CENDARI Archival Research Guide: Science and Technology in the First World War

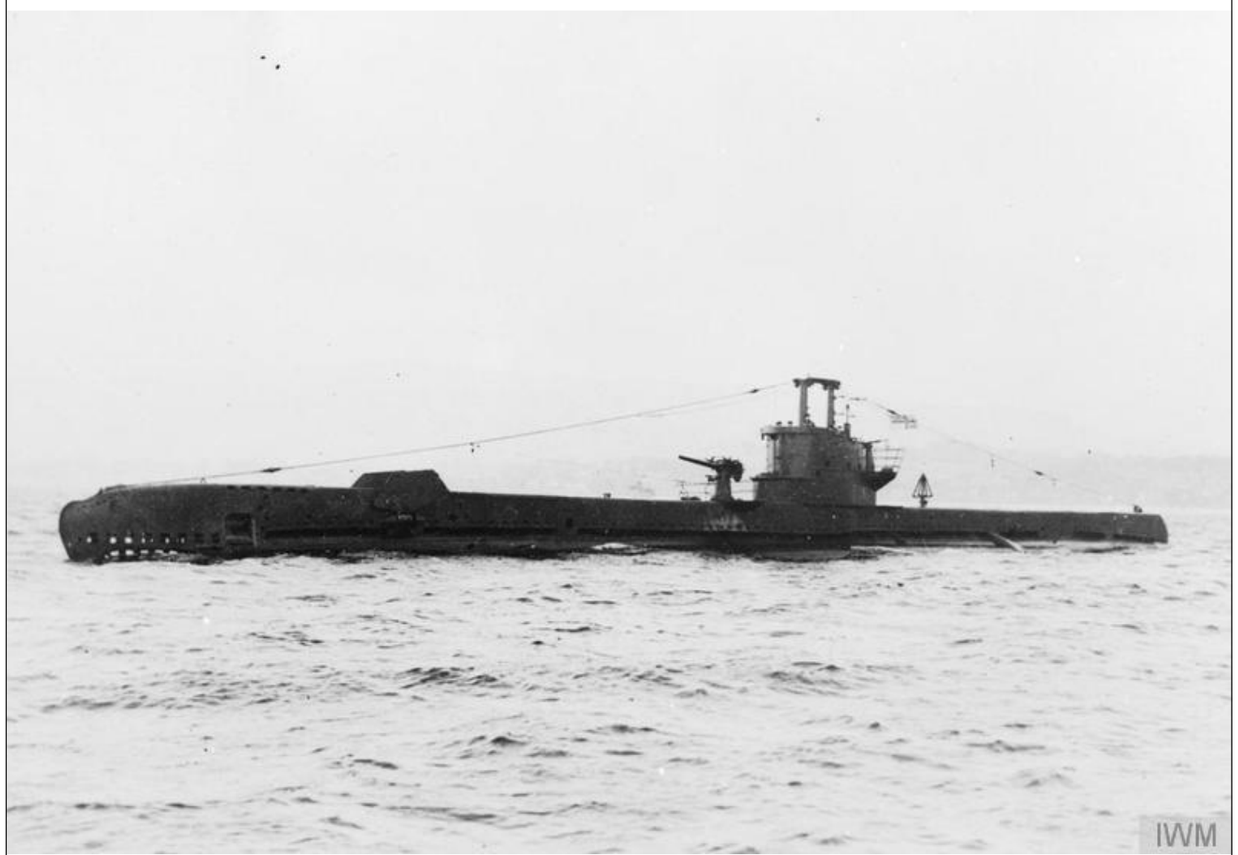
Research · December 2016

DOI: 10.13140/RG.2.2.12462.92488

2 authors:

Jörg Lehmann
Universität Bern
23 PUBLICATIONS **3** CITATIONS
SEE PROFILE

Francesca Morselli
Trinity College Dublin
4 PUBLICATIONS **1** CITATION
SEE PROFILE



British Submarine 'S' Class

CENDARI
COLLABORATIVE EUROPEAN DIGITAL ARCHIVE INFRASTRUCTURE

SCIENCE AND TECHNOLOGY IN THE FIRST WORLD WAR

AUTHOR(S)	Jörg Lehmann
COLLABORATOR(S)	Francesca Morselli
THEMES	World War I, Science, Innovation, International Research Institutions
PERIOD	1909 - 1938

CENDARI is funded by the European Commission's 7th Framework Programme for Research

TABLE OF CONTENTS

ABSTRACT

The subject “Science and Technology in the First World War” has so far been treated from the perspective on inventions and the development of new weapons, and often the focus has been on the topic of chemical warfare at the expense of other important dimensions. The approach of this Archival Research Guide, by contrast, comes from the social sciences and focuses on the establishment of relevant scientific, military and governmental bodies and on the personal networks established during the war. By examining these institutions and networks country by country, comparisons between them can be drawn, enabling further research with regard to the sociology of institutions. By pointing to the connections and channels of exchange between the nations and institutions under consideration, this approach opens up a transnational perspective and supports the paradoxal insight that transnational ties can dissolve national obstacles while simultaneously strengthening the nation-states themselves. On the individual level, the ARG takes the role of intellectuals into account, for whom scientific objectivity / neutrality and patriotic commitment seemed to have been no contradiction. It is remarkable that the First World War led to the establishment of several institutions aiming at funding science through the state, most notably in the case of France (CNRS), the U.S. (NACA/NASA) and Russia (KEPS).

Note of the Author

The text of this Archival Research Guide follows in each country section a certain structure: General introduction, a paragraph about the Academy of Sciences of each country, and a paragraph for each body / institution including the networks of scientists working in these institutions. The records for these bodies can be found in extra notes which have been linked to the main text of the Archival Research Guide. The selected institutions serve as case studies and as an example of archival and contextual analysis on which the CENDARI author has worked on. Since the selection of institutions portrayed is far from exhaustive, please feel free to contribute with descriptions of further bodies, boards, committees and networks of scientists by adding paragraphs to the text of the ARG. The selection of the case studies follows the following criteria:

- The case studies should describe institutions which connected science, industry, the military as well as governmental bodies in belligerent countries during the First World War.
- Each body or institution described should be added beginning with a new paragraph, and the most important persons related to these institutions should be named in the text.
- The social background of the individuals within the networks should be noted in order to enable subsequent readers to receive an impression about their motives to engage in war-related research.
- Special emphasis should be put onto institutions and individuals for whose commitment continuities in the interwar years can be noted, in order to enable transnational comparisons and lasting establishment of bodies created during the First World War.

The author suggests that the researchers contributing to and adding new case studies follow the recommendations stated above.

INTRODUCTION

The main outcome of the First World War with respect to Science and Technology was an unprecedented rationalization of production resulting from the new involvement of science and technology in war. Nevertheless, classical historical research has focused on more ‘tangible’ outcomes such as inventions and the development of new technologies, like chemical warfare, new weaponry, the development of planes, tanks and submarines, cameras and lenses, or wireless radio transmission; or on the development of a political consciousness of scientists and the role of science in propaganda battles, for example the famous 1914 manifesto of German scientists “An die Kulturwelt”, signed by 93 leading intellectuals. But viewed against inventions achieved during the Second World War like the atomic bomb, short-range rockets, and the development of radar technology, the First World War did not result in comparably singular inventions. To fully understand the extent of transformations resulting from new forms of interdisciplinary collaboration between science, the military and industry, and the resulting change in patterns of scientific and technological organization, the network of individual scientists, intermediary institutions between science and the military and the connective tissues with the industry have to be studied. This can be done at best at the level of the belligerent states. Based on these institutions and the networks of individuals, the connections and exchanges established between the states can be explored in order to enable a focus on the transnational dynamic of disseminating scientific expertise and assistance and to make comprehensible the shift within the transnational scientific network. Thus the emergence of a transnational community and scientific network comes into perspective, a transnational structure which gave shape to the social space of international science and to the foundation of new transnational institutions after the First World War.

Munitions Production on the Home Front
in Great Britain, 1914-1918

MAJOR RESEARCH ISSUES

If any of the belligerent nations were to win the war, it would have to master industrial mass production and the logistical challenge of supply with materiel and men. It is here, at the organizational and production level, where the major impact of science in war can be researched. Still, there are no systematic and synthesizing studies on the relation of the scientific community and the military. This is the result of nationally oriented research traditions, but also of the obvious obstacles to transnational research and the scope of the subject. Here subjects of comparison could be: the initial mobilization and industrialization of science before the First World War (especially with respect to investment in dual-use products); mobilization and discovery of resources; amount of funding by state and non-state actors; training of professionals; mono-centric vs. multi-centric industrial bases, i.e. national vs. allied endeavours and exchange of knowledge; degrees of system-driven innovations indicating the intensity of entanglement between science and industry.

From a general point of view, Germany was seen as the scientifically most advanced country before the First World War, since it had developed the capacity to industrially organize its scientific output, a fact which facilitated the organization of industrial production in wartime. The outbreak of the war led to the fragmentation of a shared European intellectual community into separate national entities. While German science became isolated – as was the case with Russia, where the war broke scientific communications and contacts with colleagues from belligerent nations until the end of the Civil War in 1920 –, the allies were able to maintain international scientific collaboration, as well as to expand it and to create new institutions. This development led to a shift in the relative strength within the scientific network, resulting in a valorisation of the position of the US, which developed into the leading scientific power during the First World War, and Germany losing completely its primary position in the scientific field. After the First World War, priority was placed on the rebuilding of networks of international scientific collaboration, which found its expression in the foundation of institutions like the International Research Council and the Union Académique Internationale in 1919, and which followed a policy of long-term ostracization of Germany.

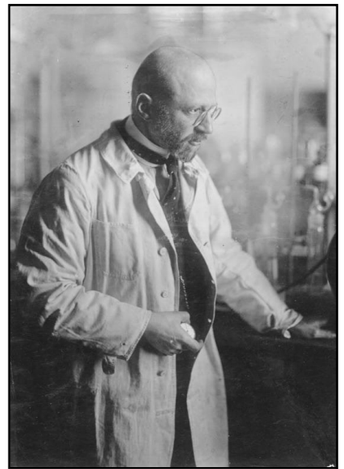
Gas attack photographed from the air
© IWM (Q 27526), Imperial War Museum [IWM Non Commercial Licence]

In order to comprehend this shift within the scientific community and to characterize the development of the network between science, the military and the industry as well as its transnational dimension, biographical sources of the persons involved as well as the documentation on the intermediary institutions between science and military during and after the war have to be studied. While the networks of individual scientists can be researched through the letters, diaries and memoirs provided by them, the records of the institutions founded during and after the war provide information on the development of the scientific-military-industrial complex. Tools like Named Entity Recognition and the visualization of most common persons provided in CENDARIs Note Taking Environment assist researchers in grasping the developments and adjustments within the networks. In this way, the new levels of cooperation between scientists and engineers, industrialists and military leaders can be put into perspective. Special attention should be paid to the scientific liaison between the belligerent nations, individual persons not only providing for connections during wartime, but also for the establishment of scientific collaboration after the war, especially in its most important institutions, the International Union of Academies and the International Research Council.

Germany

Before the First World War, the German Empire had already been the leading scientific country in the world. Close connections between academic science, industry and the government had already been established with the founding of the Kaiser-Wilhelm-Gesellschaft in 1911 with its president, the theologian Adolf von Harnack, the recipient of the Nobel Price in chemistry Emil Fischer, who served as chairman of the administrative board, and members like physician and chemist Walther Nernst, industrialist and chemist Franz Oppenheim, and the politician and collaborator of the Reichsjustizamt Ernst Trendelenburg, who served as secretary general of the Kaiser-Wilhelm-Gesellschaft between 1912 and 1918. Several senators of the Kaiser-Wilhelm-Gesellschaft belonged to the government of the German Empire. The institutes founded by the Kaiser-Wilhelm-Gesellschaft were financed by the upper classes and Jewish bankers; industrialists like Alfred Krupp and financier Leopold Koppel can serve as examples here.

Koppel financed the Kaiser-Wilhelm-Institute for Physical Chemistry und Elektrochemistry, inaugurated in 1912, for which chemist Fritz Haber served as the first director. German scientists had thus already established contacts and cooperation with industry, and the outbreak of war brought forward a dense entanglement between scientists, industrialists and military leaders. The famous manifesto “An die Kulturwelt”, which was signed in October 1914 by 93 leading German intellectuals, illustrates a hitherto unknown willingness of scientists and engineers to serve the German cause and to commit themselves to their nation. In comparison with other countries, this degree of self-mobilization was unprecedented. Researching the networks of these individuals and organisations on a broad basis would therefore answer the question of what motivated a whole social group like the mostly bourgeois, often Jewish scientists leave behind their international scientific networks and seek recognition by the military – a preserve of noble privilege – and to set aside all moral and ethical qualms.



Fritz Haber
Bundesarchiv, Bild 183-S13651, via Wikimedia Commons [CC-BY-SA 3.0]

There is already a considerable research literature on hand for prominent examples, such as: Fritz Haber, the so-called “father of chemical warfare”, who was born into a Jewish family and promoted to the rank of a captain, worked in the Kaiser-Wilhelm-Institute for Physical Chemistry and Electrochemistry and in Walther Rathenau’s Raw Materials Depart-

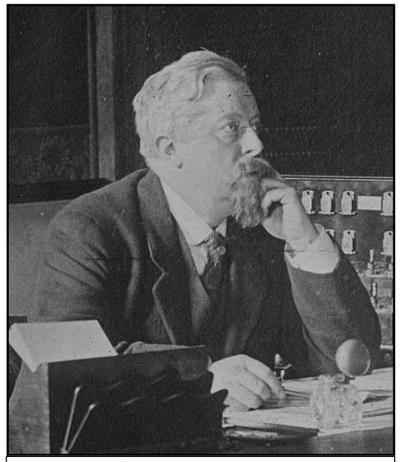
ment, and who was made head of the Chemistry Section in the Ministry of War. Scholarship has also addressed Emil Fischer, who was working with industrialist Carl Duisberg and Walther Nernst in the War Ministry, in the Kaiser-Wilhelm-Stiftung für kriegstechnische Wissenschaft (Kaiser Wilhelm Foundation for the Science of War Technology), and in close cooperation with companies like Bayer, BASF and Hoechst. But there are several other institutions and individuals, who have not yet or only marginally been in the focus of research. The best entry point for research on this subject remains the Kaiser-Wilhelm-Gesellschaft with its several institutes; the records of the KWG as well as the legacy of several scientists can be found in the archives of the Max-Planck-Gesellschaft zur Förderung der Wissenschaften, in the archives of the Berlin-Brandenburg Academy of Sciences and the Secret State Archives Prussian Cultural Heritage Foundation. Particularly committed to research was the Kaiser-Wilhelm-Institute for Physical Chemistry and Electrochemistry, financed by the Koppel-Foundation, where only one year after the outbreak of the war more than 1.500 members of staff worked. The Aerodynamische Versuchsanstalt in Göttingen had been founded in 1907 under the name "Modellversuchsanstalt für Aerodynamik der Motorluftschiff-Studiengesellschaft" with Ludwig Prandtl as its head; in 1915 the Kaiser-Wilhelm-Gesellschaft became engaged in this society, and it was formally incorporated into the KWG at the end of the war under the name "Aerodynamische Versuchsanstalt der Kaiser-Wilhelm-Gesellschaft" (AVA). The Kaiser-Wilhelm-Institute for Chemistry became involved in war-related research under its director Ernst Beckmann during the second and third year of war. One of its departments was headed by Otto Hahn. In 1916 the Kaiser-Wilhelm-Stiftung für kriegstechnische Wissenschaft was founded and also financed by Leopold Koppel via his Koppel-Foundation. To prepare the foundation of the Kaiser-Wilhelm-Stiftung für kriegstechnische Wissenschaft, Fritz Haber and Friedrich Schmidt-Ott, an assistant secretary of state in the Kultusministerium and later Prussian Minister of Culture, had led decisive conversations and drafted the charter. After the war this foundation was separated from the war ministry and attached to the Reichsministerium des Inneren, and it was renamed the Kaiser-Wilhelm-Stiftung für technische Wissenschaft. Though much of this foundation's records have not survived, it is a good example of the preparedness of the military to finance research related to military-technological questions without being directly influenced by the military. Generally, the Kaiser-Wilhelm-Gesellschaft and its institutes provide for the most interesting examples of the entanglement between science, industry and the military, since its administrative department was enlarged during the war by the entrepreneur Friedrich Springorum, the Jewish Banker Arthur Salomonsohn, the Silesian entrepreneur and researcher Paul Schottländer, and the chemist and industrialist Carl Duisberg. The relation of the Kaiser-Wilhelm-Gesellschaft vis-à-vis the state changed massively during the war due to the financial commitment of the administration of the army and the navy. Even though this influence reduced after the war, the KWG explained its orientation towards applied science only ex post.

Beyond the Kaiser-Wilhelm-Gesellschaft, several other institutions are relevant here, especially the ones at Göttingen, where close connections between science and the military were established and whose roles within the 'Göttingen system' have not yet been fully explored. Amongst them are the Institut für angewandte Elektrizität (Institute for applied electricity), which had been founded in 1905 by the physicist Hermann Theodor Simon, and where the army and the navy in collaboration with the mathematician and politician Felix Klein established a station to experiment with wireless telegraphy. In 1912, the Wissenschaftliche Gesellschaft für Luftfahrt (Scientific Society for Aviation) was founded in Göttingen, where Ludwig Prandtl was involved and whose board incorporated representatives from science, industry, state and the military (for a visualisation of the relations between Ludwig Prandtl and Felix Klein follow this link). Finally, also in 1912 the Deutsche Versuchsanstalt für Luftfahrt was founded in Berlin-Adlershof; it had colonel Hugo Schmiedecke and colonel Hermann Rieß von Scheurnschloß as its first presidents and established a body of civilian scientists and engineers to research on aviation.

It is remarkable that after the war and the ostracization of German science in the international scientific community, a lot of aforementioned scientists, notably Fritz Haber, Friedrich Schmidt-Ott, Adolf von Harnack, Max Planck and Hermann Diels founded in 1920 the Notgemeinschaft der deutschen Wissenschaft (Emergency Association of German Science), whose first president was Friedrich Schmidt-Ott. This Emergency Association was renamed in 1929 as the Deutsche Gemeinschaft zur Erhaltung und Förderung der Forschung, or, in an abbreviated and nowadays more common form, the Deutsche Forschungsgemeinschaft (DFG; German Research Foundation)

France

In France important scientific research and teaching structures existed long before the First World War, but basic research was not funded by the state and linkages between scientific research and industry were weak. The most obvious example for this can be seen in the realm of chemistry, where connections between science and industry were weak and products had to be imported from Germany, where such linkages were the strongest in Europe. Only in aviation there existed a vital collaboration between science, technology, and industry, thanks to such figures like the constructing engineer Louis Blériot. Another exception is to be found in the field of research on explosives, since there had been established a *Commission des substances explosives* with chemist and biologist Marcellin Berthelot as its president; this commission had been founded during the Franco-German War of 1870. In 1887 a *Commission d'examen des inventions intéressant les armées de terre et de mer* had been founded which included Marcellin Berthelot and several other members of the French Academy of Sciences. The First World War provided a strong stimulus to establish relations between science, technology and industry, and since there was a consensus between scientists and politicians that these relations should be established on a broad basis and that existing institutions and structures should be reformed in order to achieve a new place for science in society, institutionalization was the consequence. Finally, the social background of the persons involved should be examined; though some of the scientists and industrialists involved came from the French nobility - especially the ones committed to aviation -, most of the scientists came from the *haute bourgeoisie*. Their commitment to the war effort has to be judged within the broader development in the relations between



Jules-Louis Breton
Library of Congress digital ID ggbain.30110
[No known restrictions on publication]

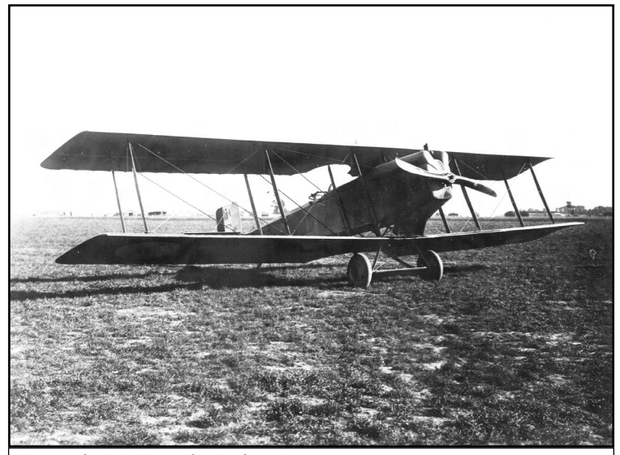
science, society and the state, i.e. a history of the intellectuals, since only 16 years had passed between the famous "J'accuse"-manifesto launched by Émile Zola (which heated up the Dreyfus Affair) and the beginning of the First World War.

The best example for this and its focus on inventions can be seen in the instalment of a Commission supérieure des Inventions, which was put in place in the first days of war and led by the mathematician Paul Appell. Though the establishment of this commission encouraged a general mobilization of scientists, it was only in November 1915 that a Direction des Inventions intéressant la défense nationale was set up by the mathematician Paul Painlevé, who had become the minister of education in October of that year. The retarded creation of the *Direction des Inventions* can be explained by the belief of many politicians and the military in a short war. The purpose of the *Direction des Inventions* was to evaluate incoming proposals by inventors on the basis of their potential contribution to industry, economy and defense, to enhance interactions between science and the industry and to back up scientific mobilization. The *Commission supérieure des Inventions* was attached to the *Direction des Inventions*, and the latter underwent several transformations in the following years.

In December 1916 it was transferred to the *Ministère de l'armement et des fabrications de guerre* and elevated to a *Sous-secrétariat d'état* headed by Jules-Louis Breton, an inventor and socialist politician. In April 1917 it was renamed to S*ous-secrétariat d'état des inventions, des études et des expériences techniques* and in September 1917 it was transferred to the Ministry of War. The fact that the *Direction des Inventions* did not cease with the end of the war shows that it and especially Jules-Louis Breton had proven that they were capable of supporting the inventors for the benefit of the whole country. After the war, Breton was elected a member of the Academy of Sciences. Under his influence, the *Direction des Inventions* was again attached to the Ministry of Public Instruction and in 1922 transformed and renamed the *Office National des recherches scientifiques, industrielles et des inventions* (ONRSII). The strong tendency in France to institutionalize and to maintain these institutions can be read from the further development of the *Office National*: Up to 1938 it existed with Breton as its director, and was then reorganized into the *Centre national de la recherche scientifique appliquée*, which was fused in 1939 with the *Caisse nationale de la recherche scientifique* to form the *Centre national de la recherche scientifique* (CNRS) – nowadays the largest governmental research organization in France. Obviously Breton had made good use of his connections established during the war, and the Office national shifted its focus from evaluating inventions towards scientific discovery, the interaction of science and technology, funding by the state and fostering close connections with governmental departments, industry and the military.

A comparable tendency to keep institutions after they had been founded can be observed in the realm of chemistry. At the beginning of the war, the number of French academic chemists was one-tenth of Germany's. In September 1914, the Office national des produits chimiques et pharmaceutiques was founded, with the chemists Auguste Béhal as head and Amand Valeur as its secretary general, and within which renowned scientists like Octave Boudouard, member of the *Collège de France*, were engaged. The *Office des produits chimiques* supported the French industry to overcome its dependence on German enterprises and technical equipment. Furthermore, the *Office des produits chimiques* rendered assistance to the foundation of production sites, since the war had disrupted the trade of chemical and pharmaceutical products. The quick upsurge of the French industry can be read from the reaction after the famous 22 April 1915 attack by the Germans. Neither Marshal Ferdinand Foch nor any of the scientists involved hesitated to develop comparable weapons. A committee on chemical warfare research was quickly set up which consisted of General Perret, Charles Moureu of the Collège de France, the physicist and chemist André Kling, the chemists Paul Lebeau and Victor Grignard (Nobel Prize winner for chemistry in 1912), and several other professors in French schools and faculties. Only two years later the French were able to reply in kind to the Germans, and the concentration of French chemical factories located along the Western front remains to this day. In terms of efficiency, the increase of production and the resourcefulness of the French scientific community and allied industry was enourmous in the case of gas warfare, even though the moral implications never seem to have been debated. Because of industrialized chemical production' dual use, covering civilian and military needs, and because the cooperation between the French government, science, and industrial chemistry was estimated to be functioning well, a *Commission des études et experiences chimiques* was established in the 1920s in the Ministry of War, with Charles Moureu and several people remaining in similar functions to regulate the import of chemical, pharmaceutical and dyes products. Though the *Office des produits chimiques* ceased to exist as an organization, it was founded again as the *Direction des industries chimiques* within the Ministry of Industry in September 1940.

Another field in which the quick upsurge of French industries and their close collaboration with scientists became visible was aviation. Before the war, there existed an Institute Aérotechnique at the University of Paris, whose laboratory was installed at the military school of Saint-Cyr. During the First World War it was put at the disposal of the army and became the headquarters of the newly created Section Technique de l'Aéronautique Militaire, with captain Emile Dorand at its head. Here, distinguished persons such as the aristocrat, industrialist and scientist Armand de Gramont (the duc de Guiche), engineer and inventor Henri Chrétien, the industrialist Émile-Louis Letord, and the engineer Albert Étévé were visible. A wind tunnel was constructed during the war, and the military created a station for testing and comparing the performance of different motors in a cold atmosphere. Until the end of the war, this institution grew in one of the best-equipped aeronautics laboratories in the world. The research section of the Institute Aérotechnique continued to exist until 1933, when it was dissolved by Paul Painlevé, who had by this time become minister of air. The *Section Technique de l'Aéronautique* was reorganized in 1919 and renamed into *Service Technique de l'Aéronautique* (STAé) and continued to exist up to 1980.



Dorand AR 1 (French Airplane)
Image by Air Service, United States Army [Public domain, Permission USGOV-PD], via Wikimedia Commons

Great Britain

The British had already in 1909 formed an Advisory Committee on Aeronautics, which set the precedent for the organization of inventions research in Britain. Its members included Dr. Richard Glazebrook, then director of the National Physical Laboratory, who served as chairman, Maj.-Gen. Sir Charles Hadden, Capt. R.H.S. Bacon, Sir G. Greenhill, Dr. W.N. Shaw, Horace Darwin, H.R.A. Mallock, Prof. J.E. Petavel, and F.W. Lanchester. During the war, the Royal Society set up a War Committee at Burlington House including William Ramsay, Sir Oliver Lodge, Sir Alfred Ewing, R.J. Strutt (later Lord Rayleigh), Arthur Schuster, and Richard Glazebrook, and others. It aimed at providing assistance to the government on scientific investigations related to the war. Several fellows of the Royal Society also took part in a whole range of committees and boards attached to ministries like the War Office, the Ministry of Munitions and the Admiralty. Amongst these committees and boards, the most notable ones were the Board of Invention and Research (BIR), which was installed with the Admiralty, and the Munitions Inventions Department (MID) at the Ministry of Munitions. Most of these committees and boards did not outlive the First World War, with the remarkable exception of the Committee for Scientific and Industrial Research, which became in 1916 the Department of Scientific and Industrial Research (DSIR) and which was maintained until 1965. The task of these committees and boards was usually to check incoming proposals by British inventors for applicability, but also to initiate and encourage scientific research. International scientific cooperation after the First World War was pursued by the Royal Society and its secretary, Franz Arthur Friedrich Schuster. Even though (or because) most of the institutions under consideration here were dissolved at the end of the war, the dense networks of scientists, the duplication of their functions and their collaboration with the military as well as the precedent they set in involving civilian scientists in the organization and administration of science have not yet been intensely studied.

On 12th November 1914, the Council of the Royal Society decided to offer its services to aid Government work. 250 years after its foundation, the Royal Society thus gave up its political neutrality, which had been seen to be founded in scientific objectivity. Though it cannot be expected that this reappraisal of the role of the scientist in society is reflected in the personal papers of Fellows of the Royal Society (FRS), this process has to be seen in the larger context of the intellectual vis-à-vis the state, and it is proof of the fact that nationalism had reached its unquestioned height with the beginning of the First World War. The Council of the Royal Society appointed a War Committee, which informed the Admiralty, the War Office, and the Board of Trade of their collaborations, and Government bodies returned lists with research questions and tasks. They then set up several Government committees like the BIR and the DSIR, populated partly with Fellows of the Royal Society. Within the Royal Society, several Sub-Committees were formed, concerned with chemistry, engineering, physics, food, grain pests, natural products, and physiology. The Sub-Committees not only consisted of Fellows of the Royal Society, but also included at times military men, like Colonel Sir Frederic Nathan, who was member of the Natural Products Committee, and Captain A.E. Boycott, who participated in the Sectional Committee on Physiology. In this way the Royal Society responded to the technical challenges of the First World War and to the lack of supplies from German factories, especially regarding pharmaceutical drugs and photographic components. Fundamental research was undertaken for example in the National Physical Laboratory (NPL) with Sir Richard Glazebrook as its Director between 1899 and 1919, and the costs were shared between the Royal Society and the Treasury; during 1918 the NPL was transferred to the Department of Scientific and Industrial Research. Like in the other belligerent nations, the overlap between the Royal Society and the Government was manifold: Several Fellows were prominent Members of Parliament (like Arthur James Balfour and Winston Churchill) and/or members of Government, or they worked in government-sponsored occupations at home and abroad, like Sir Basil Mott, an engineer who worked in France on defense schemes and on various Government Committees, or Sir Alexander Fleming, Captain in the Royal Army Medical Corps, who worked at the wartime laboratory for medical research at the casino in Boulogne.

Interestingly enough, the British case also provides an example of failure in the collaboration between scientists and the military. The Board of Invention and Research (BIR) existed between July 1915 and September 1917. It was created on the initiative of A.J. Balfour as the First Lord of the Admiralty and resulted from the need for the provision or invention of new weapons and the munitions shortages faced by the Royal Navy. The task of the BIR was to sort out propositions by inventors and to sponsor scientific research of value to naval warfare and was designed as a body of scientists preoccupied with basic research. Admiral John "Jackie" Fisher, the former First Sea Lord, became the first chairman of the BIR, and it had a central committee consisting of three eminent scientist (J.J. Thomson, Cavendish Professor of Experimental Physics at Cambridge and discoverer of the electron, Sir Charles Parsons, inventor of the steam turbine, and Dr. (later Sir) George Beilby, chairman of the Royal Technical College, Glasgow. The consulting panel consisted of twelve scientific experts with four chemists, four physicists (amongst them Sir Ernest Rutherford, Prof. W.H. Bragg, and R.J. Strutt, later Lord Rayleigh), three engineers (Mr. William Duddell, Mr. Gerald Stoney, and Professor Bertram Hopkinson, Professor of Mechanics at Cambridge), and one metallurgist. Only three military officers were present in its sub-committees. The activities of the BIR were targeted in such diverse areas as the use of helium instead of hydrogen in airships, the lighting of aerodrome runways, the research on metal erosion and corrosion, and on anti-submarine devices. Furthermore, the BIR cooperated with the French Ministry of Inventions, even if the most liaisons between British and foreign governmental institutions were established by military officers. Although the BIR acquired a reputation particularly through its anti-submarine research, it was ineffective in facilitating cooperation between the BIR and the Navy, and its approach to basic and fundamental research was in contrast with the Navy's focus on pragmatic, trial-and-error approach to research and development. These constraints led to the dissolution of the BIR in September 1917, and it was reduced to the central committee in December 1917, while research work was transferred to a new department of the Director of Experiments and Research (DER) under Charles Merz.

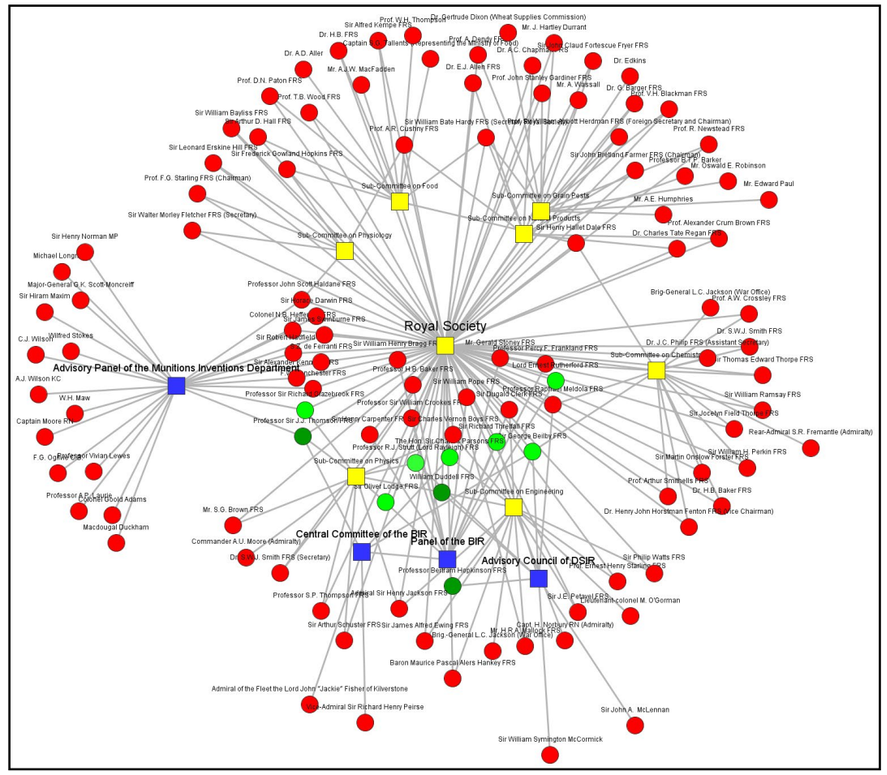
British Tank
Image by Europeana 1914-1918, [Public domain]

Much like the BIR, the Munitions Inventions Department (MID) of the Ministry of Munitions was established in August 1915, when the government faced shortages of essential supplies, and it aimed equally at sifting through inventions proposals. Lloyd George, the First Minister of Munitions, chose engineer Mr. E.W. (later Sir) Ernest Moir as a chairman, who set up the MIDs Advisory Panel consisting of Sir J.J. Thomson, FRS, Professor Richard Glazebrook, FRS, Mr. (later Sir) Horace Darwin, FRS, civil engineer and founder of the Cambridge Scientific Instruments Company, Sir Robert Hadfield, FRS, metallurgist and managing director of Hadfields Ltd, steel manufacturers, Professor J.S. Haldane, FRS, Reader in Physiology at the New College in Oxford, S.Z. de Ferranti, founder of Ferranti Ltd, electrical engineers, F.W. Lanchester, consultant aeronautical and motor engineer, and three military officers from the War Office.

Development of Mortars in the First World War
© IWM (Q 70282), Imperial War Museum
[IWM Non Commercial Licence]

The Advisory Panel grew to forty-eight members in 1918, seventeen of whom were Fellows of the Royal Society (FRS), and with notable duplications and overlaps with other bodies like the BIR, the DSIR, and the Air Inventions Committee. The MID incorporated university and industrial laboratories, private workshops, and government agencies such as the National Physical Laboratory. The emphasis of the department's work shifted during the war from evaluating inventions to initiating research programmes. The MID facilitated the development of a machine-gun belt, a gyroscope, a number of gunsights and signalling instruments, a prototype tank, and the Stokes mortar invented by Mr. F.W. (later Sir) Wilfred Stokes. Remarkable is also the Anti-Aircraft Experimental Section (AAES) of the MID, which was founded to provide a comprehensive training scheme for anti-aircraft gunners developed by physiologist Archibald Vivian Hill, who was to become one of the most prominent figures in military scientific research during the inter-war years, besides Henry Tizard and H.E. Wimperis. The MID was dissolved on 1 July 1919, and none of the scientists partaking in the Advisory Panel continued in military service. As with most bodies created during the First World War in Great Britain, the significance of the MID lies not with the inventions and development of weapons produced, but with the experience gained in establishing connections between scientists and the government.

The institution that was set up from the beginning for the longer term was the Department of Scientific and Industrial Research (DSIR). Its predecessor, the Advisory Council, was conceived within the Board of Education in July 1915. Already in autumn 1914, a scheme had been drafted by Christopher (later Viscount) Addison and Frank (later Sir Frank) Heath and related to Sir Joseph Pease, President of the Board of Education. After the Cabinet reshuffle of May 1915, Sir Lewis Amherst Selby-Bigge prepared this scheme and presented it as a White Paper in July 1915, which already underlined that the new Advisory Council would not be confined to be a wartime phenomenon. Sir William Symington McCormick was to become the first chairman of the Advisory Council, and it also included three industrial chemists (Sir George Beilby, Raphael Meldola, head of Finsbury Technical College, and Sir Richard Threlfall, consulting engineer and manufacturing chemist), two engineers (William Duddell and Bertram Hopkinson, who were at the same time members of the BIR) and two physicists (R.J. Strutt, later Lord Rayleigh and J.A. (later Sir John) McLennan, Professor of Physics at Toronto, who was currently working on antisubmarine measures). The task of the Advisory Council was to initiate and fund specific research, to support work in special scientific and technical institutions, and to direct research in technology and the physical sciences in Britain. In November 1916, the Advisory Council was confirmed as the Department of Industrial and Scientific Research (DISR), a name which eventually changed to Department of Scientific and Industrial Research (DSIR). Other than f.ex. the KEPS Commission in Russia (see below), it did not encourage scientific education funded by the state and linked with pure and applied research; teaching still remained separated from research, and research separated from industry. In this respect, the DSIR missed the chance to establish closer links between science and industry.



Visualization of the network between Fellows of the Royal Society and Governmental bodies. Individuals are shown as circles, bodies and committees as squares. Colour codes: Individuals are generally shown in red, individuals with dense networks in green. Royal Society committees are shown in yellow, governmental bodies in blue. The individuals in the center are all Fellows of the Royal Society, the individuals on the circle ring come from the government, administration, the military, or else. This visualization can be found in a higher resolution over here. It has been created by Jörg Lehmann for the CENDARI project, using the free software Visone.

USA

The U.S. developed into a major, if not the leading scientific power during the First World War. This hypothesis is substantiated by the fact that the U.S. started already in 1915 with the institutionalization of several bodies where research, the military and the industry closely collaborated – even though the official declaration of war against Germany was to be effected only on 6 April 1917. It is therefore crucial to see that the pressure to take decisions towards the founding of several institutions sprang from the economy, since several countries like Great Britain, France and Russia had placed orders for weapons, munitions, raw materials and industrial products in the U.S. The common interest between industry, the military, the state and science led in the U.S. to the most obvious development of a scientific-military-industrial complex. The United States started very early to share scientific information with their allies, and the First World War can be seen as the beginning of the intense relationship between the U.S. and Great Britain in terms of security and defence science. As early as March 1915, the National Advisory Committee for Aeronautics (NACA) was founded as a U.S. federal agency, which was to become NASA in 1958. In July 1915, a Naval Consulting Board was established on the proposition of the inventor and industrialist Thomas Edison, and he was also the one to bring forward the idea in May 1915 to create a Naval Research Laboratory (NRL), for which the Congress allocated in 1917 significant funds. From the side of the state, a Council for National Defense was created in 1916 with the task of advising decision-makers in the government, to coordinate military and civilian departments of state in munitions and other fields, and to place industrial goods and services during the war. From the side of science, the National Academy of Sciences (NAS) created in September 1916 the National Research Council (NRC); from the beginning of 1917 it was to become under the name *Department of Science and Research* part of the Council for National Defense. The National Research Council founded in December 1917 a Research Information Committee (RIC, which was later renamed into Research Information Service RIS). Finally the Chemical Warfare Service (CWS) came into being first as a Gas Service Section in 1917, the CWS was formally established in June 1918; only in 1946 it was renamed the Chemical Corps.

It is not easy to discern the networks and close collaborations established during the First World War between science, the military and the industry. At the same time it is remarkable that the transnational scientific liaisons during and after the war are especially well visible from the example of the U.S., and several central individuals in the networks should be highlighted. To begin with science, the astronomer George Ellery Hale had since 1903 been the foreign secretary of the United States National Academy of Sciences (NAS) and played a key role in supporting the government in using science for military ends. He had been delegated to the International Association of Academies in 1907, and he mobilized physicist Robert A. Millikan from the University of Chicago and Arthur A. Noyes from MIT to support the foundation of the National Research Council (NRC), whose first meeting took place in September 1916; Hale became the first chairman of the NRC and Millikan the vice-chairman. Hale and pathologist William Welch were accredited by the State Department for the first official scientific mission to Britain and France in 1916. In early 1917, the NRC took up contacts with the scientific academies and London, Paris, St. Petersburg and Rome, and the French and British governments sent delegations to the United States. From France came physicists Charles Fabry and Henri Abraham, industrialist and scientist Armand de Gramont, chemist Victor Grignard, and the wireless expert Lieutenant Paternot. The British sent physicist Sir Ernest Rutherford and Commander Cyprian Bridge. The Italian physicist Giorgio Abetti was to join the mission, sent by the Italian Inventions Board; he later became military attaché in Washington. In June 1917 a conference was organized by the NRC which provided for scientific exchange on a high level; the physicists Henry Andrew Bumstead, Nobel Prize winner Albert A. Michelson, John Zeleny and Ernest Fox Nichols of Yale took part. The National Research Council was also responsible for establishing the Research Information Committee (RIC) in December 1917, whose task was to provide the linkages with the offices of Military and Naval Intelligence and to coordinate their international scientific activities. Its first chairman became Samuel W. Stratton, director of the National Bureau of Standards and later president of the MIT. Science attachés were appointed in January 1918 and sent to Europe: engineer William Frederick Durand (who had formerly been working with the National Advisory Committee for Aeronautics) was sent to Paris together with his deputy Karl T. Compton, Henry A. Bumstead to London, engineer Samuel L.G. Knox to Rome. The offices in London, Paris and Rome sent reports on a weekly basis, and the RIC was to receive, index and distribute these records to the American military agencies. Especially Bumstead was able to create a large network around himself. In July 1918 it was renamed the "Research Information Service" (RIS) after a direct liaison between the RIC and the Information Section and Ordnance Department had been established. George Ellery Hale, who planned for the time after the war early onwards, proposed to have an Inter-Allied Research Council, and during three meetings in October (London) and November (Paris) 1918 and July (Brussels) 1919, a new body named International Research Council (IRC) was created. The executive committee included Hale, Picard, Schuster, G. Lecointe from the Académie Royale in Belgium and the Italian physicist Vito Volterra. The IRC provided the basis for future scientific collaboration and shifted the emphasis from German to English language usage – German and Austrian scientists were excluded. The RIS itself continued to exist up to the Second World War, where Durand's former deputy, Karl Compton worked for the National Research Defense Committee and the Office of Scientific Research and Development (OSRD). To sum it up, the RIC/RIS established a considerable network of personal contacts and provided a model in scientific exchange diplomacy. Systematic cooperation and effective coordination of the scientific exchange between the allies and an extensive network of personal contacts has been its major achievement.

At the beginning of the 20th century, the U.S. lagged behind European aviation capabilities. The beginning of the First World War in Europe provided for a strong stimulus to promote aviation for the benefit of both military and civilian (i.e. commercial) aircraft. Since it was unusual to receive government funding for scientific or engineering research in the period before the Second World War, it is not astonishing that the initiative to found a body promoting aeronautical science came from civil society and not from the side of the government. It was already in 1914 when the paleontologist Charles D. Walcott, then secretary of the Smithsonian institution, organized a conference in Washington D.C. to enhance aeronautical research and to restore preeminence to American aviation, and quite clearly the war served as a catalyst for the installation of an American agency. Already on 3rd March 1915 the National Advisory Council for Aeronautics was founded as an independent government agency. On that day both chambers of the Congress approved of the Naval Appropriation Bill to which the enacting legislation for the NACA was attached

as a rider. The model agency for the NACA was the British Advisory Committee for Aeronautics, which had been founded in 1909. The American legislation gave an annual budget of $5,000 to the NACA for the first five years. The limited funding underlined its advisory function, and study and research was done by a government agency or university laboratory. The Committee consisted of 12 members coming from the government, the military and from civil society: Two each from the Army and Navy, one representative from the National Bureau of Standards, the U.S. Weather Bureau, and the Smithsonian Institution. Finally, five additional at-large members were selected because of their expertise in aeronautical science; they had to come from academia and research institutions, but not from the aircraft industry. During the First World War the NACA established the Langley Memorial Aeronautical Laboratory in Hampton, Virginia. It was named after Samuel Pierpont Langley, Walcott's predecessor as a Secretary of the Smithsonian Institution, and a former military airfield was rebuilt into this research station; the laboratory was inaugurated only in 1920. It was also only after the war that George W. Lewis became the Committee's first Director of Aeronautical Research in 1923, in which position he remained until 1947. Personal continuities up to the Second World War can also be noted for the NACA: John F. Victory became the first salaried employee for the NACA in 1915, its secretary in 1921, and its executive secretary in 1948. Jerome C. Hunsaker had already been member of the NACA from 1922-23, and from 1941-1956 he chaired the Main Committee. He remained a member of the NACA until it was transformed into NASA in 1958, at which time he retired.

The quick progress the U.S. made in the field of science of technology during the First World War can be seen in chemical warfare, for which the U.S. army was not prepared. It was only in April 1917, when George Arthur Burrell began to create a research network of universities, chemical industry representatives, and private institutions, and got chemist Warren K. Lewis of MIT and physiologist Yandell Henderson of Yale as well as private companies like Dow Chemical, General Electric and the B.F. Goodrich Company involved. Governmental chemical production was established in Edgewood Arsenal in Maryland, and later on war chemicals were produced there. The major American invention was Lewisite, a war gas that fortunately was never employed in the First World War. Under the command of Major General William L. Sibert the Chemical Warfare Service (CWS) was established in June 1918, which also incorporated the 1st Gas Regiment deployed to France. Chemicals found on the battlefield were investigated in a laboratory driven by the American Expeditionary Forces (AEF). In the field, gas attacks were performed with Livens projectors, stoke mortars and artillery. By the end of the war, American chemical production was four times as high as the amount of chemicals fabricated by Germany.

The Australian Imperial Force on the Western Front
© IWM (Q 670), Imperial War Museum
[IWM Non Commercial Licence]

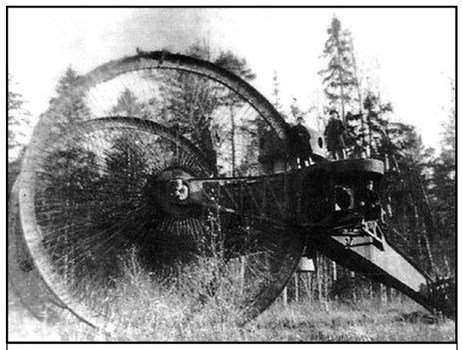
Russia

Looking at developments in Russian science and technology, three dimensions of this underresearched topic have to be taken into regard: The advancements of the Russian Academy of Sciences, who took the initiative in the foundation of the Commission for the Study of Scientific-Productive Forces (KEPS) as well as the institutions founded during the war, especially the War-Industries Committees and the Joint Committee of the Union of Zemstvos and of Towns for the Supply of Military Equipment and Munitions. Furthermore, particular institutions like the War Chemical Committee should be studied, since it later became the Institute of Applied Chemistry. Generally, the First World War led to a considerable transformation of the relations between Russian science and industry. The war pushed forward a move from theoretical, "pure" science to applied sciences, a considerable growth in the numbers of trained specialists and applied research, and the establishment of institutional foundations which survived the war and coordinated the activities of military, state, and civilian actors. While it has to be noted that the war had a lasting and transformative effect on Russian science and technology, the social aspects of these developments are particularly interesting, since the bourgeois scientists and engineers managed to establish themselves as an influential group in respect to the Tsarist regime and the Bolshevik government respectively. Although the First World War and the Russian Civil War broke scientific communications and contacts between Russian scientists and their colleagues from enemy states, the foundations of a new Soviet scientific and technological culture were laid in this time.

The Saint Petersburg Academy of Sciences was in 1899 a founding member of the International Association of Academies (IAA) and stayed in close contact with its partners in Berlin, London, Paris, Rome, Göttingen, Washington, Vienna, and elsewhere. In 1913, the last general assembly was held in Saint Petersburg; the IAA did de facto not exist anymore during the war, but it can be seen as a predecessor of the International Research Council IRC, which was founded in 1918. Several members of the Russian Academy like the orientalist Sergey Fedorovich Oldenburg and the mineralogist and geochemist Vladimir Vernadsky stayed in close contact with their colleagues from the German academies like Hermann Diels and Wilhelm von Waldeyer-Hartz, and they were to become influential figures in the Soviet era. On 21 January 1915 the Academy came forward with the proposition to found a Commission for the Study of Scientific-Productive Forces (KEPS), whose task was to produce overviews on Russian natural resources and to direct scientific and technological assistance for a more effective engagement in the war effort. The Commission was led by Vladimir Vernadsky and the biologist Nikolai Konstantinovich Koltsov and had A. E. Fersman and B.B. Golizyn as secretaries. Vernadsky developed the leading role of the KEPS within the Russian mining industry, with a focus on the search for raw materials and their appraisal. The first Soviet People's Commissar of Education Anatoly Vasilyevich Lunacharsky returned as early as March 1918 to the achievements of the KEPS Commission, and subsequently the Communist government allocated an important share of the Academy's budget to the Commission to encourage practical research. Vernadsky kept leading the Commission up to 1930, though Fersman was the one to take over management and coordination tasks. The KEPS Commission founded a range of new research institutes in the 1920s freed from educational obligations, and it took over the tasks of a planning commission for the state. The KEPS Commission thus developed into an institutional centre which

served as link between science and industry, and the institutions for applied science established by her put into effect the science policy of the new government. The favourite form of these state-sponsored research institutions was directed towards advanced research and utilitarian service.

It was only belatedly, in mid-1915, when the shortage of munitions led the Tsarist bureaucracy to set up an organization of industrialists called the War-Industries Committees to assist the state to adapt Russia's economy to the needs of the war. The chairman of the Central War-Industries Committee became Aleksander Ivanovich Guchkov, also president of the Third Duma and member of the State Council. In these Committees, large sections of the industrial bourgeoisie expanded the political and economic power of 'civil society' in the face of the government, which led to a delegitimization of the Tsarist government and the traditional state contractors which furnished the supply of war materiel. As can be read from the historical records kept in the Russian State Military History Archive, the Central State Historical Archive, and the records of the Department of Police in the Central State Archive of the October Revolution (Secret Service personnel took part in the meetings of diverse Committees), many conflicts over industrial mobilization remained unresolved, and the dialectics between the Tsarist government and the fractions of the industrial bourgeoisie in the Committees led to stagnation, inefficiency, and disintegration.



Russian "Tsar Tank"
Public domain, via Wikimedia Commons

The War-Industries Committees did not unite Russian industry as their counterparts in Germany and Great Britain did, but challenged the state bureaucratic structures. Therefore, these Committees and the Zemgor, which was the Joint Committee of the Union of Zemstvos and of Towns for the Supply of Military Equipment and Munitions, did not survive for very long after the October Revolution. In July 1918 they were dissolved. Nevertheless, the question remains whether the networks of bourgeois industrialists which had been established during war should be seen as a resource whose influence can be traced well into the 1920s.

While the mobilization of industrialists in the War-Industries Committees in general had an ambivalent outcome, the Russian economy developed dynamically during the war, starting from a low productivity level and being heavily dependent on imports of raw materials from abroad. A good example for this rapid development is evident in the chemical industries. The construction of several factories devoted to the production of chemicals formed the basis for a domestic Russian chemical industry, amongst which were plants to produce toluene and benzol, which were key components in the production of munitions and explosives. In May 1915, a "Special Commission on Poison Gases" was established with I.A. Krylov as chairman and with the support of the Russian Physical-Chemical Society. On initiative of the Commission and the Society, a War Chemical Committee was established in September 1915 , which after the First World War became the Institute for Applied Chemistry. In December 1914, the Central Scientific-Technical Laboratory was established, which had Professor-chemist and General A.A. Zabudskiy as its commander and which was in 1920 renamed to the State Scientific-Technical Institute (GONTI) with the chemist

Vladimir N. Ipatieff as its director. Russia even produced its own gas masks, developed by Nikolai Zelinsky and Eduard L. Kumant in 1916. These accomplishments prove the lasting and catalysing effect on Russian science of the First World War, which resulted in the expansion of industrial production, the reorientation of scientists from theoretical to applied science, and the creation of institutional foundations for applied scientific research during and after the war.

Italy

In Italy the Great War represented a turning point in relation to the organization and promotion of scientific research. The mobilization of Italian scientists followed a different route if compared with that of other European countries such as Germany, France or the UK: there was indeed no strong national interest toward the creation of scientific associations or councils.

1915 sees the creation of the Comitato Nazionale delle Invenzioni di Guerra (CNIG); it was founded on the initiative of the Milanese member of parliament Giuseppe De Capitani d'Arzago. The Ministry of War at the time, led by Antonio Salandra, was pretty much designed according to liberalist rules and not aiming at intervening in the private sector; however, in the context of the engineering university in Milan (Politecnico di Milano), the idea of creating a similar initiative of that of the Ministry of war started to take shape. Some of the major representatives of the Italian industry and science took part in the committee, such as Giuseppe Colombo, Giovanni Battista Pirelli, Carlo Esterle, Luigi Albertini and Guglielmo Marconi. The activities of the committee recalled foreign policies, such as the ones in Great Britain or the United States, and it recognized the need to support, even monetarily, unexplored and unverified proposals and to set a preferential connection with the military administration.

In other intellectual and academic environments a new trend started to take shape, especially around the figure of the mathematician Vito Volterra. In 1916 he founded an "Italian Association for Intellectual Understanding between the allied countries and friends" (Associazione Italiana per l'Intesa Intellettuale fra i Paesi Alleati e Amici AIIIPAA) which was an important center for exchanging ideas as well as very active in the editorial world and in the diffusion of Italian books; it continued its publication also after the end of the war. This association demonstrated to be appealing for the government who decided to intervene, especially on the topic of scientific mobilization, following the example of other warring countries.

Vito Volterra
Public domain, via Wikimedia Commons

Also in 1916 the Comitato Nazionale Scientifico Tecnico per lo Sviluppo e l'Incremento dell'Industria Italiana (CNST) was created following the idea of a group of industrial owners in Milan. The objective of this association was that of tightening the connections between scientific research and industry. While the economic investment for this committee was not substantial, it nonetheless had

the power of putting pressure on the government, which in 1917 emitted a 3 million-lira investment directed to physics and chemical labs.

In 1918 Volterra founded the Ufficio Invenzioni e Ricerche (UIR) within the War Ministry and he was able to attract distinguished physics such as Orso Mario Corbino, Antonino Lo Surdo, Occhialini e Piola, the chemist Raffaello Nasini and the geologist Federico Millosevich. Volterra was also very capable of maintaining good relationships with the French intellectual class, where the Comité Interallié des Inventions was established by the mathematician Paul Painlevé; its role was to connect and exchange international scientific research and its applications.

At the end of the war the idea of setting up an international organization for the support of international scientific research started to take shape. The Consiglio Internazionale delle Ricerche (CIR) was established after a few international conferences: the first, in London in October 1918 (during the war) with the participation of nine allied countries; the second one in Paris in November 1918, where the "Consiglio Internazionale delle Ricerce provvisorio" was indeed set up. The Italian participation to the initiative was enthusiastic, and Volterra was elected in the executive committee, together with representatives of countries such as France, UK, US and Belgium.

In the years after the war it was crucial for Italy to set up a clear role of the scientific research within the structures of the state and of private industry. Volterra aspired to establish the Consiglio Nazionale delle Ricerche (CNR). In 1919 a dedicated commission started to prepare a project for the constitution of a National Research Council; the aim was to gather the expertise of other institutions such as of the UIR, the committee for the chemical industry of the Ministry of Industry, the National Scientific Committee and the Central Institute for Aeronautics. The council should have had the role of organizing and promote scientific and industrial research for the national defense.

The CNR would be based in Rome and be controlled by the Ministry of Industry. The council would be focused on promotional aspects of scientific and applied research, on the reuse of the country's resources and would have a strong affiliation with the public administration. Relevant, but not a priority, would be the relation with international scientific centers. The main scientific subjects represented in the first CNR design were mathematics, engineering and mechanics, physics and its applications, chemistry and its applications, mineralogy and geology, aerodynamics, biological science and its applications (especially agriculture and cattle-breeding), applications in relation to national defense.

Unfortunately the years 1919/ 1920 saw very slow development of the plan for setting up the CNR, mainly due to the fact that the council was not considered a high priority for the Nitti Government. It is only with the establishment of the Mussolini government in 1923 that new perspectives for the constitution of the CNR showed up. In fact, in 1923 the Consiglio Nazionale delle Ricerche was established, directed by Vito Volterra and following the focus points designed just a few years earlier. The main addition worthwhile mentioning here is the strong international component, in particular with the Union Académique Internationale, based in Bruxelles.

BIBLIOGRAPHY

Brophy, Leo P., and Miles, Wyndham D., and Cochrane, Rexman C. *The Chemical Warfare Service: From Laboratory to Field*. Washington D.C: Office of the Chief of Military History Department of the Army, 1959.
(Chapter on the First World War online here: http://tothosewhoserved.org/usa/ts/usatsc02/chapter01.html, chapter on the interwar years online here: http://tothosewhoserved.org/usa/ts/usatsc02/chapter02.html)

Burchardt, Lothar. "Die Kaiser-Wilhelm-Gesellschaft im Ersten Weltkrieg (1914-1918)." In: *Forschung im Spannungsfeld von Politik und Gesellschaft. Geschichte und Struktur der Kaiser-Wilhelm- / Max-Planck-Gesellschaft. Aus Anlass ihres 75jährigen Bestehens*, edited by Rudolf Vierhaus and Bernhard vom Brocke,163-196. Stuttgart: Deutsche Verlags-Anstalt, 1990.

Forman, Paul, and Sánchez-Ron, J.M., editors. *National Military Establishments and the Advancement of Science and Technology. Studies in the 20th Century History*. Dordrecht: Kluwer Academic, 1996.

Galvez-Behar, Gabriel. "Le Savant, l'inventeur et la politique. Le role du sous-secrétariat d'Etat aux Inventions Durant la Première Guerre mondial." In: *Vingtième siècle. Revue d'histoire*, vol. 185, no.1 (2005): 103-117.

Haber, Ludwig Fritz. *The poisonous cloud: chemical warfare in the First World War*. Oxford: Clarendon Press, 1986.

Hartcup, Guy. *The War of Invention. Scientific Developments, 1914-1918*. London: Brassey's Defence Publishers, 1989.

Kolchinskii, Eduard Izrailevich, and Beyrau, Dietrich, editors. *Nauka, tekhnika, i obshchestvo Rossii i Germanii vo vremia Pervoi Mirovoi Voiny [Science, technology, and society in Russia and Germany during the First World War]*. St. Petersburg: Nestor-Istoriia, 2007.

MacLeod, Roy, and Johnson, Jeffrey A., editors. *Frontline and Factory: Comparative Perspectives on the Chemical Industry at War, 1914-1924*. Dordrecht: Kluwer Academic, 2006.

MacLeod, Roy, and Andrews, Kay E. "Scientific Advice in the War at Sea, 1915-1918: The Board of Invention and Research." In: *Journal of Contemporary History*, vol. 6, no.2 (1971): 3-40.

MacLeod, Roy. "Secrets Among Friends: The Research Information Service and the „Special Relationship" in Allied Scientific Information and Intelligence, 1916-1918." In: *Minerva*, vol. 37 (1999): 201-233.

Pattison, Mark. "Scientists, Inventors and the Military in Britain 1915-1919: The Munitions inventions Department." In: *Social Studies of Science*, vol. 13, no.4 (1983): 521-68.

Paul, Harry W. *From Knowledge to Power. The Rise of Science Empire in France 1860-1939.* Cambridge: Cambridge University Press, 1985, 320-325.

Polikarpov., Vladimir V. *Russkaja voenno-promyshlennaja politika. 1914—1917. Gosudarstvennye zadachi i chastnye interesy* [Russian military-industrial policy. 1914-1917. State objectives and private interests]. Moscow: ZAO Izdatel'stvo Centrpoligraf, 2015.

Rasmussen, Anne. "Science and Technology." In: *A Companion to World War I*, edited by John Horne. 307-322. Malden / Massachusetts: Wiley-Blackwell, 2010.

Roland, Alex. "The Impact of War upon Aeronautical Progress: The Experience of NACA." In: *Air Power and Warfare*, edited by Alex F. Hurley and Robert C. Ehrhart. 262-285. Washington D.C: U.S. Government Printing Office, 1979.

Roussel, Yves. "L'Histoire d'une politique des inventions 1887-1918." In: *Cahiers pour l'histoire du CNRS 1939-1989*, vol. 3 (1989): 19-57.

Schröder-Gudehus, Brigitte. *Deutsche Wissenschaft und internationale Zusammenarbeit 1914-1928. Ein Beitrag zum Studium kultureller Beziehungen in politischen Krisenzeiten*. Geneva: Dumaret & Golay, 1966.

Siegelbaum, Lewis H. *The Politics of Industrial Mobilization in Russia, 1914-17. A Study of the War-Industries Committees*. New York: St. Martin's Press, 1983.

Simili, Raffaella, and Paolini, Giovanni, editors. P*er una storia del Consiglio Nazionale delle Ricerche*. Vol. 1 Rome: Laterza, 2001.

Szöllösi-Janze, Margit. *Fritz Haber 1863-1934. Eine Biographie*. München: C.H. Beck, 1998.

Vucinich, Alexander. *Empire of Knowledge. The Academy of Sciences of the USSR (1917–1970)*. Berkeley: University of California Press, 1984.