Chair); Victoria Borwick; Chris Green; Dr Tania Mathias; Carol Monaghan; Derek Thomas.

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Witnesses

I: Sandy Starr, Communications Officer, Progress Educational Trust.

II: Bob Ward, Policy and Communications Director, Grantham Research Institute on Climate Change and the Environment.

III: Amanda Lyne, Chair, UK Hydrogen and Fuel Cell Association.

IV: Dr Bryn Jones.

V: Dr Stephanie Mathisen, Sense about Science.

VI: Professor John Finney, British Pugwash Group.

VII: Professor Shahin Rahimifard, Professor of Sustainable Engineering, Loughborough University.

VIII: Dr Michael Brand, Sensor100.

IX: Professor Becky Parker MBE, Institute for Research in Schools.

Written evidence from witnesses:

- Progress Educational Trust
- Grantham Research Institute on Climate Change and the Environment
- UK Hydrogen and Fuel Cell Association
- Dr Bryn Jones
- British Pugwash Group
- Centre for SMART, Loughborough University
- Sensor100

– Institute for Research in Schools

Examination of witness

Witness: Sandy Starr.

Q1 **Chair:** Good morning, everyone. Welcome, and thank you for taking time to join us for My Science Inquiry. Time is tight, so I am going to call our first presenter, Sandy Starr. Please come forward and take the podium. Sandy is from the Progress Educational Trust and is going to talk to us about human embryo research. Sandy, you have 10 minutes; thank you.

Sandy Starr: Research using human embryos can only be conducted legally in the UK with a licence from the regulator—the Human Fertilisation and Embryology Authority—but even a licensed researcher will be in breach of the law if they do one of the following two things: if they keep a human embryo alive in the laboratory for more than 14 days; or if they keep a human embryo alive in the laboratory after observing the appearance of a feature called the primitive streak. These stipulations are often referred to by the shorthand "the 14-day rule."

The charity I work for—the Progress Educational Trust—believes that, in light of recent developments and current debates, the time is right for this Committee to conduct an inquiry into whether there is a case for extending the 14-day rule.

The idea of a 14-day rule was first proposed in 1979 by the ethics advisory board of the USA's Department of Health, Education, and Welfare. The idea was then proposed in the UK in the 1984 Warnock report, which was commissioned by the UK Government and written by a committee led by Mary Warnock, now Baroness Warnock, the patron of our charity. The rule was brought into law with the Human Fertilisation and Embryology Act 1990 and has since been emulated in various countries around the world.

The reason 14 days was chosen by the Warnock committee was because it corresponded roughly with—in fact, it slightly preceded—the expected appearance of the primitive streak. The primitive streak represents the earliest beginnings of the symmetry of the eventual human organism. It does not represent, as is often misleadingly suggested, the beginnings of the spinal cord or the nervous system. Rather, it represents the beginning of a process that sees part of the embryo divided into three layers of cells, and it is out of one of these three layers that the beginnings of the nervous system, including the beginnings of the spinal cord, will eventually emerge.

It has long been possible to keep the cells of a human embryo alive for a continuous extended period—in other words, to culture an embryo—in the laboratory while it loses what coherence and structure it has and loses any prospect of the primitive streak appearing. Indeed, the British IVF pioneer and future Nobel laureate Professor Robert Edwards described doing precisely this for a period of 13 days in a paper that was published before the Warnock report, but what no researcher was able to do was

keep a human embryo alive in the laboratory while having the embryo retain its emerging coherence and structure for much longer than a week, which is approaching the point when the embryo would normally implant in the lining of the uterus.

However, in May 2016, the Cambridge-based researcher Professor Magdalena Zernicka-Goetz published two papers explaining how she and her colleagues had succeeded in keeping human embryos alive in the laboratory for 13 days by culturing them in specially devised conditions. Embryos still alive at 13 days were destroyed so as not to be in breach of the law. Whether or not the conditions devised could support the life of an embryo beyond 14 days or whether that would require further innovation is, as yet, unknown.

To say that this achievement has had a significant impact would be an understatement. Since May last year, there has been continuous high-profile debate and discussion in both specialist and lay circles about the discoveries that could be made and the benefits that might accrue to science and medicine if human embryos were developed beyond 14 days. The third and fourth weeks of embryo development are part of a period known as the black box, because up until now there has been little or no opportunity for direct observation of the developing embryo during this period. It is a period in which crucial but poorly understood events in the development of the embryo can go awry, leading to loss or disorders of pregnancy, or causing or contributing to congenital disease in a resulting child, or perhaps even diseases that arise later in life.

A number of researchers and clinicians are arguing that by studying embryo development in the third and fourth weeks in the laboratory—by looking into this black box—they could unravel some of these mysteries, better treat or avoid disease and improve IVF success rates. This is an exciting prospect both scientifically and ethically, but it also raises ethical concerns and, from some quarters, strong ethical objections, and these have been very much a part of the debate that has taken place since these papers by Professor Zernicka-Goetz and colleagues were published in May 2016. Consequently, there is already a rich body of material that an inquiry on this subject could draw upon and a rich variety of experts and stakeholders from various disciplines whom this Committee could approach for evidence on this topic.

Our own charity, the Progress Educational Trust, recently held a major conference on the science and ethics of this issue where speakers included Baroness Warnock and Professor Zernicka-Goetz.

The Nuffield Council on Bioethics has also held a recent discussion of the issue, and a report of those proceedings is due to be published imminently.

The issue has been widely discussed everywhere from *Science* magazine to *The Sun* newspaper. Professor Zernicka-Goetz's studies won in the people's choice category of *Science* magazine 2016 Breakthrough of the

Year, voted for by the readers of that magazine. To give some perspective, the runner-up in the people's choice category was the first ever observation of gravitational waves.

Only last month, BBC Radio 4 broadcast a two-part documentary on the issue, entitled "Revisiting the 14-Day Rule." The BBC commissioned an opinion poll by YouGov to accompany its documentary, asking the general public whether they would support a revision of the 14-day rule and, if so, what sort of revision they might support. The polls showed that almost half the British public—48%—would support a doubling of the 14-day limit to 28 days; 19% think the limit should remain at 14 days; 10% would like human embryo research to be prohibited entirely; and 23% are unsure of where they stand on the issue.

In conclusion, the UK has long been a world leader, not only of the science of embryo research and the practice of fertility treatment but of public debate, ethical and legal consideration, and progressive but careful and trusted regulation of these fields.

Our charity believes this is a tradition worth upholding and a reputation worth maintaining. This is why we are asking this Committee to examine the issue of the 14-day rule now. The issue falls very much within the remit of this Committee, and we believe an inquiry into the matter would be both timely and constructive. Thank you.

Chair: Thank you very much for your informative and timely presentation; excellent.

Q2 **Dr Mathias:** That was brilliant and really clear. Thank you so much. My only question is: do you think, if we were to scrutinise this, it would be useful for us to get information from other countries where they go beyond the 14 days?

Sandy Starr: Yes, I do think that would be useful. This is a debate that is taking place internationally. Harvard University held a conference on it in November. A law lecturer in Australia, Patrick Foong, has just issued a call for debate about the rule to begin in earnest there. There are at least 11 countries besides the UK that have some version of the 14-day rule written in their laws. A further five countries have a version written into their national scientific guidelines, and the rule is promulgated through some international guidelines as well. The key thing to understand is that Professor Zernicka-Goetz's papers mean that viable protocols for developing a human embryo up to and possibly beyond 14 days are now publicly available to any researcher in the world who wishes to try.

Q3 **Chair:** Thank you very much. In terms of the scale of the inquiry that we might conduct, are you suggesting that we as a Committee should look at examining the 14 days and make a recommendation to extend it perhaps to 28, or are you suggesting that we look at whether the time is right for the science around that issue to be handed to an independent inquiry to come up with the final answer, if you see the subtle difference?

Sandy Starr: Yes. I do not know if this helps answer your question, but there is a useful precedent for this in the recent examination of the issue of mitochondrial donation, in that an inquiry by this Committee could form the initial basis for a public consultation exercise by the Human Fertilisation and Embryology Authority. The chair and the director of strategy of that regulator were interviewed in the Radio 4 programme and indicated that they think it would be appropriate to conduct such an exercise if they were asked to by Parliament or Government.

Chair: Fantastic. Thank you very much indeed. Are there any other comments from colleagues? No. In which case, thank you very much for your very clear and precise presentation; it was very informative.

Examination of witness

Witness: Bob Ward.

Q4 **Chair:** We will move on to our second presentation, which is on the use of evidence by the Cabinet Office. Bob Ward is going to talk to us. He is from the Grantham Research Institute on Climate Change and the Environment. Bob, you have 10 minutes.

Bob Ward: Thank you very much, Chair, and good morning. I am here today to make a case for the Committee carrying out an inquiry into the use of evidence by the Cabinet Office. I am grateful to the Committee for allowing me this opportunity to make the case.

The Cabinet Office describes its role as supporting the Prime Minister and ensuring the effective running of government; its responsibilities include supporting collective government and helping to ensure the effective development, co-ordination and implementation of policy. The Cabinet Office, with about 2,000 staff, is unlike most Government Departments in that it does not have sole responsibility for a major area of public policy but does play an important role in devising and delivering policies, particularly those that relate to more than one Department. However, recent experience indicates that the Cabinet Office currently has a problem with the use of evidence, particularly scientific evidence.

I believe that the Select Committee is uniquely placed to carry out an inquiry into how the Cabinet Office currently uses evidence, and to make effective recommendations to improve its operations. Two examples illustrate the problem at the Cabinet Office.

On 6 February 2016, the Cabinet Office issued a press release announcing that a new clause would be inserted into all new Government grant agreements from May 2016. The clause was: "The following costs are not Eligible Expenditure: Payments that support activity intended to influence or attempt to influence Parliament, government or political parties, or attempting to influence the awarding or renewal of contracts and grants, or attempting to influence legislative or regulatory action."

However, the Cabinet Office soon faced a backlash, particularly from university scientists, when it became apparent that this draconian new rule would affect, for instance, researchers with grants from research councils and the Higher Education Funding Council for England. The rule could have, in theory, stopped researchers from using Government grants, for instance, to give evidence to parliamentary committees like yourselves if there was a danger that it might influence policy. The backlash included an official petition with more than 30,000 signatures, which eventually forced the Cabinet Office to withdraw the new rule.

However, there are still questions over how the Cabinet Office came to draft such a rule in the first place. Did it, for instance, consult the chief scientific adviser or the Minister for Science about its potential impact? It is not clear. Extraordinarily, the Cabinet Office's original press release only cited a highly controversial pamphlet from the Institute of Economic Affairs called "The Sock Doctrine - What can be done about state-funded political activism?" The Institute of Economic Affairs is not an academic institution, and its website states that its role is to "promote the intellectual case for a free economy, low taxes, freedom in education, health and welfare and lower levels of regulation."

The Cabinet Office is, of course, entitled to consider evidence from any source, even a free-market lobby group that campaigned, for instance, to stop anti-smoking groups from using Government money to recommend policies to cut lung cancer and other diseases. But how many, if any, other external groups did the Cabinet Office consult? Did it consult, for instance, the Royal Society, or was the Cabinet Office only interested in receiving evidence from an organisation with which Ministers felt politically aligned, rather than from organisations that offered robust evidence, no matter how politically inconvenient?

While the Cabinet Office has subsequently produced a heavily revised version of the rule, which will not deprive policy makers of advice and guidance from Government-funded scientists, it is not clear that it has scrutinised its own processes to learn lessons from its aborted initial launch. The scrutiny from the House of Commons Science and Technology Committee could help Ministers and senior officials in the Cabinet Office to reflect on this sorry episode and to identify ways to prevent any similar mistakes in the future.

The second example is the National Flood Resilience Review, which was announced in January 2016 and chaired by the Chancellor of the Duchy of Lancaster, Oliver Letwin. As part of the evidence-gathering for the review, I attended a meeting of experts in March 2016 at the Cabinet Office, which was chaired by Mr Letwin and attended by members of the review team from the Cabinet Office and the Department for Environment, Food and Rural Affairs. It became apparent during the meeting that the review was not going to consider the risk from surface water flooding, which was extremely surprising, since the review's terms of reference stated that it would "carry out a new assessment of the

damage that extreme rainfall could cause across England." Mr Letwin said that it was not being considered because the most recent flooding event in winter 2015/16 had mainly arisen from rivers.

Several experts told Mr Letwin that surface water flooding threatens more properties than either river or coastal flooding, and that in cities like London it could pose a real threat to life, particularly for people living in basement flats. It is not clear why the review team from the Cabinet Office and DEFRA ignored the advice of experts, and no justification was offered in the review's final report in September 2016. While the Government's chief scientific adviser, Sir Mark Walport, was clearly involved in some aspects of the review, he did not attend the meeting with experts. This highlights one of the central issues that the Committee could explore.

The Cabinet Office, unlike other Government Departments, does not have a dedicated chief scientific adviser, so how can it benefit from the services of the Government network of chief scientific advisers? Perhaps it is time for the Cabinet Office to have its own chief scientific adviser, or at least for the Government's chief scientific adviser to have the Cabinet Office explicitly included among their responsibilities.

Of course questions about the Cabinet Office and scientific advice are not new. Indeed, a previous inquiry by this Committee in 2011 examined scientific advice and evidence in emergencies. Among its many recommendations was that the Government Office for Science, while remaining a semi-autonomous body, should be located within the Cabinet Office on the grounds that both "have cross-departmental remits and a shared aim of helping departments improve their policy processes." The Government rejected this recommendation, claiming, "We believe that the Government Office for Science location in" the Department for Business Innovation and Skills "does not inhibit close and effective cooperation between the staff of the" Government chief scientific adviser "and the Cabinet Office."

Much of the output from the Government Office for Science is excellent. For instance, in February 2015 it published "Chief Scientific Advisers and their officials: an introduction." It states: "Departments are expected to produce and publish high quality science, research, and evidence strategies that link science to departmental objectives, and on which plans for future research investment should be based." The Cabinet Office does not appear to have such a strategy. The Committee would be well placed to explore whether it is time that the Cabinet Office did indeed have a science, research and evidence strategy.

The document published by the Government Office for Science also devotes an annexe to "Developing a Science and Evidence Strategy." It also has an annexe on "Science Assurance," which raises important questions such as, "Does your department have processes in place to ensure that science and engineering are embedded into policy making

and that this evidence is robust, relevant and high quality?" It seems from the examples I have given today that science assurance in the Cabinet Office needs to be improved.

In summary, the Cabinet Office plays an important role in devising and delivering Government policy, but recent events suggest it may not be making the best use of evidence, including scientific evidence. An inquiry by the House of Commons Science and Technology Committee could help the Cabinet Office to re-examine its processes and improve its operations. As part of an inquiry, the Committee could take evidence from current and past Ministers and senior officials, and help to spotlight the reasons for recent failures. In doing so, the Committee would be helping to fulfil its role in ensuring that Government policy and decision making are based on good scientific and engineering advice and evidence. Thank you.

Chair: Thank you very much. You have made a very clear point, and a very valid one as well, I think.

Q5 **Chris Green:** There is no one here from the Cabinet Office to defend the position and evidence that they took. Could this be typecast as "Organisations that do not like the results or remit of an inquiry or report will challenge the result, and the basis for it"? How do you argue against that?

Bob Ward: I do not think so. The Cabinet Office admitted that it had got the rule wrong in the first place, withdrew it and had to redraft it. It seems clear that they did not consult widely and ended up with a bad rule.

Q6 **Chris Green:** In that sense, there was a revising process; they changed and improved.

Bob Ward: The change improved, but it caused an enormous amount of unhappiness among researchers, who, for instance, have had a great deal of pressure put on them recently to engage more with parliamentary processes, and here was a rule that was apparently telling them not to do it because there was a danger that they would have their funding withdrawn because of lobbying.

Q7 **Chris Green:** But the concerns at the beginning quite often were consultations. People do not like the remit of the initial consultation; there is a big discussion—a big argument—and then the results are actually reasonably close to what most people have accepted as fair.

Bob Ward: It depends on your point of view as to whether the point of a Government Department is to put a badly drafted rule out there, wait until somebody kicks up a fuss and then withdraw it and have to redraft it, or to go through the proper process of consultation to start with and make sure that the rule is properly drafted when they produce it.

On the national flood resilience review, the consequences are coming down the road. The Government have excluded the largest cause or threat of flooding from its national flood resilience review, and we will see in the next big flood event whether that was sensible or not. Remember, the biggest flood event, the one that caused the most economic damage, was in the summer of 2007, and that was primarily surface water flooding in cities. There is no excuse for leaving it out just because your last particular crisis happened to be something else.

Q8 **Chair:** Thank you very much. Obviously, you are suggesting that we launch an inquiry into how the Cabinet Office uses scientific evidence. Why limit it to the Cabinet Office, as opposed to other Departments that do not have a chief scientific adviser?

Bob Ward: There have been a number of inquiries into the chief scientific advisory system and the use of scientific advice, and that would be useful, but this is a targeted thing that you could do in a fixed amount of time with a limited number of people, and it would target a specific problem. It would make best use of your valuable time in achieving a targeted objective.

Chair: Bob Ward, thank you very much indeed for your submissions. We are keeping to time, which is excellent.

Examination of witness

Witness: Amanda Lyne.

Q9 **Chair:** Next, I invite Amanda Lyne to join us from the UK Hydrogen and Fuel Cell Association, who is going to talk to us about the role of hydrogen and fuel cells in a holistic energy system. Amanda, the floor is yours.

Amanda Lyne: Thank you very much for inviting us to present our case. To introduce the UK Hydrogen and Fuel Cell Association, we are an industry association largely made up of SMEs, academics or small departments of large corporates. We include companies and stakeholders that are making, using or researching hydrogen as a clean energy vector, and/or companies and stakeholders involved in deploying and researching fuel cell technology as ultra-efficient routes to electricity and heat generation or ultra-low emission transport. Our activities are particularly targeted at advocacy and supporting members to develop markets for these low-carbon, low-emission technologies.

We believe that hydrogen is important because the way we do energy is changing. In fact, many people describe it not just as a transformation but an actual revolution. A cost-effective decarbonised energy system will need to balance the energy requirements of very different sectors—electricity, heat and transport—in a world where decisions and energy itself will be democratised and valued differently across industry, consumers, the Government and global trading partners. This future

energy system, and particularly the interconnections between heat, power and transport, is a nationally significant issue. Failure to carefully plan the development of the whole energy system will result, at best, in huge increases in cost and/or, at worst, complete failure to deliver. Our policies, evidence base and regulations need to revolutionise now, as many of our current policy decisions and choices will and already have an impact on our costs today and on the future system.

We believe a decarbonised energy system will be cheaper with hydrogen than without it, because hydrogen is an energy vector that has the capability to make the connections across all the energy sectors—heat, transport and power—and, for instance, it could help us address the energy storage challenge from intermittent electricity from renewables, maybe when we are copper-constrained or we want storage greater than half an hour, or even seasonally adjusted. It creates flexibility in the overall energy system, and it has potential to address low-carbon energy for transport, particularly for long journeys or commercial vehicles. It is our belief that it can do all the above at better value or with less compromise than would be afforded by batteries and electricity alone.

We believe that a Science and Technology Committee inquiry in this area would deliver the evidence base for valuing the cost-effective part of our proposition. It will have impact across a range of policy objectives, including carbon reduction, enhanced air quality, energy security and resilience. It will enhance the UK's potential for the future energy system to be optimised and therefore become affordable, and create a set of clearly defined actions for relevant Government Departments and the routes through which they could realise the value from them.

Fundamental to the delivery of a successful inquiry would be supporting and encouraging joined-up Government thinking. An inquiry will synchronise thinking, planning and policy across a range of Departments. I have already mentioned the policy areas. For instance, the recently published BEIS and Ofgem call for evidence is an example where, notwithstanding the title "A smart, flexible energy system", the actual focus of the consultation was purely on electricity, with no consideration of the opportunities across the wider energy system. Failure to carefully plan and deliver the development of a whole energy system will result at best in huge cost increases, or at worst complete failure to deliver. The Science and Technology Committee is well placed to look at this, because where else is it possible to work across such diverse sectors and Departments? We firmly believe that the answers on costs will come at the overlap, and this needs a wide perspective.

Optimising requires innovative thinking, and as a disruptive approach, where today's evidence base is slim and the answers are complicated, science ought to be able to help. It needs a long-term view, and at present policy decision making fails to take account of the connections across energy systems, and, more particularly for us, the role that hydrogen and fuel cell technology will make in this.

It is needed now, because decisions are being made now, and at least need to be started now to be able to deliver 2030 and 2050 targets. The recent industrial strategy Green Paper stresses the need to deliver affordable energy and clean growth. The evidence for how hydrogen and fuel cell technology can help deliver this is not yet prioritised and could play a critical role in addressing issues such as the increasing concerns of industry in the cost of electricity infrastructure and/or the behavioural changes needed to embrace electric vehicles only. The Committee would have the opportunity to capitalise on various industrial and academic studies recently published to highlight the role of hydrogen and fuel cell technology, such as the H21 study that looked at hydrogen for heat, showing how we could use existing and recent investments in the gas grid to help provide a future energy storage solution, or recent investments in academic studies, or in fact the wide-ranging UK road map, in which our industry association and the Scottish association were active participators.

The Committee could seek evidence in this inquiry from a broad spectrum of stakeholders: as I mentioned, academic groups, such as the Supergen EPSRC-funded group, who are about to publish three reports; the trade associations; ourselves; plus the Renewable Energy Association and a whole variety of energy-related organisations; a number of think-thanks, whether that is the CCC or the Energy Technologies Institute; and a range of companies across the energy landscape and our industrial heartlands, including utilities, specialist technology providers, and representatives from power, heat and transport supply chains.

In conclusion, we believe that the Committee is best placed to lead this inquiry. This is an opportunity to put all the current knowledge and thinking in one place, so that it can inform all parts of Government. The most important thing is that, in the long run, there is huge financial value to the UK in getting this right. Thank you.

Q10 **Chair:** Thank you very much indeed for your very clear, insightful presentation. Do colleagues have any questions? You mentioned the road map. Just over a year ago, E4tech produced a hydrogen and fuel cell road map. What do you think our inquiry would add to that? That was commissioned by Innovate UK and DECC, I think.

Amanda Lyne: Yes. Therein lies the point: it was commissioned by Innovate UK, and DECC specifically was involved for a very tight part of the remit. It involved Transport Scotland, Scottish Enterprise and a whole variety of other organisations. To coin their phrase, our phrase and/or the phrase of the Government representatives who were involved, we think the road map tells you how, but it does not tell you why. We still see—it is quite understandable—that there are lots of different lobbies and different advocacies for different parts of the energy system. We are trying to say that hydrogen goes across the board, but we want to see more progress in the acceptance of why we would do hydrogen across the system.

Chair: Thank you.

Q11 **Chris Green:** There is an enormous possibility in terms of a healthier and cleaner environment, but something the Government would be thinking of is energy security, which you touched upon. Where would be the source of the hydrogen? Where would we manufacture the hydrogen, and would that be a secure location?

Amanda Lyne: The beauty of hydrogen is that you can make it from lots of different places, and in fact in Canada they can make it from nuclear. It absolutely helps to provide the breadth of security that you might want. It will be split across the country in different places, rather than necessarily in centralised locations, or we may have some major strategic places where we produce hydrogen as well.

Q12 **Chris Green:** Is that around the world or in the UK?

Amanda Lyne: In the UK. That is the point. It is a way of us making our own fuel. I have a great example: we are doing a project with a farmer in Cheshire who has renewables, and we have connected the system up. It is an Innovate UK-supported project. He is making his own fuel from the renewables and the hydrogen on site. It is a way of us, as the whole of the UK, being able to become more resilient.

Victoria Borwick: Excuse my terrible cold. What is interesting is that it is slightly cross-cutting and brings forward something that people know something about, but perhaps not a great deal. It is an opportunity for being a bit innovative, which I think is interesting here, because often it is very particular. Where we always have a problem is when we have more than one Government Department involved, but it is true that unless we think a bit out of the box, we are not going to make progress.

Chair: Absolutely. You have given us something to think about; that was very interesting. Thank you very much indeed for coming before us.

Examination of witness

Witness: Dr Bryn Jones.

Q13 **Chair:** We will move swiftly on and invite Dr Bryn Jones to take the podium. He wants to talk to us about scientific research careers in UK universities. I believe you are doing this in an individual capacity, rather than representing any particular organisation. The floor is yours for 10 minutes.

Dr Jones: Thank you very much. I am Bryn Jones and I am here to suggest that you hold an inquiry at some time into scientific research careers in British universities.

As you know, research careers and the research output of post-doctoral scientists in universities is of critical importance to the United Kingdom's scientific output, to the activities that are done in basic science and in

many branches of applied science. However, I contend that there are significant problems within the career system, and these are characterised by, for example, career instability for individual scientists. There is an over-competitiveness within the system, and there is a need to leave university research careers for a majority of people within the system.

The Committee held inquiries into short-term contracts in science and engineering about 15 years ago, and it held an inquiry into women in scientific careers about three years ago, but you have not held an inquiry into broader issues concerning careers for scientists within British universities.

Perhaps I can summarise what I am talking about. I am talking here about post-doctoral research assistants, post-doctoral research associates and research fellows. These are people who will all have completed a PhD within the British university system. They have done the three years of funded research as post-graduate research students, and have been awarded PhDs so have deep experience within some field.

These post-doctoral research assistants tend to be on fixed-term contracts. They are funded by grants that come primarily from the research councils, although some other funding is available—for example, in the medical field, from charities. Some of these are on rolling grants, which give them an element of continuity. There are some fellowships available, but these are very competitive to apply for, and there are some restrictions on who can apply for various types of fellowships. There are some three-year more junior fellowships, and there are five-year fellowships that allow a person to become established within academia, to go on to an academic career. In many fields, the only permanent long-term jobs are as academics—that is to say, lecturers, readers, professors and what have you. In many fields, those are the only permanent positions, although some fields also have research institutes.

I contend that there are problems. There is a strong imbalance in the number of post-doctoral research assistants to the long-term academic positions available. I would argue it is several to one; that is to say, you have several post-doctoral scientists for every one academic position that can come up within British universities, which means that a majority are going to have to leave academic research and move to research in industry, or into business or the public sector, or leave science altogether.

In my old field, I estimate, going through figures, that there are only enough academic positions for about one in five of the research assistants, and therefore four out of five, roughly, will have to leave. Pressure in this comes from the considerable number of PhD studentships that are provided compared with the number of long-term academic positions. It is about a 10:1 to 20:1 imbalance, but there are good

reasons for that. We do want to train lots of people to PhD standard to go out into the wider world, but there is a severe imbalance in the numbers.

There are hierarchical structures in academia. These are imposed by attitudes within universities and by policies of research councils. That gives a lack of freedom for some research assistants to carry out the research that they might think is best carried out, or to choose the methods to carry out research projects that they are working on.

There are some project support roles, and people in those project research roles can produce fewer publications because their time goes on supporting, for example, computing activities, so they do not get the publications that enable them to compete for academic positions later on. There is also an over-emphasis on short-term contracts. We have people predominantly on three-year contracts. Some of them can be rolled on beyond that.

There is an ageism in the system, in that the post-doctoral research assistant contracts tend to be seen mostly as junior roles and tend not to be given to people in their middle career or more mature researchers. Researchers will commonly take one, two or three research assistant contracts of three years' duration. A minority of those will be able to get fellowships and move on to academic positions. The majority have to leave academia for industry, business or the public sector.

Another significant problem is that there is very little subject-specific support for academic scientists to make a transition to industry or business; that is to say, careers advice that is subject-specific is very limited.

There are consequences. I would argue that these issues lead to an inefficiency within the research community. Research projects have to be abandoned sometimes when short-term contracts expire. There is an importance of luck and patronage in establishing academic careers—for example, to support fellowship applications or to release funds to attend conferences. There tends to be preferential support for certain people, which can introduce biases, unconscious or even conscious; for example, it can lead to the under-representation of certain sectors, such as women, ethnic minorities or people from non-traditional backgrounds. There is disruption to personal lives as people move every few years to take up new contracts in new locations.

There is a loss of talent from the academic system. Universities lose talented people because they move on to other fields and they are often lost from science altogether. There tends to be a culture of pessimism among the research community, and I would say that many research assistants are demoralised; there is a demoralised community out there.

I am also concerned that, were this situation to become widely known, it could deter people from applying for PhD studentships, leading to a decline in the quality of the PhD student body, which will have an impact

on the supply of talented people in the future.I think this is relevant to the Committee because lots of these problems are determined by research council policies, and therefore they are of concern to you.

A majority of the PhD studentships are funded by research councils, as are research assistantships, and the majority of research fellowships also are funded by research councils. The conditions that post-doctoral research assistants work under are determined quite considerably by research councils, plus the universities they work in.

If you take up this suggestion, you need to take evidence from post-doctoral research assistants themselves, if you can get them to come forward; from research fellows, if they are willing to speak out; from universities; from research councils, including the chief executives; and at ministerial level. There are a number of questions you can ask, such as: is the imbalance of PhD studentships to long-term posts correct, or is it too extreme? Is there a mismatch between the policies of research councils that fund primarily the positions of early career researchers and the Higher Education Funding Council for England, which puts research funds into supporting middle and later-career academics? What is the source of the imbalance in the ratio of PhD post-doctoral research assistants to long-term academic positions? Is the origin the research councils, the Department for Business, Energy and Industrial Strategy, or the Treasury?

I am proposing that you hold an inquiry into scientific research careers in universities because there are significant career problems, you have not done it before, and I do not think anyone else is likely to do it. This is the elephant in the room of British science. There is a loss of talent from the university system, and, above all, it is unfair on the individuals within the system—the post-doctoral research assistants and fellows. Therefore, it is your opportunity to do this, your responsibility and your duty. I will stop there.

Chair: Thank you very much indeed. That was bang on your 10 minutes; I am very impressed.

Q14 **Derek Thomas:** Thank you very much. You have very clearly set out the problem. Would you recognise that students are deterred, because of this problem that you have highlighted, from applying to do a PhD?

Dr Jones: Some are, but there is still a very good supply of quite talented PhD students—that is to say, graduates who apply for PhD studentships. We are still seeing them come forward. There is a considerable ignorance among the student and therefore the graduate population about the academic career problems. Many people who start PhDs are a bit shocked when they find out that there is perhaps, I would say, a 5% or 10% chance that they can carry on to an academic career. They find out probably too late. I would argue that there is a vulnerability to post-docs getting their act together—post-doctoral research assistants arguing their case.

Q15 **Derek Thomas:** Speaking for myself, I would want to see a smooth transition into other careers, as you have highlighted a problem with that. But if you were to achieve a situation where someone could stay with the university much longer and make it their career, would that reduce the opportunity for postgraduates to take up PhDs? Do we need that natural progression into other jobs in order to create the space for others to come behind?

Dr Jones: The way the system works is that large numbers of people have to leave. If we are talking about our PhD studentships—people who obtain PhDs—we are talking about 95%, or certainly 90% of them, not staying on in the very long term through to retirement in the university system. That is how extreme the situation is. We need that—we need to produce lots of PhDs—but my contention is that it is too extreme. I would be happy if it was 70% or 80%, not 90% or 95%.

Q16 **Carol Monaghan:** I have a very quick question. Are there other countries that we should be looking at that have a different system?

Dr Jones: That is a good question, because there are problems of this type—perhaps not as extreme—quite widely across the western world. I can remember seeing reports several years ago that in the United States, a person completing a PhD who was really quite good and committed to staying in academia could do that. The situation in the United States was said to be very different from Britain, but things have declined in the United States. There are problems quite widely across European countries. I do not know where the problem originated, but we were certainly, here in Britain, the first to start on this process of producing very large numbers of PhD studentships and therefore a post-doctoral research assistant population who could not continue, even a substantial minority of them, in the long term. It is quite a wide problem, and it is true quite widely across Europe, but that does not mean that we do not have the responsibility to fix things in this country.

Chair: Thank you very much indeed, Dr Bryn Jones. We will consider your request and see if we think an inquiry would lead to just an identification of the problem, or whether we could find potential solutions. Thank you for that.

Examination of witness

Witness: Dr Stephanie Mathisen.

Q17 **Chair:** I now invite Stephanie Mathisen to take the stand from Sense about Science, who is going to talk to us about algorithms. Stephanie, 10 minutes.

Dr Mathisen: Hi. Thank you very much for inviting me to elaborate on my suggestion. I called my proposal "Algorithms," but I want to clarify what I think you should look into.

The term algorithm just means a set of instructions carried out by a computer to achieve an outcome set by the algorithm's creator. A cake recipe is a pretty good analogy. You have to take specific ingredients, mix them in the right order, in the right way, and then bake them at a particular temperature for a specific length of time, and hopefully you will get an edible cake.

Algorithms are everywhere and are not in themselves good or bad. I bet you do not realise that they run cash machines and place mobile phone calls, automating many steps that most people do not even contemplate. Algorithms can analyse huge amounts of data, measuring many things. They conduct complicated calculations that individual humans just could not manage. What is more, they do it quickly and cheaply; they are efficient.

However, I think the Committee should investigate the use of algorithms in decision making. Quite rapidly, and without debate, algorithms have come to replace humans in making decisions that affect many aspects of our lives. Of course, manual decision procedures would have existed before the use of a computer. What is different about computer algorithms is their sheer scale and complexity—in many cases, their lack of transparency.

Algorithms are used to inform, and sometimes automate entirely, a huge range of decisions that really impact on people's lives. For instance, local authorities are facing deep funding cuts of around 25%. This means they have to make difficult decisions about which services they can provide among those that people need and want in order to balance the books. In education, algorithms have been used to rate teaching performance and sack underperforming teachers. They are used to provide sentencing guidelines in criminal justice systems and to determine credit scores, which in turn control whether you can get a loan, a mortgage or a credit card, and in some cases even a job. You probably know you have a credit score, but do you have any idea how it is calculated?

Algorithms help GDS work out what it should make available on the new GOV.UK website, and the recent GO-Science report on artificial intelligence suggests that the Government might use them to decide how to deploy resources for health, social care and emergency services.

Let us take one of those examples. Surely it is better to decide which teachers are underperforming, and therefore remove them from the system, using a formula, not someone's biased assessment. That is what happened in the Washington school district in the US. Teachers were ranked largely on the basis of test scores between years, and at the end of the 2009-10 school year, those in the bottom 2% were fired. A further 5%—or 206 "bad" teachers—lost their jobs the following year. Getting rid of underperforming teachers frees up resources to employ new, better teachers, so it can only be a good thing, right? But what if they were not bad teachers? What if the formula did not get it right, and how did it

make that decision anyway? It is essential to Government, to Parliament and to the public that we understand how decisions about our lives are being made. Without knowing that, we cannot know whether those decisions are the right ones. Algorithm-supported systems can and do make bad decisions that seriously impact people's lives, and there are some serious issues with algorithms. Here are half a dozen.

Algorithms are often totally opaque. That makes them unchallengeable. If we do not know exactly how they arrive at decisions, what data has been analysed and how it was factored in, how can people who feel that they have been treated unfairly challenge them? Furthermore, there are things that cannot be measured with numbers, or at least not measured well, such as how much a teacher engages their students or helps them with family or personal problems. That means the use of proxies, or that those factors are not considered at all. Often, these systems never learn when they were wrong because there is no effective challenge and feedback.

Algorithms or formulae in decision-making processes are seen to be objective. Being objective is a good thing, but that notion can engender some abdication of responsibility. There is a perception that algorithms are unbiased, but they are only as unbiased as the people who create them. They contain the values and opinions of their creators, which data to include and exclude, and how to weight each component. How good they are in what they achieve depends on the creator's definition of success.

Bias can also exist within data itself. This relates to the concept of "garbage in, garbage out," but in a way that not many people consider. For example, if a university uses a machine-learning algorithm to assess applications for admission, it will be trained on historical data. That data contains the biases, whether they were conscious or unconscious, of earlier admissions processes. The university might have decided to use an algorithm to eliminate bias, but they might actually entrench it instead.

There is another notion of fairness to consider. There is a huge amount of excitement about big data. We can create models that predict what people will do. But can we? How good are the models really? Algorithms process a slew of statistics and they come up with a probability that a certain person might be a bad hire, a bad teacher or a risky borrower. Even if we can predict that probability reasonably well, is it fair to treat people on the basis of a probability?

So far, I have described lots of examples of the use of algorithms in decision making and some of the issues with that use. Because they are opaque and we do not know exactly how they come to decisions, there is a lot of scope for hokum—for organisations, including Government agencies, to be sold products or services by snake-oil salesmen. The GO-Science report on AI certainly indicates that the Government are

keen to increase their use of algorithms. There is a great risk of people being treated unfairly and with no point of challenge.

What do we need? As you might imagine I would say, working for Sense about Science and with my "I love evidence" badge on, I would say we need to ask for the evidence. If teacher performance is to be ranked with consequences, criminals sentenced, services cut or their deployment altered, we might want to be sure that we can all see exactly how those decisions are made. You, as Committees, need to strip away the obfuscations.

What might the Government do? They could apply standards to their own use of algorithms in decision making. It is extremely important for Government's accountability that their decisions are transparent, that people are treated fairly and that hidden prejudice is avoided. If the Government are using algorithm-assisted decision making, they should be setting the right example.

A suggested code of conduct was published late last year that includes five principles of good algorithms: responsibility, explainability, accuracy, auditability and fairness. Government or Select Committees should ask questions about the protection of people. There must be points of challenge—ways to feed back into algorithms, so that they can make better decisions in future. Government could ensure that there is an appropriate mechanism for recourse in the event that people have been treated unfairly. There might be an ombudsman or third-party regulator for people affected by automated decisions to go to. You might also look into liability for harm caused by the use of algorithms and automated decision making.

Even if no solution could be arrived at, there are a number of things that an inquiry could usefully achieve. Areas where algorithmic decision making presents a risk of harm to citizens require careful monitoring. The Committee could determine in which areas this is particularly risky and therefore where greater care needs to be taken, such as the criminal justice system, but it may be that there are also less obvious ways in which people could be harmed or where things could go awry, and they also need to be examined.

The Committee is in a good position to look into this topic, building, as it would, on a number of your previous inquiries, including on AI and robotics, driverless cars and digital skills. You could approach DeepMind, which is based in London, the Alan Turing Institute or academic computer science departments. The Royal Statistical Society might be able to help with aspects, and the Royal Society and the British Academy are currently doing work on machine learning.

An inquiry into this topic is extremely timely. The new general data protection regulation is being drafted right now and it is set to be adopted by Britain and EU member states in 2018. GDS staff received training on it just last week. This legislation will govern how artificial intelligence can

be challenged. Early drafts have included a right to explanation, but this is not guaranteed. The Committee could determine what protection should be enshrined in law.

Perhaps most importantly on the timeliness of this inquiry, issues with using algorithms in decision making are not just problems that will arise in the future; they are happening now. We know that the Government are keen to increase their use of algorithms, including machine learning. Parliament needs to be able to scrutinise that use, so we need to be having this discussion in public now.

Q18 **Chair:** Thank you very much. You have given us quite a lot to think about. You think that it is better to look at the overall, broad principle of how algorithms are used, rather than look at it on an individual, one-by-one basis? You do not think it is too big an issue to look at in the whole?

Dr Mathisen: Yes, it certainly is a broad issue; they are ubiquitous in the things I mentioned, such as cash machines. In particular for you, it would be good to know exactly where the Government are using them. I would expect the Science and Technology Committee to be able to tell me that. I do not know how widely they are used, but I would like to know. You should probably then look at it on a case-by-case basis, because how good an algorithm is in a given scenario depends on what it is looking at and what it is set to achieve.

Q19 **Dr Mathias:** I do not know if this is relevant, so tell me. That was very useful and very clear; thank you. You live up to the name of Sense about Science. Do you think the Government science advisers should be doing this already?

Dr Mathisen: I would hope, to some extent, they are, given the artificial intelligence report by GO-Science. They use the term artificial intelligence quite loosely, probably inaccurately, because they use it to cover everything from algorithms up to genuine artificial intelligence and machine learning, so it is somewhere in between. I think they are doing this, but there is definitely scope to do more specific work.

Q20 **Chris Green:** I sympathise or agree with pretty much everything you said. The biggest concern I have is that, whether it is politicians in Government, local government, business or schools, we need to challenge the decisions, and not the process through which we came to those decisions. You actually challenge that; you are talking about dealing with the process, not the outcome.

Dr Mathisen: I am talking about the process because it is integral to coming to that decision. If the decision is wrong, you are going to have to be able to argue about why it is wrong, and if you cannot see how the decision was made, you have no idea how it was made.

Q21 **Chris Green:** But if someone is not in a position to say, or finds it very difficult to justify a decision they have made, because the algorithm was

so opaque to them also, then they are in no position to justify their decision, and so you can challenge the decision maker.

Dr Mathisen: That is a problem, yes. If you are going to challenge the decision maker, if they used an algorithm to decide that, they should be able to explain what that algorithm did. You have to challenge both.

Chair: Thank you very much indeed. As Dr Mathias said, Sense about Science—very good.

Examination of witness

Witness: Professor John Finney.

Q22 **Chair:** On we go. Next I invite Professor John Finney to take the podium. You are from the British Pugwash Group. Is that right?

Professor Finney: Correct, yes.

Q23 **Chair:** Fantastic. You are going to talk to us about pre-emptive regulation of emerging and converging technologies, which I suppose moves on quite well from the previous proposal.

Professor Finney: It fits very well with the previous one, as I hope to demonstrate.

I would like to focus on two characteristics of the way science and technology are developing. The first of these is the speed with which advances are made, and the second is the interdisciplinary nature of many of these advances. These are increasingly cases of convergence of different technologies, usually involving information technology combined with one or more of nanotechnology, cognitive science and biotechnology.

As we all know, science and technology developments can have significant effects on society. In many cases, these effects are positive. However, pretty much all science is inherently dual-use; it can be used in ways that are both beneficial and harmful. Where we recognise regressive aspects, we may try to control or mitigate them with appropriate governance or regulation.

However, regulation is becoming increasingly difficult for two main reasons. First, the time taken to devise new regulation is increasingly outstripped by the speed at which the technologies have developed, and, secondly, the convergent nature of the developments can take them outside the purview of existing legal frameworks or regulations. My proposal to the Committee is to investigate this problem with a view to looking at ways and means of helping to prevent or mitigate potential regressive outcomes.

Perhaps a few examples will illustrate the kind of things about which I am thinking. My first was going to be the use of software in making societal decisions, which my colleague Dr Mathisen has done a great job of doing for me just now, so I will move on to robotics.

The increasing versatility of modern robotic systems is leading to their use in a wide range of roles. In a civilian context, significant issues arise when a robot interacts with a human: examples include telesurgery and in the care of both the young and the elderly. Robotic vehicles used in surveillance overcome many of the limitations of CCTV and satellite observation. They can hear as well as see; they can explore space in three dimensions; they are flexible, persistent and have 24/7 capability. The implications for privacy and data protection are therefore significant.

In policing, a suspect was killed last year by a bomb-disposal robot, and questions can be asked about using robotics with sub-lethal weapons in crowd control. The increasing availability of small, remotely-piloted vehicles is already giving rise to problems in air traffic lanes and in criminal use. Their potential use by terrorists is also an increasing concern.

Biomachine hybrids are under development. Insects can already be controlled remotely, robots can be controlled by cells from rat brains, and there is potential to control birds carrying significant payloads. The uses to which such developments could be put clearly can be regressive.

My second example is, if you like, the ultimate development of armed robots into autonomous weapons. Although these do not yet exist, their development would change fundamentally the nature of warfare. It is likely that their use would contravene the conditions of distinction and proportionality set out in the additional protocol to the Geneva convention and hence they would break international humanitarian law. In fact, the UN Special Rapporteur on extrajudicial executions has commented that, if the international legal framework is to be reinforced against the kind of future these weapons portend, it must be done while it is still possible. If not, the availability of the systems and the power of vested interests may preclude efforts at appropriate control.

My third example is the convergence of chemistry and biology, which raises issues for the chemical and biological weapons conventions. For example, we can now expand the number of potential threat agents by using chemistry to do biology, and biology to do chemistry, and we can also exploit nanotechnology in smart-targeted delivery of biological and chemical agents. Such agents or delivery systems were not foreseen when the conventions were designed and so could fall through the cracks in the convention articles. To their credit, recognising that the speed of developments outpaces their review cycles, discussions within both conventions have recognised the problem. Their consequent working groups examining the implications for both treaties could provide a case study for the Committee to examine.

My final example is continuing developments that have major implications for the undersea battle space. The invulnerability of submarine platforms for nuclear weapons depends critically on their being undetectable. Technological developments in undersea detection and communications

allied to unmanned underwater vehicles are beginning to query how long this invisibility will last. Indeed, one expert in undersea communications recently stated here in a discussion in the House that he expects the seas to become effectively transparent within as short a time as five years. Once the seas are transparent, a central pillar of our defence strategy will be in ruins.

I hope these examples illustrate the kinds of problems raised by both the speed and the convergent nature of developing technologies. Difficult though it may be, we need to try to anticipate these problems and develop procedures to try to prevent or at least mitigate potential regressive consequences before it is too late to control them or to prevent their proliferation.

We were asked to respond to five specific questions. What might an inquiry in this area usefully achieve? First, it could review and assess the sufficiency of the Government's capacity for identifying potential risks from emerging and converging technologies, based on the Government's established risk identification practices across the whole of Government. Secondly, it could review and asses the practices for developing guidance standards, information and regulation to reduce credible risks.

What is the policy angle? The MOD's Development, Concepts and Doctrine Centre regularly publishes a Global Strategic Trends report—very thick—to complement national security strategies and strategic defence and security reviews. Although these reports do not look specifically at possible regulation in relation to technological advances with the potential for causing harm, they are an example of the type of detailed horizon-scanning undertaken by the Government of the sort envisaged here.

Why the Science and Technology Committee? Developments stemming from the convergence of technologies will have many beneficial effects for society, but as I have tried to demonstrate, there are imminent possibilities for pathological outcomes with the potential to cause significant harm. The Committee is well placed to examine the relationship between science and technology, the potential for significant harm and appropriate practices for guidance, advice and regulation.

Why would an inquiry here be timely? It is because of the current speed and breadth of developments, but the UK prides itself on its support for the international rule of law, including the regulation of weapon technologies capable of causing indiscriminate and widespread harm. It has also taken a lead in the development of robust risk mitigation and resilience in security strategies.

Identification of guidance, standard setting and regulation of plausibly pathological applications does not appear to have been systematically embedded in UK practices. The pace and breadth of science and technology advances suggests there would be value in a more deliberate

development of an oversight capability that would be able to advise on a range of regulatory responses to reduce the risk of significant harm.

There is a wide range of potentially interested bodies and many interested Government Departments, through their chief scientific advisers. They include the MOD, the Department for Business, Energy and Industrial Strategy, the Foreign Office, the Department of Health, the Home Office, the academies, the Royal Society, the Royal Academy of Engineering and the Royal Society of Arts, professional bodies of the various scientific disciplines, including social science, research scientists, business leaders, and so on. It is a very wide and cross-cutting issue that we are trying to address. There are NGOs, such as Article36, Scientists for Global Responsibility, Sense about Science and Pugwash.

In conclusion, as new technologies emerge into the world, it is vital for Governments to open them up, look at their moving parts and decide how to realise their potential while guarding against their risks. I would emphasise that it is not about strict precautionary regulation of emerging technologies, but maximising awareness of plausibly harmful applications and systematic consideration of mitigation measures. These could include multi-actor and multilateral regulations that might in some circumstances extend to a case for pre-emptive regulation, for which we have an example in the prohibition in the 1990s of blinding laser weapons before they were introduced. The Committee is ideally placed to examine this increasingly cross-cutting, important and wide-ranging issue, and I hope it will. Thank you.

Chair: Professor Finney, thank you very much indeed, particularly for addressing the five questions that we posed.

Q24 **Carol Monaghan:** Thank you very much for your presentation. It was very interesting and there was certainly a lot of food for thought there. Is one of the issues, though, that we cannot regulate because we do not know what is going to come, what is going to emerge? It is trying to regulate as it is happening. Surely that is a problem.

Professor Finney: That is the problem I am trying to get a handle on. As I tried to say, it is difficult to envisage what may happen, but just because it is difficult does not mean to say that we should not be looking, being creative about the kinds of things that might develop from certain developments. The autonomous weapons example is a clear case where we can see the kinds of things that would happen to the nature of warfare if these things were developed and used, and therefore there is a case for looking into that particular issue in terms of the way in which we think it is going to affect certain aspects of society in the future.

Q25 **Carol Monaghan:** Is there a danger that regulating at the early stages, though, stifles the innovation?

Professor Finney: There is a danger, but that is a danger that needs to be avoided. As I said, I am not suggesting that we should be trying to

pre-regulate everything and control the development of science and technology, but rather to try to see the choke points at which those developments could be put to malign use and try perhaps to choke off those choke points. There are ways of doing it, as you know, within the nuclear non-proliferation treaty. If you look at trying to regulate the problems of cyber warfare, those choke points are very difficult to find because the laptops are all over the place. You need to look at the way in which these technologies are developed, and how in particular cases you might be able to find a way of cutting off how that could be developed in a negative way. I am not saying it is an easy problem, which is why I am bringing it to you.

Q26 **Chair:** Looking at this from how we might conduct an inquiry into this issue, it is how one might structure it: whether we have an inquiry into how quickly we should be able to come up with regulations for emerging and converging technologies, and whether we should do that potentially through the use of case study; or whether we should be trying to conduct an inquiry on a case-by-case basis—for example, you mentioned autonomous weapons systems, whether we should look at that as a specific—or whether you think there is a wider challenge, and that the output of our inquiry might be to lay out a road map of how you could regulate going forward, or how the Government would be able to react to the technologies that we cannot even imagine at the moment.

Professor Finney: It is a very wide issue in which case studies can provide some way in, but that is not going to be the only way of looking at it. There was one example I did not mention: the National Institute for Health and Care Excellence has its own procedures for looking at these issues within the health and care system. It really is cross-cutting: it is across the social, economic, business, military and security aspects. Case studies could be looked at of attempts that have been made or opportunities that may have been missed,s to try to learn how we can work from that to try to identify those areas that could be particularly difficult and awkward.

Chair: Thank you very much indeed. That was very useful, informative and food for thought. Thank you very much indeed, Professor Finney.

Examination of witness

Witness: Professor Shahin Rahimifard.

Q27 **Chair:** I invite our next speaker to take the podium. Welcome and thank you for joining us, Professor Shahin Rahimifard, professor of sustainable engineering from Loughborough University, who is going to talk to us about whether net-positive manufacturing is a realistic goal. I will be honest that it is a phrase I had not come across before, hence we are very interested to hear what you have to say.

Professor Rahimifard: Good morning and thank you for the opportunity to come and make a case for net-positive manufacturing. Increasing

evidence points to an unprecedented list of changes and challenges faced by societies around the world and in the UK due to climate change and global warming. At the heart of our proposed inquiry is the simple belief that aspiring to achieve "less bad" is not good enough any more. By "less bad" in this case, I refer to a number of regional and national legislative and incremental efficiency measures whose benefits are too small and too slow to tackle the needs of tomorrow.

What is net-positive manufacturing? A simple definition is that net-positive manufacturing is helping businesses put back more into society and the environment than they take out. At the core of our proposed inquiry is the belief that a strong and internationally competitive manufacturing sector is vital for UK prosperity, and we see the establishment of an independent office for manufacturing in the UK as a key enabler to achieve this goal. I am going to use the rest of the time that I have to justify this claim.

Net-positive manufacturing sounds great, but is it feasible? At the moment, net-positive manufacturing exists in the form of 12 principles developed by the Forum for the Future, WWF-UK and the Climate Group, intended to guide organisational transition to a net-positive role. However, these are high-level guidelines that lack practical implementation models and, more importantly, do not specify science and technology requirements and solutions.

Why would an inquiry in this area be timely? A key element of the UK Government's strategy to deal with ongoing global economic turmoil and forthcoming financial and trade challenges post-Brexit is an industrialist strategy and an aspiration for unparalleled growth in UK manufacturing capabilities and exports, as was outlined by Prime Minister Theresa May only two weeks ago.

What are the inherent dangers and risks in this strategy? You need only consider the impact of uncontrolled industrial growth in places such as BRIC countries, China and India being prime examples, which have suffered extreme and at times irreparable damage to the environment, as well as to the health of their people, in an attempt to sustain economic growth at any cost. Such short-termism and oversight often lead to expensive mistakes that need to be paid for later.

Why is the Science and Technology Committee well placed to look at this issue? My understanding is that one of the main remits of this Committee is to ensure that governmental policy and decision making is underpinned by robust scientific evidence, hence the Committee is well placed to examine the science and technology challenges involved in net-positive manufacturing.

Going back to what I said earlier, what is in existence at the moment is mainly management guidelines. This includes identifying the tools and metrics for measuring and rewarding positive impact to encourage adoption of best practices by individual companies, in particular SMEs,

which, as I am sure you know, account for a substantial amount of overall UK manufacturing output, in particular in the food and drink sectors.

From what sorts of organisations and individuals could the Committee seek evidence? The Committee should seek evidence from both national and international sources. Due to the time limitation, I am going to focus only on national sources, but I could provide a list of international sources if required at a later date.

National sources would include companies that have begun the process of adopting the principle of net-positive manufacture in the UK, such as BT, Toyota, PepsiCo, Kingfisher and Dell, to name a few. It would clearly be very beneficial to seek evidence from those that formulated the 12 pioneering principles of net-positive manufacturing, namely Forum for the Future, WWF-UK and Climate Group.

When it comes to the science and technology consideration, the research and innovation groups, such as the organisation that I am representing today, Centre for SMART at Loughborough, the industrial sustainability group at Cambridge and Tyndall climate change group at Manchester, among others, could also offer their insights. But, more importantly, it is our recommendation that the Committee should also involve and consult with representatives from UK manufacturing SMEs through organisations such as the Engineering Industries Association and the Food and Drink Federation.

What is the policy angle in this? What should Government or its agencies do, or in fact stop doing, as a result of this inquiry? I am going to focus on only two specific issues, while I am happy to discuss this in more detail at a later date.

First, there has been an array of relevant legislation, policies and guidelines by various Governments or Departments, such as the Water Resources Act 1991, the resource efficiency part of the Environmental Protection Act 1990, the Climate Change Act 2008, the National Renewable Energy Action Plan 2009, the waste legislation and regulations 2013, the universal credit regulations 2013, the national living wage 2016 and workplace pensions 2016.

Looking at the broad range of areas that these cover, there is an urgent need to understand contemporary interactions and any possible conflicts among these to unify and simplify them. Joined-up thinking would be vital to undertake net-positive manufacturing among UK businesses.

Secondly, there is a need for developing new policies for a longer-term perspective and, more importantly, independently of the instabilities produced by the electoral cycles. Examples of where this has been achieved with varying levels of success are an independent Bank of England to implement monetary policy, the National Institute for Health and Care Excellence—better known as NICE—to advise the NHS on the

take-up of new treatments, the Agriculture and Horticulture Development Board, which helps to improve efficiency of UK agriculture, and the Office for Budget Responsibility, established to provide an independent economic forecast analysis of public finances.

This brings me to my final consideration. What would this inquiry achieve? We believe this inquiry would produce an overwhelming case for the adoption of net-positive manufacturing as a part of our forthcoming industrial strategy. It could also investigate the benefit and possibility of creating an independent office for manufacturing in the UK, run and managed by staff with the appropriate skill set and experience, which would be tasked with coupling economic growth through manufacturing with environmental improvements and social accountability; advise on where cross-Government co-ordination on manufacturing activities can, or indeed should, be strengthened and simplified; identify relevant international best practices and highlight this to the Government; regularly evaluate the effectiveness of industrial policies relevant to manufacturing; and ensure the collation and effective use of the new performance metrics for manufacturing, such as productivity and resilience measures, drawing intelligence from the wider public sectors, including BEIS, the research councils and Innovate UK.

I hope this speech has effectively highlighted the importance of and urgent need for this inquiry, particularly at this very sensitive and exciting juncture for UK industry. I look forward to discussing some of the more technical details during the questions or on another occasion. Thank you for your attention. I am happy to answer any questions that you may have.

Q28 **Chair:** Professor Rahimifard, thank you very much indeed. That was very insightful and informative. Do colleagues have any particular questions? Would the aim of an inquiry at this early stage be to highlight, as you said in your closing remarks, the best practice around the world—to bring that forward, to show how it is possible—or would you expect the outcome of our inquiry to be a recommendation that we regulate and mandate business to start to move towards net-positive manufacturing?

Professor Rahimifard: There would be two stages in achieving net-positive manufacturing. The first is looking at what motivates and runs most policy making and what businesses do in this area—to try to learn— because there is a body of activities about cradle-to-cradle, the idea of zero carbon and the circular economy. Each of these somehow or other is adopted by a subset of a company and achieves a subset of what we need. Initially, the inquiry would look at how these fit together, what the reasons are behind a specific company adopting them, and trying to integrate and get connectivity to all these ideas, as well as the legislation that I have listed. That, in itself, creates an insight, in terms of what are the best practices, because without that insight, identifying those best practices, whether in the UK or internationally, may be difficult.

Q29 **Chair:** Thank you very much. You have said that the timing is right now

because of the industrial strategy, but in your view, if we do not do this, what do you think will be lost?

Professor Rahimifard: It is an interesting question. Having been involved in these activities for about 20 years, you see this cycle of interest and disinterest—disinterest is a strong word; you see less interest in some of the issues. If you were to study the 10 points in our industrial strategy, you will see that the balance is more towards growth as opposed to environmental considerations. I am not saying these are being ignored. We are still one of the countries with the greatest amount of legislation in this area that is enforcing and protecting our environment, but I exemplify what has happened in China and India. If we somehow lose sight of that for now, for obvious reasons—for industrial growth, for manufacturing sector growth and for the trade opportunities—and just put more focus on this, in years to come we would have to spend billions. Just look at what the Chinese have to do in spending billions on purifying their air quality and the consequent health problems that are caused. For me, not to exaggerate, it is such a vital point that if we get it wrong now, we are going to pay handsomely later.

Chair: Thank you. That is very clear about why we should be doing this. Professor Rahimifard, thank you very much indeed for your contribution today.

Examination of witness

Witness: Dr Michael Brand.

Q30 **Chair:** I would now like to invite Dr Michael Brand to come forward from Sensor100, who is going to talk to us about early-stage cancer diagnostics. Dr Brand, the floor is yours. I believe we have a hand-out on this one.

Dr Brand: You do. Thank you very much for inviting me here today. I would like to start by explaining what Sensor100 is, in case that is an issue. Sensor100 is a network of people and organisations around the world who are active in research and development in biosensor technology. It currently has about 3,000 members and is represented in over 70 countries worldwide, so it is a very big research area.

I want to talk to you about diagnosing cancer, which is something that probably a lot of people would prefer not to think about. I will give some background to start with. As a basic principle, the earlier the diagnosis is made, the greater the chance of a cure. It is a prevalent disease; one in two of us will be diagnosed with cancer. If it is not you, you certainly know a number of people who have had cancer or are in the process of being treated for cancer. It is not one disease. There are over 200 different types, and doctors tend to classify them on the stage of development, from 1 through 4, where stage 1 is a very early stage and stage 4 is when it has spread throughout your body—I can never say

"metastasise," but that is what it is. There are other classifications as well, depending on how aggressive the cancer is.

Almost 50% of diagnoses are made at stages 3 and 4, and the probability of a cure there is lowest. The UK has among the lowest survival rates in Europe. Our cancer survival rate is around 50%, whereas Sweden, for example, has 65%.

To put all this in perspective, if we diagnosed all the bowel cancers in the UK at stage 1, we would save about 20,000 lives a year. Why is this? Why are we so poor at diagnosing cancer? There are a number of reasons proposed, but one of them certainly is that we do not refer people on soon enough. A 10-minute GP appointment is not sufficient to diagnose cancer, and I can speak from personal experience on this. My wife went from an initial GP visit to, three years later, being diagnosed with stage 3 ovarian cancer. Fortunately, she is still alive—one of the lucky 20% at that stage.

Why is cancer diagnosis so ineffective? It is based on symptoms. You have a cough, you are in pain or you are bleeding; then you are likely to be sent for an image, a mammogram, an MRI scan or whatever; if a lump is found, you will get a biopsy. By that stage, of course, the cancer has developed, so it is not at the early stage any more. We want an early-stage test before the cancer becomes symptomatic, and an ideal test would be accurate, non-invasive, low cost, sensitive and one that can be operated by a lay person. Taking a blood sample or breathing into a tube—things like that—would be an ideal kind of screening test, and you can imagine that everybody gets one done every year. Liquid biopsy is being developed, which is essentially a blood sample test for cancer. There is a lot of research in the area but it has not yet been approved.

Now let us talk about biosensors. What do I mean by a biosensor? It is a measuring device that links a biological entity—such as a molecule, perhaps a fragment of DNA, a protein like an antibody, or a cell or a number of other pieces of biology that cancers tend to throw off—to a sensor, to a measuring technology, which could be electrochemical, optical, acoustic or a variety of other things. This is a huge area of research.

One exciting thing is that it has become very miniature. In the States now, there has been approved a very tiny sensor that should be embedded in all medicines, in all pills, and when you swallow the pill, your smartphone will record that you have taken your medicine. For people who are not compliant with medicine, it will be apparent that they are not, and this will encourage them to be. This is reality; it is not something that is fanciful; it is happening right now.

UK universities have world-leading research groups in this technology. We are very good at it. We are not very good at commercialising the results. The University of Oxford, for example, has a group that

developed the first glucose test for diabetics. A diabetic tests their blood several times a day. Pregnancy tests are another familiar biosensor.

We need to develop biosensors to do tests on blood, breath, urine and saliva. These things will be the most likely way that we can screen for early-stage cancer.

What do we need to develop this technology for cancer? We need an open debate on the feasibility and viability of the biosensor approach, and Sensor100 is planning a conference on this subject in April this year. The problem is how to design this optimum biosensor for cancer. There are a number of biomarkers—these small molecules, proteins or cells; there is a variety of things like that. There is a variety of sensor tests that can be used to identify them. We need to find the optimum combination of those, and there is probably more than one, because we are talking about 200 different diseases here.

We are proposing that we should have a cloud-based innovation platform to allow a selection of people who are informed on this subject to propose ideas and then vote on them. It would not be the usual expert panel, but a wide-range, cloud-based innovation platform. That sort of approach is now increasingly being used by industry to develop new products.

We need to realign research funding so that it is not just funding for biology or funding for engineering, but somewhere between the two. We need more cancer funds for diagnosis; 75% of all cancer research funds are spent on therapy, not on diagnostics, and the ones that are spent on diagnostics are certainly not spent on biosensors. That is a problem, of course, because the people who decide how to spend their funds—MRC and BBSRC—tend to be cancer people in therapy, so they are not going to look favourably on doing a biosensor project. This is a zero-sum game; there is only so much funding and where it goes is important, so it needs to be looked at. It would be good if we could adequately fund a centre for early-stage cancer diagnostics. The University of Oxford has just acquired over £100 million to set up a centre for type 2 diabetes. It would be nice if we had something like that for cancer.

Why biosensors for cancer? The early-stage diagnosis of cancer is among the leading social, humanitarian unsolved needs. We have a unique advantage here. We are very good at this sort of technology, but we are not very good at commercialising it.

I would like to propose to the Committee that an inquiry should focus attention on this area. I do not believe that the funding bodies are going to move unless there is some attention paid to this subject. This would be a viable opportunity to position this country at the leading edge of this technology. Thank you very much.

Chair: Thank you, Dr Brand. That was very informative and an area of great interest, I am sure, not only to those in the room but outside as well. Colleagues, does anyone want to ask anything?

Victoria Borwick: There might be more expertise on the Health Committee about this.

Q31 **Chair:** That is a very good question. Do you think we are the right Committee, or would it be better dealt with by the Health Committee?

Dr Brand: Who would be better?

Chair: The Health Select Committee.

Dr Brand: I do not know the answer to that. You probably know better than I do.

Q32 **Chair:** That is fine. You talked about a cloud-based innovation platform working together and coming up with potential solutions. Other than raising the profile of this issue, what would you imagine the outcome of an inquiry would be, bearing in mind that our role is often to make recommendations to Government specifically?

Dr Brand: I hope it would encourage the cancer research bodies to give some attention to this and put some funding into it. I do not think you are going to influence Cancer Research UK very much, but you certainly could influence the research councils, and that would have a knock-on effect at Cancer Research UK and other cancer-funding bodies.

Q33 **Chair:** The link between early diagnostics and better outcomes is very well established, so why do you think this is an area that has not received the attention that you suggest we now give it?

Dr Brand: It is beginning to. If you look at the development of biosensor technology in health, it started with measuring electrolytes in blood; it went to glucose; pregnancy tests came in shortly afterwards; and then there is an increasing move today towards diagnosing infectious diseases using biosensors. But cancer is beginning to appear on the horizon. There is certainly one very major project going on in this area in the United States, which supposedly hired 100 MIT PhDs to work on it; so that is years away, not decades away.

Q34 **Chair:** Thank you. I have perhaps one final point. You talked about 200 types of cancers. Do they all have a common marker that would be detectable, or would you have to develop 200 different tests?

Dr Brand: There are some crossovers. They are not all 200 separate ones—that is for sure—but there is not one common one that would do 200.

Chair: Thank you very much indeed for that. I am sure we will think carefully on how we might take that forward. Dr Brand, thank you.

Examination of witness

Witness: Professor Becky Parker MBE.

Q35 **Chair:** Finally, but by no means least, I would like to invite Professor

Becky Parker from the Institute for Research in Schools to talk to us about science research in schools.

Professor Parker: Thank you very much for inviting me. I am a physics teacher, but I set up the Institute for Research in Schools with colleagues to promote opportunities for young people to do science research while they are at school. We launched in March at the Science Museum, and we are moving to our base at the Science Museum now with Lord Martin Rees. We have notable people such as Sir Leszek Borysiewicz, the vice-chancellor of Cambridge, and Dame Julie Goodfellow as trustees.

We are working with a number of people to try to change science education. We are proposing an inquiry to try to align science education more closely with science itself, because science itself is about asking questions and not knowing what the answer is, challenging questions, being aware of limitations, gathering experimental evidence and looking at errors. School science, I am afraid, is not that much about that. If anybody has a child in year 11 at the moment, they know that it is probably more about cramming a whole load of stuff that is all known to try to tick boxes to get exam results. That is a travesty for many reasons. This is why we think that having an inquiry could achieve something.

We want to give teachers time to do this sort of thing. We want to encourage our students to be competent citizens who know about all these discussions—things that have been talked about before—and we want research to be done by school students. Why wait till they have done their PhD? There is so much potential. We already have lots of track record on this. We have had students working with NASA, CERN, the Genome Campus and biosciences; we launched a project analysing Higgs data with Peter Higgs himself; and we are working on atmospheric chemistry.

Why you? The reason it should be you rather than the Education Committee is because you are about the science research community, and that is what we are about. We are about tying in teachers, students and the research community with school science, not making it a completely separate thing where students do not have any experience of the careers, the exciting opportunities and the whole world that they can help to change and improve.

Why is it timely? It is particularly timely because we can do this now. Last night I had the great delight to be at a lecture at the Francis Crick Institute with Professor Sir Mike Stratton, and we talked afterwards about how schools could have a genome to analyse. That data is out there. There is so much data. Students are much better at doing many IT and computational things, and, if there is a reason for them to use data, why not? There is lots of consensus among the scientific community and the educational scientific community—the Royal Society, the Wellcome Trust, British Science Association and the learned bodies, universities, research councils, industries—who are all very keen. There is evidence to show that this approach of giving students the opportunity to do project work

or to engage in research improves their GCSE grades and—this is the CREST award—evidence that it improves GCSE grades, especially of those in areas that provide free school meals. It contributes to social mobility and encourages those students to think about science careers.

I know this is slightly ambitious, but we have a chance to do this, and you are the people, I am sure, who can do this. The idea would be to give teachers a day a week to do continuing professional development, to do research alongside their students. Already, since March, we at the Institute for Research in Schools have 290 schools signed up, which is about 10% of schools. The barrier to teachers doing this is time. They are doing endless stuff. I am sure we would have to say that much of it is very useful, but a lot of it is not about empowering our students and giving them the opportunities to feel part of all these questions, to feel part of the scientific community, how it is going to affect them and—whether they are going to be scientists or not—how they should be responsible, scientific, literate people in the future.

Our suggestion is a day a week for science teachers. In our experience, we have found that a number of people who have research backgrounds love this. There are so many teachers, especially physics teachers—I am a physics teacher—who say, "Thanks, Beck, you have kept us in the profession," because it is a bit gruelling. If you can keep up a research profile with your students, it keeps them going, and that makes teaching more manageable. We are recruiting from all across the world now, are we not? We need more science teachers. Why not keep the ones we have? Why not encourage people who are doing post-docs and perhaps not going into academic fields to go into teaching, because they can do research at the same time alongside their students?

We are also thinking about the university engagement profile. So often that is about, "We will tell you about what we do as scientists." Why can't that be, "We will encourage you and support you to be scientists, and then you will understand what being a scientist is like"? One reason I went into teaching was that I realised when I was doing research in Chicago that there were so few women, and, even though I loved the foundations of quantum mechanics, I thought perhaps I would be better doing teaching and trying to encourage more girls. The Institute of Physics has done research on this with Ruislip High. I have had huge numbers of girls going into physics because they can see that they can research dark matter or can look at atmospheric chemistry problems. There is so much to be gained from empowering our students to be part of solving world problems.

It should be you, it is timely, and there is plenty of research evidence. Research in schools is not high on the agenda in terms of examinations at the moment. Any individual project investigation has gone from A-level chemistry. Teachers are worried about that, because it has become far more concentrated on getting the syllabus, and that is not really giving

students an experience of science. There are so many people who are in agreement on this—the Royal Society, Gatsby and Wellcome.

My passion, in conclusion, is for suggesting that this could be a way of really generating a new group of people who are curious, inspired about the world we are living in and want to change it, and that is our young people. Why do we just ignore all that potential? One of my students has looked at two types of breast cancer, one of which is not curable, and has been trying to turn the incurable one into a curable one, and he has got funding from a drugs company to look into that, working with a university research group. That is one amazing student, but there are loads of amazing students, and we are just not giving them the chance to flourish.

Young people can be at the heart of this. Their teachers can be more committed, stay in teaching and encourage more high-quality people into teaching, who might think that teaching is just about delivering a body of knowledge. It should be about delivering teachers who are really invigorated and inspired by the science they are teaching.

The time is now. We can lead the world on this. Americans are joining up to IRIS. NASA has promoted it; we are analysing data from the International Space Station. Why can we not lead the world and say that we should realign science teaching and give young people and their teachers, and then university research groups who can benefit from this, the chance to be part of science, contribute and change the world? Thank you.

Chair: Fantastic. Thank you very much indeed. I do not think anyone is going to doubt your enthusiasm for this, which, of course, is great. It is great to see someone so engaged with their subject. We have questions from Victoria and then Carol.

Q36 **Victoria Borwick:** Certainly, I commend you. We are all absolutely on side. As the MP for Kensington, I am very happy to support you. If you have an event at the Science Museum, do include me.

Professor Parker: Thank you.

Victoria Borwick: Again, I am not absolutely sure that this is work for this Committee, but I am sure we all commend you on your enthusiasm. In a previous job, I visited many schools across London, and the pressures on some of our teachers in engineering and a whole range of STEM subjects are quite tricky, but you also might think about working, certainly in London, with the GLA, because they have a London curriculum. I am sure they would be interested in some of your ideas. I would commend you to the Deputy Mayor for Education or something like that, too, because they have quite a number of programmes where they disseminate information throughout all the schools, and that might be helpful.

Professor Parker: Thank you.

Q37 **Carol Monaghan:** I am also a physics teacher. Everything you say makes perfect sense, and I know certainly that getting an experience of real science does turn a switch on in students' heads. I am trying to get a bit of clarification on the one day a week. How does that work? Is it one day out of all classes, is it one period a week, or what does that mean?

Professor Parker: That would be the ideal. Headteachers who sign up to IRIS are managing to find probably about two hours a week for their teachers because they see it is important, but if we want a different vision for a science teaching profession, we might start with half a day a week—that entitlement for teachers to feel that they can advance their own knowledge and, in doing so, inspire young people, and get so much out of those young people. That is a small price to pay for keeping an inspired workforce, and that is why it should come to this Committee. It is about getting scientists in to inspire the future—not just the future scientists but giving all people who are going to do science at school an experience of exciting science so that, in future, they can see how it impacts on their lives.

Q38 **Carol Monaghan:** I am with you on all of that. I am wondering and still do not quite understand, as a teacher, whether it is two hours without any pupils or two hours with students. When do they do the work with the students then?

Professor Parker: There is a school in Scotland that has already done this just because they can see it is a good idea. They have Wednesday afternoons off, and the students join up with particular teachers who are doing different things. It is about following different passions. For one of our projects with the Wellcome Trust—authentic biology—the Wellcome Trust could see the benefits of this, and they have allowed the teachers involved to have a bit of time so that they can run after-school, lunchtime and extra sessions doing proper biomedical science research with their students. It might be worth thinking about whether the set curriculum needs to stay as it is and making some modification so that students could be involved in doing research projects, but currently—

Q39 **Carol Monaghan:** Like Scotland, where the curriculum is totally different.

Professor Parker: Yes, exactly. We have many Scottish schools that have signed up.

Chair: Thank you. There is a quick point from Dr Tania Mathias.

Dr Mathias: Thank you, again. Whether this is for our Committee or another, I want to highlight that, yes, we have breakfast clubs—I love the idea of research people going into schools—in the National Physical Laboratory in my area, which is local. I love that idea, going forward, regardless of whether or not we scrutinise this. It is really good; thank you.

Chair: Thank you very much indeed for your presentation. We will have

to think about whether this is something that the Government have the ability to implement on a systemic scale or whether this is for individual schools, but you have certainly put your views firmly on the record. Thank you very much indeed for that.

Professor Parker: Thank you.

Chair: Can I thank each and every one of our presenters this morning? It has been a fascinating and wide-ranging set of views and topics that we might consider looking at.

As we draw this session to a close, can I encourage you all, please, to send through your notes and so on to the Clerk, so we can put those on record? We will respond to each of you, once we have come to a view, on how we may take this forward and what the outcome of your presentation will be this morning.

All of you have undoubtedly put your views on the permanent parliamentary record this morning that will stand for ever, and when you read *Hansard*, which I would encourage you to do, you will know you have made a contribution to the body of scientific knowledge here in Parliament. On behalf of all of us, thank you very much indeed for your time and for doing that.