The responsibility of the scientist

What can history teach us about how scientists should handle research that has the potential to create harm?

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The fulminant development of science and the technical innovations that it has spawned have had a profound impact on our day-to-day lives. Information and communication technology, molecular biology, physics, engineering and chemistry have all markedly changed the lives of most humans during the past century. Scientific research is crucial for creating the knowledge base for this progress, which puts scientists in a particular, and sometimes difficult, position. On the one hand, society elevates scientists to the level of ‘super experts’, who are expected by the public to provide expertise and knowledge to solve societal problems. On the other hand, many people remain cautious and even fearful of the technological and medical progress enabled by scientific research. We, the society, assign scientists a high degree of responsibility ‘for our lives’ and we expect them to dedicate themselves to the benefit of humanity.

Do scientists really have a greater responsibility to contribute to society than, say, politicians, judges or journalists, or any other of us? And if so, can we define this responsibility? To address this question, it might help to look at historical examples of how certain scientists acted in extreme situations, and whether they showed an awareness of or commitment to a special responsibility.

Wernher von Braun (1912–1977) was a brilliant engineer and rocket scientist who was fascinated with space flight from a young age. In 1930, he attended the Berlin Institute of Technology, Germany, and graduated in 1932 with a bachelor's degree in aeronautical engineering. He joined the Spaceflight Society in Berlin in 1930, for which he built and tested liquid-fuel rocket motors. His work caught the attention

of the Heereswaffenamt—the technical department of the German Army—who began to finance his experiments. Von Braun was so obsessed with building rockets that he subordinated everything to this end. His doctoral thesis in physics, which documented rocket flights with liquid-fuel motors, became classified for its military use. In 1937, he became a member of the NSDAP—the ruling Nazi party—and the Technical Director of the newly founded army research institution and testing facility at Peenemünde, close to the Baltic Sea. He also joined the SS (Schutzstaffel)—the paramilitary force of the German Reich.

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With massive financial and political backing, von Braun made rapid progress. The first supersonic rocket became ‘combat ready’ in mid-1943, and mass production started at an underground concentration camp at Mittelbau-Dora. Some 20,000 workers perished in the harsh conditions. In 1944, more than 3,200 V-2 rockets were fired towards London and Antwerp, killing 8,000 civilians. Only the defeat of Nazi Germany prevented von Braun and his co-workers from building missiles with an even greater range. In April 1945, von Braun moved with many of his co-workers to southern Germany to surrender to the US Army. The US government were well aware of his valuable expertise and quickly approved the transfer of von Braun and many of his engineers to the USA, where von Braun started

a new career building rockets. The first US rocket was tested in 1953, with the Jupiter-C rockets and the Saturn programme following shortly after. Von Braun became Director of the Marshall Space Flight Centre in Huntsville, Alabama, in 1960.

von Braun is an example of a scientist so enthralled by his work that he did not spare much thought for the societal and political consequences of how it was used. He was called an “amoral opportunist” [1]. Confronted with the damage caused by the V-2, he might have said “this is not my department”, as the American singer Tom Lehrer phrased it (<http://www.youtube.com/watch?v=QEJ9HrZq7Ro>).

The German chemist Fritz Haber (1868–1934) was born in Breslau into a Jewish merchant family. At the age of 30 he became Associate Professor of Technical Chemistry at Karlsruhe University in Germany, at which he and Carl Bosch developed the so-called ‘Haber–Bosch’ process to synthesize ammonia from hydrogen and atmospheric nitrogen. In 1919, Haber was awarded the 1918 Nobel Prize in Chemistry for this work. The process was a milestone in industrial chemistry and enabled synthetic fertilizer production and the so-called ‘Green Revolution’ in food production that has supported the growing world population. In addition, the process also enabled the production of explosives and chemical feedstocks. In 1911, Haber was appointed Director of the newly founded Kaiser-Wilhelm Institute for Chemistry in Berlin.

Fritz Haber has been described as compassionate, modest and pleasant. He was also, as were many others at the time, a staunch patriot. At the beginning of the First World War, Haber offered his services

to the German Army Headquarters. As a result of the sea blockade by the British Navy, Germany could no longer import nitrates from Chile, which hampered the production of explosives. The Haber–Bosch ammonia process solved this problem and the German Emperor Wilhelm II endowed Haber with the rank of Captain in the army—an exception because this rank was usually blocked for Jews.

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To help find a solution to the trench warfare in the West, Haber proposed using toxic gas against enemy soldiers. Numerous chemical compounds were tested for toxicity and applicability, and gaseous chlorine was first used in Ypern in 1915. The gas was heavier than air, penetrated into the trenches and was highly toxic. Later in the war both sides used even more toxic gases. Haber had a major role in promoting and organizing the gas warfare, despite criticism from contemporary scientists [2]. Ironically, Haber was forced to give up his Directorship at the Kaiser-Wilhelm Institute in 1933 because of his Jewish heritage.

Haber reflected the patriotic attitude of the society in which he lived. Regarding his role in the First World War, he said: “During peace time a scientist belongs to the World, but during war time he belongs to his country.” Nevertheless, after the suicide of his first wife in 1915, Haber expressed, perhaps transiently, doubts about his actions.

Edward Teller (1908–2003) was a nuclear physicist of Hungarian Jewish origin who made several important discoveries in physics and chemistry, but he is best known as the ‘father of the hydrogen bomb’ in the USA. At the age of 18, Teller moved to Germany, dissatisfied with the right-wing Horthy regime in Hungary. He graduated from the University of Karlsruhe with a degree in chemical engineering and received his PhD in physics at the University of Leipzig under the supervision of Werner Heisenberg. Teller eventually left Germany in 1933, first to travel to England, and then to Denmark, where he worked

with Nils Bohr in Copenhagen. In 1935, Teller was invited to the USA and became Professor of Physics at George Washington University. His experience of the Horthy regime and his emigration from Germany after the Nazis came to power instilled in him a lingering animosity towards both communism and fascism.

When Teller heard news of the discovery of nuclear fission by Otto Hahn and the possibility of a fission chain reaction, he realized that the enormous energy released could be used to design a bomb and became a proponent of this research. Teller supposedly urged Albert Einstein to sign the Einstein–Szilard letter to US President Franklin D. Roosevelt that ultimately led to the Manhattan Project and the first atomic bombs. Through the decades, Teller exerted enormous influence on political decisions, from the development and use of nuclear weapons to US President Ronald Reagan’s strategic defence initiative, and was a vigorous advocate for military strength. Teller was resistant to the ethical and even scientific arguments against the use of nuclear weapons, even when other scientists criticized the nuclear arms race. To an extent, Teller, similarly to Haber, was a patriot intent on defending his new home country from the Soviet threat.

Andrei Sakharov (1921–1989) was born in Moscow and studied physics at Moscow State University. In 1941, when the German Wehrmacht advanced to Moscow, he was evacuated to Asgabat, where he continued his work. Sakharov worked with Igor Tamm and Igor Kurchatov on the first Soviet atomic bomb, which was tested in 1949. In the 1950s, Sakharov developed nuclear reactor technology for energy production and became the ‘father’ of the Soviet hydrogen bomb. At the same time, he became concerned about the nuclear arms race with the USA. Unlike Teller, Sakharov spoke up against the atmospheric testing of nuclear weapons, and he was instrumental in the 1963 Test Ban Treaty. He wrote to the Soviet government and urged them to stop the arms race with antiballistic missiles, as a nuclear war of this magnitude could wipe out human civilization. Sakharov’s activism went beyond the nuclear arms race to include peace and intellectual freedom. In 1970, Sakharov was also one of the founders of the Committee on Human Rights in the USSR. After publication of his views—first as *samizdat*, a self-published bulletin, then in the

Dutch newspaper *Het Parool* and in *The New York Times*—the Soviet government banned Sakharov from all military-related research. Sakharov and his second wife, Yelena Bonner, suffered during the Soviet regime from the media campaign against him in 1973/74, his exile to Gorky and constant surveillance after their protest against the invasion of Afghanistan. Only after Mikhail Gorbachev came to power were the couple allowed to return to Moscow.

Teller and Sakharov were both crucially involved in developing thermonuclear bombs—the most destructive weapons ever invented by mankind. In contrast with Teller, however, Sakharov became a popular critic of his country’s political and military goals after recognizing that the so-called ‘balance of nuclear terror’ might lead to disaster.

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Although these are rather extreme examples of how scientists have interpreted their special responsibility, we can nevertheless derive some lessons. First, a well-known and respected scientist, or a small group of scientists, can exert enormous influence on politics and society. Second, it is almost impossible to keep an invention secret, even if it has great military value or can do enormous harm. Third, scientists, as with general society, vary in their behaviour. All four of these men worked on weapons of mass destruction and death, but each had different justifications and reactions to the use of their science: some claimed to be patriots, others were willfully ignorant of the wider use of their work and one of them realized the harm he had done and dedicated his life to remedying it.

The world has certainly changed since the First and Second World Wars and the Cold War. Most scientists in Western societies are now supported by public money and enjoy much more freedom than their predecessors. The question of responsibility has, however, not gone away. Numerous technological advances, from the internet to image recognition and autonomous drones, further fuel the debate

Wernher von Braun (1912 – 1977)

German rocket scientist who developed the V-2 rocket used to bomb London during the Second World War. His passion was rocketry and he seemed ambivalent about the deadly effects of his contributions to the war effort.

The propulsion unit of a V rocket bomb, developed by von Braun, set against the damage caused during one of the many Blitz raids on London during the Second World War.

A Jupiter C rocket sits on its launch pad with a satellite payload. Von Braun developed these rockets after the war for the American space program.

Fritz Haber (1868 – 1934)

Source: Bundesarchiv, Bild 183-S13851 / CC-BY-SA

The equipment used by Haber to create ammonia from hydrogen and atmospheric nitrogen under high temperature and pressure. This equipment is on display at the Jewish Museum in Berlin, Germany.

The First World War saw extensive use of poison gas in trench warfare. Haber developed gas (and gas masks) for the German military and was on hand to supervise its use.

Edward Teller (1908 – 2003)

Source: Lawrence Livermore National Laboratory

Theoretical physicist born in Hungary who emigrated to the USA in the 1930s. He became known as 'the father of the hydrogen bomb' owing to his relentless push to develop a fusion-based weapon.

In the USA, he was involved in the development of the atom bomb, which was ultimately used to bomb the Japanese city of Hiroshima (pictured), killing between 90,000 and 140,000 people.

After the war, Teller continued to be involved in both nuclear energy and weapons, including the non-military use of nuclear explosions and the development of the USA's hydrogen bomb.

Andrei Sakharov (1921 – 1989)

Source: The Hague, National Archive: ANFO, 1945-1989

Source: RIA Novosti archive, image #502968 / N. Sakharov / CC-BY-SA 3.0

Soviet nuclear physicist who received the Nobel Peace Prize in 1975 for standing up to the Soviet regime. He did not regret helping to develop thermonuclear weapons, but later spoke out against their proliferation.

Sakharov was instrumental in the development of the Soviet hydrogen bomb after the end of the Second World War. He also contributed significantly to the development of civil nuclear energy, and to research into particle physics and cosmology.

Source: RIA Novosti archive, #359290 / Yuri Abramochkin / CC-BY-SA 3.0

In later life, Sakharov joined Mikhail Gorbachev's (pictured) new parliament as a member of the opposition, but died 3 years before the formal end of the USSR.

We are grateful to Wikipedia, which served as the source of much of this information.

about the application of research. To make the point, I choose examples from molecular biology, which has become the most disputed research field by the public and has generated debate about its applications and the responsibility of scientists. It is, therefore, instructive to analyse how contemporary biologists, free from the political and ideological constraints that influenced von Braun, Haber, Sakharov and Teller, have taken responsibility for research that could do enormous harm.

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In 2001, the virology community was stirred up by a research article from Australian scientists who had tried to construct an artificial mousepox virus against the rapidly expanding murine population in Australia [3]. On the basis of previous work with poxvirus strains that caused infertility in mice, the researchers inserted the gene for interleukin-4 into the virus to inhibit an antiviral immune response and thus kill mice more efficiently. The alarming result, however, was that the virus also killed animals that had been vaccinated. Mousepox virus is closely related to human smallpox virus—one of the deadliest scourges of mankind—and the discovery has the potential to create a modified version of smallpox capable of infecting and killing vaccinated people. Indeed, poxviruses are suitable agents for biological weapons: they are resistant to heat and other environmental factors, and are highly infectious. *Variola major*, the human smallpox virus, causes disease after an incubation period of 20 days, which allows it to spread before the first symptoms appear. Imagine how our vulnerable cities and societies would be threatened by such a highly infectious agent. *Variola major* also has a high mortality rate of up to 40%. A research result obtained for a beneficial purpose could potentially create adverse uses—a situation named ‘dual use’.

The authors, Ian Ramshaw and Ronald Jackson at the Australian National University in Canberra, had intense discussions with their institute and various Australian agencies about whether to publish the results [4].

As much as we might appreciate the expertise and knowledge of individual scientists, they will almost always behave in accordance with the values of the societies in which they work

The publication led to persisting worldwide pro and contra discussion of poxvirus research. Among others, a group of high-ranking US scientists came to the conclusion that such research should be done and published [5]. One of their major arguments in favour of publishing was that today’s technologies would allow the rapid discovery of antiviral drugs and make a terrorist or military attack with smallpox less efficient. In light of the difficulty of keeping data secret, the same committee recommended open access to research in general and transparency for alerting the global research community about the finding, providing them with knowledge and the time needed to devise counter-measures, and to warn the public about impending dangers.

A year later, another publication triggered a similar discussion about dual-use research and bioweapons. The laboratory of Eckard Wimmer, at Stony Brook University in the USA, reported that they had synthesized a viable, synthetic poliovirus by using just the genome sequence of the virus [6,7]. They had first synthesized a DNA molecule complementary to poliovirus RNA and then converted this synthetic molecule into RNA and to virus particles in the test tube. Synthesizing viruses is a helpful research tool: Wimmer’s team identified a mutant that reduced the neurological effects of the virus [8]. Improving polio vaccine strains has been another important goal.

Wimmer reported that in his original draft he had included a comment on the societal and security implications of his work, but that the editors of the journal *Science* had removed this text before publication [7]. The Wimmer paper triggered concerns about using this technology for terrorist purposes, and kept the debate alive on how to handle sensitive scientific information. Perhaps ironically, Wimmer’s work was funded by the US Defense Advanced Research Project Agency, but he and his colleagues were aware of their responsibility to society to discuss the putatively dangerous implications of their research.

Most recently, two publications about the conversion of an avian influenza virus into a human pathogen drew wide attention and intense discussion about the possible misuse of biological research. Influenza viruses are species-specific, but can mutate such that they cross species barriers. Public fears arose after reports that, since 2003, some 600 humans in South-east Asia have been infected by the avian flu virus H5N1. About one-half of the infected people died, but the virus has shown no signs of human-to-human transmission. Two researchers, Ron Fouchier in the Netherlands and Yoshihiro Kawaoka in the USA, and their colleagues, began to study whether and how the avian virus could become infectious to humans and, more importantly, if it could become transmissible among humans.

The two labs discovered that only four mutations in the viral haemagglutinin gene were needed to create a highly pathogenic virus that was transmissible among ferrets, which are model organisms for human infectivity. The editors of the journals who received the manuscript, the researchers themselves and many other experts worried whether publication would inspire others to generate purposefully highly infectious human influenza virus. The virologists agreed on a 60-day moratorium to halt research on influenza to discuss the implications of these results [9].

This work on H5N1 had a precursor: the reconstruction of the Spanish flu virus that caused the devastating epidemic in 1918 in which 50–100 million people died [10]. In addition to other similarly controversial research, the flu virus reconstruction precipitated the formation of the US National Science Advisory Board for Biosecurity (NSABB), which nevertheless recommended that the paper be published. In 2011, looking at the new H5N1 experiments, both the Dutch government and the NSABB advised that it should not be published or that certain details should be concealed. After numerous discussions and after the researchers revised their manuscripts, the NSABB changed its view and advised publication in March 2012 [11,12]. It also recommended that researchers regularly seek advice from biosafety experts to recognize better the putative hazards of their research. The moratorium was extended to eight months, after which the virologists involved argued for ending the pause [13,14].

Irrespective of the dangers of misuse or the putative development of new therapies, the experiments with mousepox, polio and influenza raised awareness of biosafety issues and triggered a flood of comments from scientists, politicians and members of the public, which we might consider a good thing.

The question is whether the scientists involved acted more responsibly than von Braun, Haber and Teller. In my view, the answer is both yes and no. 'Yes' because they actively started discussions on biosecurity, dual-use research and possible abuse after the potential harm became obvious, and because they had no intention to weaponize their research. 'No' because despite the potential for misuse of their work, they still published it; we should not underestimate the publication pressure and the conditions needed to advance academic careers.

There are some differences, however, between the contemporary and the historical examples. Jackson, Ramshaw, Wimmer, Fouchier and Kawaoka live in countries that are much more liberal and open than the German Empire, Nazi Germany, the Soviet Union or even the USA of the 1950s. Their work was dedicated to the benefit of humanity: battling a pest invasion or understanding a deadly virus. By contrast, von Braun, Haber, Teller and Sakharov were actively developing weapons of mass death and destruction for the military. Even so there are striking similarities in the original motivations of the wartime scientists—they too originally sought to serve the public good: civil energy production, agriculture, space flight or a greater understanding of theoretical physics.

Should we therefore expect modern scientists, who do not live in oppressive regimes that are not directly at war, to be more responsible about the intended or unintended consequences of their work? Do they have a special responsibility to warn society about putative dangers, or would that be expecting too much of them?

The public might call for regulations or even legislative measures to control or even ban research that could be used to cause harm and that could cause harm even without misuse. However, it is the nature of research that its results and their possible use cannot be foreseen. Almost any research can create dual use—potential risks and benefits. As we might be asking too much of the

individual researcher, it has been suggested that advisory scientific committees could be established, to help where there is doubt. In January 2003, a committee of the American Academies recommended better education about responsibility, and the development of criteria to help researchers judge potential dual-use problems. Unfortunately, the discussions were driven by the biosciences and barely considered other areas of research [15–17]. Research cannot be regulated before its dual-use nature becomes apparent, unless all research efforts are to be abandoned. My conclusion is that there is only one way to achieve any progress: we need to raise awareness among scientists about the possibility of adverse uses of their inventions.

In my view, universities and research institutes should have a much more proactive role in raising awareness and supporting responsible behaviour through explicit declarations, such as the statutes of the University of California at Berkeley, which demand absolute transparency of funding resources and state that the university "does not accept classified research projects from any sponsor". Similarly, and for historical reasons, the Technical University of Berlin's constitution states a ban on arms research at the university—it was demanded by the British military government as a condition for the university to re-open after the war, but remains in place to this day—whilst the German nuclear research centre at Karlsruhe (now the Karlsruhe Institute of Technology) was founded in 1956 with the statement that "the organization pursues exclusively peaceful aims".

I see no reason why every research institution should not incorporate similar statements into their statutes. The usual counter-argument is that this would restrict the 'freedom of research and education', but I do not find this valid. Education to enhance a sense of responsibility for the consequences of their work among scientists is not an obstacle to freedom of research; certainly not more than the US Federal Communicable Diseases Act, for example, which imposes regulations and sanctions for non-registered and non-approved research on pathogens. A good start, and a goal in itself, would be to require the total transparency of funding and open access to all research data. I realize that sensitive research on police and security measures, as well as the protection of intellectual property,

requires particular attention. Both problems are certainly no obstacles for the goal of increasing awareness among scientists about adverse developments.

Would Fritz Haber, Edvard Teller or Wernher von Braun have acted differently if dual-use research and the responsibility of researchers towards society had been drilled into them as part of their respective educations? We cannot know, although one suspects that such knowledge would not have changed their actions: they were products of the societies in which they lived, in which they were educated, and in which they worked and sought recognition for their work. This problem remains today. As much as we might appreciate the expertise and knowledge of individual scientists, they will almost always behave in accordance with the values of the societies in which they work. This puts the onus on all of us, not only on the scientists. All of us should feel responsible for upholding moral values, for educating the next generation about those values and for making responsible decisions about the use of inventions.

ACKNOWLEDGEMENTS

In memory of the charismatic physicist Peter Buckel. I am grateful to Peter Walter (University of California San Francisco), Klaus Eyferth (Technical University Berlin, Berlin) and Aspasia Ploubidou (Fritz Lipmann Institute, Jena) for their comments.

CONFLICT OF INTEREST

The author declares that he has no conflict of interest.

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EMBO reports (2013) **14**, 759–764; published online 13 August 2013; doi:10.1038/embor.2013.116