LEVERHULME TRUST

The Leverhulme Trust Annual Lecture 2017

Professor Sir Paul Nurse: 'Research and the Public Good'

Good evening, and thank you for this invitation to speak at the Leverhulme. This evening I will talk about how research can promote the public good in all senses of the words public good. Research in all disciplines, including the natural and social sciences, medicine, mathematics, technologies, the arts and the humanities, produces knowledge that enhances our culture and civilisation, and which can also be used for the public good. I will focus on the natural sciences tonight but what I say is relevant to all academic disciplines and so hopefully relevant to the Leverhulme as well.

Scientific research is aimed at generating knowledge of the natural world and of ourselves, and also at developing that knowledge into useful applications, including driving innovation for sustainable productive economic growth and better public services, improving health, prosperity and the quality of life, and protecting the environment. This has always been the case for science. In the early seventeenth century Francis Bacon argued that science improved learning and knowledge which "leads to the relief of man's estate", and Robert Hooke fifty years later maintained that "discoveries concerning motion, light, gravity and the heavens helped to improve shipping, watches and engines for trade and carriage", all of interest to the society of those times.

Today the world faces major problems, food security, climate change, global health and making economies sustainable, all of which can benefit from scientific research. It is critical for our society to have mature discussions about these issues. But we have to be aware that these debates are sometimes threatened by a misinformed sense of balance and inappropriate headlines in the media, which can give credence to views not supported by the science. Threats also come from those who distort science because they are driven by their ideology, politics, or religion. This includes some politicians, although rather rarely in the UK in my experience, and also newspaper columnists and other commentators, as well as lobbyists all driving their particular agendas.

Research, then, can be very useful, but it is not solely utilitarian. It generates knowledge that more generally enhances humanity through culture and civilisation. In the words of Robert Wilson, Director of the Fermilab particle accelerator – when asked by the US Congressional Joint Committee on Atomic Energy whether the accelerator in any way involved the security of the country, he famously replied, "It only has to do with the respect with which we regard one another … our love of culture … it has nothing to do directly with defending our country, except to make it worth defending."

Research is best described as a network of activity, ranging from discovery science acquiring new knowledge, through translation of knowledge into innovation, and of developments of that innovation for useful applications. It is a complex interactive system, with knowledge generated at different places within the spectrum of activities influencing both upstream in the creation of new

discoveries and downstream in the production of new inventions and applications. New discoveries enable new inventions, and new inventions enable new discoveries.

The most effective research systems at producing knowledge for the public good are characterized by how the research society operates. It thrives on freedom of action and movement: there needs to be permeability and fluidity, allowing the ready transfer of ideas, skills and people in all directions between the different sectors, research disciplines, and various parts of the research endeavour. Artificial barriers which reduce permeability or mutual respect between the different parts of the system, such as BREXIT for example, should be resisted, as they reduce the effectiveness of the research system – both to produce knowledge and for the effective use of that knowledge for applications.

Research systems thrive on excellent research scientists who are strongly motivated, most often by a great curiosity and by freedom to pursue their intellectual interests. They can make a difference to our understanding of the world – whether from within a single discipline, or in collaboration with others who can bring different disciplinary perspectives to bear on complex problems.

Scientific research, wherever it is carried out, shares common values and practices. It must be built on a respect for reliable and reproducible data; a sceptical approach which challenges both orthodoxy and the researcher's own ideas; an abhorrence of the falsification or cherry-picking of data; and a commitment to the pursuit of truth. Science can only succeed when it is grounded in integrity and ethical behaviour. There are a number of personal qualities of scientists which are important for the reliability of science, including a sceptical attitude, honesty and transparency, courtesy in scientific dispute. Humility and self-doubt help as well, as the seventeenth century philosopher of science Francis Bacon said: "If a man will begin with certainties, he shall end in doubts, but if he will be content to begin with doubts, he shall end in certainties."

The work of science can also require courage, as it sometimes strikes at the heart of accepted thinking. Challenging established opinion is part of science, and can bring about revolutionary changes, which can be very unsettling for society. Copernicus and Galileo displaced the earth from the centre of the universe. The earth was moved first to an orbit around the sun, then to the arm of a galaxy, then to a galaxy within an infinity of galaxies and then possibly to an infinity of universes. This has had a profound effect on the position of human kind who have moved from the centre of the universe to inhabiting a tiny displaced speck in an unimportant location within the universe. Some did not like this. When Galileo argued that the earth orbited the sun, the Inquisition did not argue back with science, they simply showed him the instruments of torture.

Evolution has had a similar dramatic impact on our view of humanity, moving us from being specially created and separate from the rest of life, to being related to every living organism on the planet.

Charles Darwin recognized this in his *Descent of Man*: "Man with all his qualities, with sympathy… with benevolence … with his god-like intellect… with all these exalted powers – man still bears in his bodily frame the indelible stamp of his lowly origin."

There are still many on the planet who cannot accept this. These ideas about the earth and human kind were once almost universally unthinkable and heretical, but are now fully accepted, at least by all those who respect knowledge and the power of reason.

The network of discovery, translational and applied research shares many practices but there are differences in different parts of the system. In all parts of the system the bedrock from which science flows is reliable observation and reproducible experiment. This means that ultimately what is observed – the data – trumps all, even the most beautiful idea. Scientists need to take account of all observations and experiments, and not just cherry-pick data that happen to support their own ideas and theories. Scientific issues are settled by the overall strength of evidence. Discovery research aims at acquiring new knowledge about the natural world and ourselves. Sometimes, scientists make observations without a precise idea – or hypothesis – in mind. More whimsically I call this "following where nature leads you". But most often it is a particular idea that drives what observations a scientist makes. It then frequently proceeds through an iterative process of hypothesis generation and challenge, as has been emphasised by the philosopher Karl Popper.

A researcher considers what is known about the subject of interest, and generates a hypothesis. These hypotheses are then tested by investigating the predictions that they make through experiment and observation. Should the new data obtained not support the hypothesis being tested, then it is either rejected or modified, and new hypotheses tested by further observations and experiments. We can generalise this to say scientific research usually proceeds by hypotheses being tested and then modified or rejected when they are found to be unsatisfactory. This approach is complemented by other more exploratory ways of working, aimed at accumulating sufficient knowledge to define a field of study, which ultimately generates hypotheses that can be tested.

A consequence of research proceeding by hypotheses that are then tested and rejected if found wanting, is that the ideas driving a research study may well change during the course of its investigation. The original hypotheses can change and even the phenomena under study may change. An important outcome is that, although discovery research is efficient at producing knowledge, it is often difficult to predict where the research may go. Through this mechanism of challenge and modification, the scientific process is essentially self-correcting, and it is this characteristic together with the application of the proper values and practices that make scientific research such a reliable way to gather knowledge.

Applied research at the other end of the spectrum is essentially goal-directed, aimed at achieving specific objectives and outcomes. For this to work successfully there are two necessary conditions:

- The objectives need to be well chosen, which requires understanding of the potential beneficiaries' needs, whether societal or commercial, so that the applications being developed by the research are worthwhile, and
- the knowledge base required for the application has to be sufficiently well developed such that effective development of the application is generally foreseeable.

Therefore, research in this part of the system must be based on both knowledge of the relevant phenomena and an understanding of the societal, customer and market or policy needs.

In the middle of the spectrum is translational research which aims to bridge discovery and application research. It can be considered as oriented discovery research, that is research carried out with the expectation that it will produce a base of knowledge likely to form the background to the solution of current or future problems or possibilities. The objective is essentially to expand the knowledge base in a certain area to a point when more directed development work becomes possible that leads to desired applications.

However, there is a danger with some translational activities that if more directed approaches are applied too early, the research may become less responsive to the self-corrective mechanisms crucial for the scientific process, whereby the research changes direction as a consequence of new data, ideas and hypotheses – wasting effort to the ultimate detriment of the long-term objectives. If the ultimate driving force is to achieve a specific objective rather than to gain knowledge relevant for that objective, then the researcher may not respond effectively to the signals from the new knowledge being gathered, which indicate that the original aim may not be achievable using that approach. To rush into translation may result in becoming lost in translation.

The aim of translational research should be to increase the knowledge base to determine what applications may be possible, whereupon more highly directed approaches can be taken. It is usually more effective to identify research objectives in a broadly scoped manner, giving freedom for the individual researcher to propose a specific programme within that wider umbrella, and to pursue that research wherever it may lead.

It should not be thought that discovery, translational and applied research are completely distinct. The boundaries between them can be blurred, with discoveries being made during applied research, and applications emerging during discovery research. Nor is it correct to view it as a unidirectional process, moving from discovery through to application – as already mentioned, knowledge transfer occurs in all directions. What is important, is that all three modes must be pursued if the research endeavour is to be effective in bringing about social benefits. Generally, but not always, discovery research activities take longer before they lead to benefits than applied research, but when they do so they can lead to very significant benefits.

One aspect of promoting the public good is how can we drive our economy most effectively? The Industrial Revolution brought scientists, engineers, technologists and entrepreneurs together to apply science to industry and the economy. The result was the steam engine providing power, chemistry and geology improving ceramics and the use of natural resources, mechanics and engineering constructing machines for transport and manufacture.

This era is symbolized by the Lunar Society, a group of British intellectuals including James Watt, Erasmus Darwin, Matthew Boulton and Josiah Wedgewood, who discussed science and how science leads to new technologies and inventions supporting the economy. They met together in the Midlands in the middle of England once a month under the full moon, to illuminate them during their ride home after dinner. They discussed contemporary scientific advances and how they could be applied to everyday life including the economy. And where would our economy be today without electricity and electromagnetism, electronics, synthetic chemistry, atomic physics, biochemistry and molecular biology? Some say, Michael Faraday answered the prime minister of his day, when asked what good his inventions of the electric transformer, generator and motor might be, by saying: “Why, Prime Minister, some day you can tax it.”

Although almost certainly never said by Faraday, this anecdote captures the view of some politicians and business leaders who fail to grasp how discovery science can enhance industrial capabilities and create wealth.

Similarly, science can drive the public good more generally in all parts of society. It is a mainspring for improving health, the quality of our lives, for promoting sustainability and protecting the environment. And of course research in all disciplines supports this agenda, not just science.

Much is spoken about the valley of death, the gap between the generation of new knowledge and the application of that new knowledge particularly for commercialisation. Usually the focus of discussion is on providing research support to bridge that gap, but attention also needs to be paid to pushing the bridgeheads further out into the valley. This is one of the problems that can arise when attempts to translate are made too prematurely before knowledge is sufficiently reliable and complete.

A firmer bridgehead needs to be built involving a more extended and secure knowledge base in the area of interest before attempting to pass over the valley of death. Similarly, the bridgehead on the other side needs to be extended out, with more investment from industry in research aimed at capturing new knowledge from the other side of the valley. Without research capacity and knowledge in industry it will be difficult to build back over the valley of death.

So how do we decide what research to do?

Doing high quality research is hard and there needs to be a clear focus on excellence, generally best assessed by highly accomplished researchers in the relevant field. Assessment has to be made of both the researchers and the research they plan to undertake, recognising that the actual outcomes achieved may not be quite what was originally planned. Excellence is essential and the highest standards need to be applied when judging whether research is indeed excellent. Three factors are particularly important for research funding decisions: the researchers undertaking the research; the research programme itself; and the circumstances under which the research is to be pursued.

Let us start with who should do research: Research discoveries are usually associated with talented individuals who combine a number of qualities: they need to have in-depth knowledge and the necessary skills, be creative, understand the values of research and how it is done, be motivated, and be effective in what they do. In-depth knowledge is essential but needs to be combined with a wider peripheral understanding of related research activities, especially when a research problem requires multi-disciplinary or inter-disciplinary approaches. Creativity is core and requires freedom of thought and action to pursue an investigation wherever it leads. A researcher who is too strongly directed, or whose thoughts are restrained by their community or society, is unlikely to be fully effective in research. Similarly, in my view, societies which do not encourage freedom will find it harder to excel in research.

Moving now to what research should be done: Research should tackle interesting problems and should demonstrate both a creative and a practical approach. In the discovery part of the research continuum the problem being proposed for study needs to have the potential for scholarly impact, which should be a significant part of any judgement of impact of research activity. This aspect of impact does not receive the attention it deserves.

A similar approach should be used for most translational research with the ultimate long-term aim of improving the knowledge base relevant for an application of potential societal or commercial benefit. However, as already stressed, the outcome of discovery and translational research activities may turn out to be different, in some cases quite different, to that proposed in the research programme. For research aimed at a specific application when a more directed approach is required, there also needs to be an assessment of the needs for the customer and of the market in the research application.

And finally to where it should be done: What needs to be considered here is the circumstances under which the research is being carried out. It is crucial to ensure that it is practical to pursue the research proposed in the proposed location and circumstances where it is to take place, recognising that collaborative arrangements in different locations may also be involved. Centres of research excellence in specific areas help define a satisfactory local environment, but funding mechanisms should be flexible and need to be inclusive, so that support is possible wherever quality research can take place. Sometimes novel approaches to problems can emerge more readily when carried out away from conventional centres of excellence, which can become too dominated by current fashions and the contemporary research leadership.

Good science has a tradition of respect for empiricism, emphasising reliable observation and experiment. Most importantly, science should be carried out in a culture of openness and freedom without boundaries. The scientific endeavour is at its most successful when there is freedom of thought. Scientists need to be able to freely express doubts, to be sceptical about established orthodoxy, and must not be too strongly directed from the top, which stifles creativity.

This will be encouraged if there is greater permeability between sectors, encouraging the transfer of both ideas and people more freely. We need to reduce the boundaries between people, ideas and disciplines. We have in place too many barriers and silos that inhibit free transfer and encourage suspicion between the very people that need to be working closely together. One of the problems is that increasing knowledge has led to specialisation, making interactions between different scientists, industry, the public services and other professions more difficult. The promotion of translation and innovation requires lowering the boundaries and good permeability across the sectors.

Researchers of all disciplines should not stay in their labs or offices all the time. They should mix more with the best minds from industry, the City, the public services, the media. This is research without boundaries. If what I have said this evening sometimes sounded a bit like anarchy, that is because it is a bit like anarchy. It is often in mixed up and chaotic circumstances that the most creative work is done. Remember Harry Lime in *The Third Man* who said:"In Italy for 30 years under the Borgias they had warfare, terror, murder and bloodshed, but they produced Michelangelo, Leonardo Da Vinci and the Renaissance. In Switzerland they had brotherly love – they had 500 years of democracy and peace, and what did that produce? The cuckoo clock."

Thank you for listening to me.

Professor Sir Paul Nurse
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