Science, Innovation and Technical Change in Modern Industry

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Electrical Engineering and Electrical Industry:
The Relationship between the 'Technische Hochschulen' and
Industry in Pre-World War I - Germany

For the development of industry and for the development of the interrelationship of industry and science - since the late 19th century - often the term 'science-based-industry' is used. More concretely speaking, some authors content, that particularly the German chemical and electrical industries were prototypes of such science-based industries. However, these authors do not explain the characteristics of such industries.

I insist that the notion 'science-based-industry' if it is used for the science-industry-relationship is misleading, because it implies the existence of a 'one-way-road', leading only into the direction from science to industry. In reality, however, there are influences in both directions, which means one should speak of an increasing interrelationship of science and industry. In pre-World-War I, in the electrical engineering area science profitted even more from industry than industry from science. Therefore, I suggest to speak of electrical engineering as an 'industry-based science'.

In the following, the various forms of industry-science-relations in electrical engineering which were distinguished from those in chemistry will be enumerated and described.

As in chemical industry, electrical industry occupied a higher share of academically-trained personnel than other industries. The number of electrical engineering students reached a peak at the turn of the century. After it declined sharply due to the crisis of the German electrical industry in 1901 and 1902, it recovered slowly until World War I. In general, statistics show that in electrical engineering student admission resembled that in other technical subjects, but the maxima and minima were markedly more extreme. My estimations are that about 50 percent of the students were foreigners coming from all over the world, but especially from countries of East and South-East Europe.

Industry supported in various ways electrotechnical education. So it gave donations of modern electrical equipment to the teaching laboratories. Students received insight in practical work during excursions and had to work one year in industry either before or during their studies.

Direct <u>financing</u> of electrical engineering institutions by industry was seldom. As an exception the 'Robert-Bosch-Stiftung', which was founded in 1910, gave considerable donations to the TH Stuttgart Institute.

In the 1880's and 1890's <u>professors</u> of electrical engineering normally were physicist without any experience in industry. This changed in the years at the turn of the century. By then professors who taught the practical subjects, that is, not theoretical electrical engineering, but machine and facility building, were electrical and mechanical engineers who had worked for several years in industrial positions. This transfer of personnel was only one-sided. Only very few professors went back into industry. And these spent only a short time at the 'Technische Hochschulen' being frustrated by low salaries, bureaucratic difficulties, and quarrels with colleagues.

<u>Research and development</u> being performed for industrial clients, at the 'Technische Hochschulen' was not important. The reasons were the professors' lack of competence, the poor equipment of the teaching laboratories and the overload by huge student numbers. After 1900 conditions improved concerning all three factors. In particular, institutes got laboratories ('Versuchs- und Prüffelder') which were better equipped with heavy machinery being erected not only for teaching purposes ('Laboratorien') but as well for research work. At this time research cooperations between industry and professors took place in a specific manner: Professors served as consultants, research and development work was done in the much better suited laboratories and workshops of industry.

In comparison, professors from the 1880's onwards played an important role as <u>consultants in electrification projects</u>. Especially in the time period when competence was rare they were intermediaries between towns, firms, or other institutions, planning to equip their facilities with electric power, and electrical equipment companies.

professors planned and supervised smaller electrification projects or they served as experts for greater ones. After the turn of the century, professor's consulting and expertise work became more difficult and decreased. Firstly, it suffered under the competition of electro-technical private consultants and [illegible] had established technical expertise of their own.

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INDUSTRIAL REVOLUTION OR TECHNICAL EVOLUTION?

- The Swedish Iron Industry during the 19th Century -

INTRODUCTION

In this paper I will address the question whether there was a striking technical breakthrough in the process we often call the industrial revolution, or if earlier historians writing about that process have overestimated the technical change. More specific I want to discuss the technical development of the Swedish iron industry during the period from the end of the napoleonic wars up to the closing years of the century. I will dwell more upon the period preceding the introduction of the modern steel-processes than the period after.

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In my research I deal with the question of technical change in a broader context. In my present study on the iron industry my chief aim is to analyze the relationship between the household sphere and the work sphere in the Swedish iron industry, during the period 1750-1900. More precise the study is about the connection between the changing functions and structures of the forgemen's households and the changing working conditions in the forge. The technical development is of course an important feature in this respect.[1]

I am presently involved in two project dealing with this sort of problems. The first one, is a comparative project which deals with the iron industry and the lumber industry in Sweden. The project is called *Household and Work*. The second project, under the leadership of professor Torstendahl, is a very ambitious one, trying to compare the Swedish iron industry with the Russian iron industry from the beginning of the 17th century to the late 19th century. The aim is not to compare the structure of the industry or market relations but to compare the different ways of organizing the production. We are five Swedish historians in the project and about ten Russians. I am responsible for the technical aspect of the Swedish part and the discussion about household and family.

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[1] See my paper: Rydén, Göran (1991) *Household production in an emerging capitalist society*. Paper presented at the scientific seminar in Sverdlovsk, March 1991.

I will begin this paper by giving You a brief introduction to the Swedish iron industry during the 18th and 19th centuries. I will stress the main technical changes. In the following section I will deal with the dominant view in Swedish historical writings on the industrial revolution, especially those concerned with the iron industry. Then comes the main section of the paper in which I, in detail, will describe the introduction and the development of a new refining method of pig-iron into wrought iron, the Lancashire process, into the industry. I will try to explore the links between this process and the processes preceding it and coming after it. This means that I will try to insert the Lancashire method in some kind of an evolutionary technical process beginning with the earlier Swedish forging methods and ending with the modern steel processes.

THE SWEDISH IRON INDUSTRY DURING THE 18TH AND 19TH CENTURIES[2]

At the beginning of the 18th century Sweden was by far the largest producer of bar-iron in Europe, and as such it was also the biggest supplier of iron to areas lacking iron of its own. It has been estimated that of the total European production of bar-iron Swedens contribution was somewhere between a third and a fourth. Most of the iron, more than 90%, was exported, and England was the biggest receiver. The first half of the 18th century was a period of expansion, and the production rose from about 30 000 ton at the beginning of the century to almost 50 000 ton in the 1770ies.

During the second half of the century the Russian iron took over Swedens leading position i Europe. The iron industry in the Ural began to expand in the beginning of the century and half way through, it had grown to the biggest iron producing area in the world. At the British market the Swedish share declined from about 80% around 1700 to about 40% 80 years later. At the same time the Russian share rose from nothing to over 50%. This development was partly an effect of the Swedish mercantilistic politic. It was, by the middle of the century, decided to freeze any further expansion of the production of bar-iron. Every production unit was given a maximum production level and no new units were allowed to be builded. The change in politics was motivated by a fear of a to intensive use of the Swedish forests and monopolistic thoughts that low output would lead to higher prices. (During this period there existed ideas of trying to persuade the Russians to limit their production as well.)

During the 18th century two different methods of bar-iron manufacturing was used. In the very east part of Sweden, Uppland, around the famous mine, Dannemora, the Walloon method was employed. The iron produced there was of very high quality, and most of it was sold to the Sheffield area where it was used in the steel production.

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[2] This section is foremost based on Hildebrand, Karl-Gustaf (1987) *Svenskt Järn. Sexton- och sjuttonhundratal. Exportindustri före industrialismen*, and Attman, Artur (1986) *Svenskt järn och stål 1800-1914*. See also Torstendahl, R., Florén, A., Ågren, M. and Rydén, G. (1991) *Swedish Iron. From medieval times to the industrial revolution. Towards a Synthesis*. Paper presented at the scientific seminar in Sverdlovsk, march 1991.

Only about 10% of the Swedish bar-iron production was made according to the Walloon process. The remaining part was manufactured in what is called the German breaking-up process, or purely the German process. The iron manufactured by this method was of ordinary quality and therefore more exposed to competition from other producers.

After the napoleonic wars the opportunities for the Swedish iron industry changed radically. In England puddling, introduced in the 1780ies, expanded, and the country changed in a few years from being an iron importing country to a country that exported iron.[3] This was a severe blow to the Swedish iron masters as England had always been the biggest market for Swedish bar-iron. The American market, however, expanded at the same time and could receive the Swedish production. This solution, though, could only be seen as temporary as the expansion of the puddling soon reached America.

The long-term solution for the Swedish ironmasters, using the German process, was to reorganize the industry in a swift and powerful way. Instead of trying to compete with the puddle-iron they had to make a high quality iron. The period 1820-1840 is characterized by an eager activity of experiments with new forging methods. As a result a totally new method was developed, the Lancashire process. It began to spread over the country towards the end of the 1840ies. In two decades the new method totally took over from the outmoded German process. The Walloon process, though, remained untouched, as it already produced a high-quality iron.

The first half of the 19th century was a period of change and a modification in the states attitude towards the iron industry occurred. The production restrictions were gradually abolished, in 1803 a general rise in production level were allowed and in 1838 came another decree allowing further rise. Eight years later, 1846, the regulation policy was abandoned, and the production of bar-iron was set free.

After the swift and successful introduction of the Lancashire process in Sweden and the abolishment of the regulation policy the technical change really set pace. Rolling mills were introduced and there was a rise in productivity. The other side of this process was an important structure reorganization rocess that goes under the name of *Ironworks Closures* (*"Bruksdöden"*), in which a lot of the smaller production units were closed down.

The Lancashire process in combination with rolling mills were only the first step in row of technical innovations in the industry. In 1858 Bessemer steel was made successfully for the first time. It took place at the blast furnace in Edsken in the county of Gästrikland, in the east of Sweden. Soon after, the new method spread round the world. In Sweden the Bessemer process never got the importance it got in other countries, but during the two decades after 1858 large quantities of Bessemer Steel were produced. About twenty iron works used the method, but only in ten cases the workings became permanent.

It was instead the second new steel method, the open hearth process, that became of real significance for the Swedish iron industry. It was introduced at

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[3] For an brief introduction to the British iron industry see Harris, J.R. (1988) *The British Iron Industry 1700-1850*.

Munkfors iron works in the county of Värmland, in the west of Sweden, towards the end of the 1860ies, but the breakthrough did not come until the period after 1885. 1880 five ironworks used the open hearth process. Ten years later the number hade risen to 21, and by the turn of the century the level had reached 26 iron works. Measured in production the open hearth process caught up with the Bessemer process in the early 1890ies. Thereafter the open hearth steel production increased in a rapid pace while the Bessemer production stagnated. Both steel methods were of course combined with rolling mills.

With the new steel methods the Swedish iron industry entered a new era. The earlier generation of historian would have said that the pre-industrial stage was passed and that the Swedish iron industry thereafter was to be understood as a fully developed industry. The new methods had their foundations on totally different conditions. Where the iron masters earlier had been depended up on skilled forgemen, who only with a few tools, in a hearth, and by their hands manufactured the bar-iron, the steel was produced in giant furnaces and converters operated by a few work men. It was also a big difference in production levels. In the older iron works, employing the Lancashire process, the production could reach about 2000 ton a year, while the big steel works often produced ten times that amount, and sometimes even more.

The subject for the rest of this paper is to discuss whether this is a correct description of the development or not, and if there was there a marked break between the 'old' and the 'new' or not. I will ask the question whether the Lancashire process more belonged to the old iron industry or to the new steel industry, and I will put forward a view that tries to analyze this process as an intermediate phase in the development from iron to steel that includes features from both the 'old' and the 'new'.

IRON IN THE INDUSTRIAL REVOLUTION IN SWEDEN

The iron industry has had a very important place, as the major branch in the Swedish economy, beside agriculture, throughout the centuries. This is clearly visible in the different disciplines of history. Especially in economic history the iron industry has had an exceptional position. Almost all of the older generation of economic historian, of whom Eli Heckscher is probably the internationally most known, has written something, often at least one book, about the iron industry. During the golden years of the 50ies and 60ies it was very common that the iron work companies had their history written by some famous historian, and quite a number of monographs were produced during that period. A lot of research was also undertaken on a national scale and some very important books about the general trends in the industry were written during that period.[4]

Surprisingly this research has had very little impact on the writings on the industrial revolution i Sweden, although textbooks on that theme often were

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[4] Attman (1986), but also Heckscher, Eli (1941) *Svenskt Arbete och Liv*, Montgomery, Artur (1947) *Industrialismens Genombrott i Sverige* and Gårdlund, Torsten (1941) *Industrialismens Samhälle*.

written by the same historians. The industrial revolution in its traditional interpretation in the Swedish historiography has meant a rapid transformation of the industry, including a swift technical break, created by an increased foreign demand. Instead of linking the iron industry to the process of change the historians have often pointed towards the lumber industry, after the introduction of steam power 1849, as the leading branch in this development. The breakthrough is believed to have occurred sometimes after 1870.

The reason for this standpoint, as I see it, is that these historians has found it difficult to explain something new, the industrial society, with something that has existed for a very long time, the iron industry. And at the same time it is perfectly clear that they tried to explain the industrial revolution in Sweden by an export orientated increase in demand. This happened in the lumber industry (and later in the pulp and engineering industries) while the iron industry in the late 19th century was characterized by a change in demand towards the home market.

Of course historians have talked about a radical change, or an industrial revolution, in the iron industry, but that change has not been attached to have any impact on the development outside the industry. Instead it was the change in the lumber, pulp, engineering, etc industries that transformed Sweden to an industrial society. When talking about the lumber and pulp industries historians have stressed the impact on a national scale while talking about the iron industry it was only in terms of an internal change. The iron industry is said to have become 'a fully developed industry' as soon as the modern steel process had been introduced.

I have at another place,[5] at length, analyzed the position of the iron industry in the Swedish historiography of the industrial revolution. I have also discussed alternative models for analyzing this development, mostly by relating the iron industry to the notion of proto-industrialisation. My conclusion there was that neither of these two ways of explaining the process of change, that occurred sometimes during the 19th century, was very convincingly. Instead am I, together with Anders Florén - a colleague in the comparative project with the Russians, elaborating a new model from which it is possible to analyze the development of the iron industry during the period from the early 17th century to the late 19th century.

This model takes its starting point in the thesis of combined and uneven economic development as put forward by some English historians, as Maxine Berg, Pat Hudson, Jonathan Zeitlin, Charles Sabel, Patrick Joyce etc.[6] The iron industry, at least in Sweden, is very suitable for an analyze in these terms. This industry, during its long existence of almost 300 years, was characterized not by one way of organizing the production but several. The traditional iron work was an enterprise combining iron production with forestry and agriculture,

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[5] Rydén, Göran (1991) *Industrialiseringen och Järnhanteringen*. Unpublished paper, Department of Economic History, University of Uppsala.

[6] See for an introduction of these thoughts Joyce, Patrick (1990) Work, in *The Cambridge Social History of Britain 1750-1950. Volume 2. People and their environment*, edited by Thompson, F.M.L.

each one with its own different way of arranging the production. In the two last branches the ironmaster acted as a landlord and the tenants paid the rent in kind, charcoal, or by doing labour service, often transport work. This part of the enterprise is organized in a partly feudal way. The iron production, on the contrary, was dominated by the wage-labour relationship, the forgeman and his partners in the blast furnace and the black-smiths shop worked for wage. But it was a very undeveloped relationship, where payments in kind and sub-contracting flourished. Anyhow, it is possible to analyze this relationship as a capitalist one.

It is, for most of the period, not possible to assert that the ironmaster was a typical capitalist employing lots of workers, or that he was a typical landlord exploiting his tenants. Instead he was both, using, at the same time, different ways of organizing the production. He was using both old and new ways of organizing the production simultaneously. Of course there was a slow development toward a more capitalist way of dealing with the production, but even during the early stages of the 20th century there remained vital element of older forms of organizing the production.

It is in this setting I want to discuss the technical change in the Swedish iron industry. The earlier version of 'The Industrial Revolution' put great emphasis on a rapid technical breakthrough during a short period. An alternative model trying to explain the development towards the industrial society in a more slow pace, although with elements of discontinuity in mind, has to generate a discussion on the technical development in a slightly new way. We have to put more emphasis on the continuity in the development.

THE LANCASHIRE PROCESS

The purpose of the Lancashire process is the same as in other refining processes, that is to lower the carbon content in the pig iron from about 4% down to about ½%. The iron becomes malleable in this process. The procedure in refining was to melt down the pig iron on a charcoal hearth under the influence of air coming from bellows. The iron melted down and the refining took place. Thereafter it was hammered to solid pieces, called blooms, which once again was taken to the hearth and re-heated. Finally the iron was drawn out to bars under the hammer. The variation between different refining methods was whether the same hearth was used for both the melting/refining procedure and the reheating procedure. The number of, and types of, hammers could also differ. In the German process only one hearth and one hammer was used, while the forgemen in the Walloon process, at least in Sweden, used two hearths and one hammer.

In puddling the basic procedure was different. The iron was separated from the fuel, which no longer was charcoal but coal. The pig-iron was put in a reverberatory furnace and was melted by the hot gas from a coal fire. After the melting/refining procedure the same old method could have been used. First hammering, the re-heating and finally the manufacturing of bars. There was, though, a technical change in the last sequence in that rolling mills were inserted instead of hammers. By using coal instead of charcoal it was in England possible both to expand the production and to lower the production costs.

In this section I will first discuss the Lancashire process on a macro level, I will talk about the introduction of the method in more detail and give some figures on its relative importance through out its existence. Thereafter I will change view and discuss the development of the process on a micro level. I will relate the aspect of technical change to the notion of division of labour.

The introduction of the Lancashire process in Sweden[7]

After the napoleonic wars, as was noted above, the Swedish iron industry was confronted with what up to that time was their greatest threat. Puddling had developed since the introduction in the late 18th century, and was beginning to have a severe effect upon the Swedish iron producers. The wet puddling was introduced in the 1830ies, and the quality of the manufactured iron was getting better. The use of the process also expanded over Britain, and the export of wrought-iron from England increased about ten times during the twenty years from 1830 to 1850. In spite of the technical development, though, the puddle iron of that time was of ordinary quality and was therefore foremost a threat to Swedish iron made by the German process.

For the conservative Swedish ironmasters the change in market situation was a severe blow. They had for a century a more been used to a situation where they could sell their whole production. They learned the lesson, though, from the new circumstance, and a change in attitude was visible. The Swedish Iron Masters' Association (*"Jernkontoret"*) was reorganized in order to better correspond to the new demand. In order to keep up with the technical change abroad the Association sent out observers, mostly to Britain. This in turn speeded up the pace of the technical development in Sweden. Puddling was for instance tried as early as 1811, and introduced in a bigger scale during the 1830ies. Two works employed the imported method.

The debate in Sweden, in the 1820ies and 1830ies, about the future for the iron industry was divided into two main argument. According to the first the German process ought to be replaced with ironworks combining puddling and rolling. According to the other line of argument the Swedish iron was the best in Europe and the thing to do in order to meet the competition from England was to develop the existing methods further. The solution was in the end a compromise between these two lines.

One of the observers going to England during this period was a young metallurgist named Gustaf Ekman.[8] During his long stay in England, 1828-29, he studied puddling and rolling. In two places, in Ulverstone, Lancashire, and in South Wales, he also saw remains of the English version of the Walloon process.

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[7] This section is foremost based on Boethius, Bertil (1955) *Jernkontorets Historia III*, Attman (1986) and Rydén, Göran (1990) *Hammarlag och Hushåll*.

[8] See Ekman, Gustaf (1944) *Gustaf Ekman. Svenska järnhanteringens nydanare för 100 år sedan*. Jernkontorets Bergshistoriska Skriftserie N:r 12.

What he saw there, that differed compared to the Swedish version was that the chafery, where the re-heating took place, had been replaced with an furnace. This meant that a higher reheating temperature was achievable and that it therefore was feasible to combine traditional refining methods with rolling. This, in turn, also meant that it would be possible to go on manufacturing iron with high quality from older refining processes and at the same time increase productivity, rise production and lower the price on quality iron.

The only problem for Ekman, and for Sweden, was the lack of one essential resource - coal. The British re-heating furnaces, both in connection with puddling and with the Walloon process, were fired with coal. It is easier to get a high temperature with coal than with most other fuels. Anyhow Ekman started experiments in Sweden as soon he came home. The process was called 'the English Walloon process' or the 'Lancashire process'. It was not an immediate success. On the contrary, it was a failure.

At the same time an ironmaster from Bäckefors, in Dalsland in the very West of Sweden, Carl Fredrik Waern, imported a few forgemen from the ironwork in South Wales where they used the Walloon method. They brought with them what was called the English method of pig-iron refining. It has been a slight dispute between some scholars, or rather 'local historians', about the origin of the new method, whether it came from Bäckefors and the English forgemen, or if Ekman was the innovator. However it lasted until 1845 before anything important happened.[9]

By that time Ekman had invented a re-heating furnace fired by charcoal or firewood. Ekman had inherited an ironwork of his own, Lesjöfors in Värmland, in the West of Sweden, and could devote both time and money to his mission in life, namely to work for a change in the Swedish iron industry. The industry responded very quickly to his invention, and especially ironmasters in Värmland replaced their hearths for the German process with Lancashire hearths and Ekmans reheating furnaces. Without any adequate statistics it is impossible to say how long this replacement of forging technic took, but around 1860 some 75% of all wrought iron production ought to have been manufactured with the Lancashire method. (About 10% was Walloon iron and the remaining 15% was divided into minor methods, including puddling and the German method.)

The first rolling mill for bar-iron i Sweden were builded in combination with the two puddling works in Surahammar and Nyby during the 1840ies. It lasted until 1851 before rolling was combined with the Lancashire process. This happened in Finspång under the guidance of Carl Ekman, a brother of Gustaf Ekman. After that rolling of Lancashire blooms expanded.

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[9] Se Adamson, Rolf (1981) Lancashiresmidets införande vid Bäckefors bruk, in *Dalsland, Svenska Turistföreningens årsskrift 1981*.

Wrought Iron Production and the Steel Processes[10]

One effect of the underestimation of the impact on the industrial change coming from the iron industry has been a miscalculation of the growth rate of the industry. It has been argued that the production started to rise sometimes after the mid-century, but the growth started earlier. The wrought iron production was about 50 000 ton in the 1770ies, as was noted above. 50 years later, in the 1820ies, it had risen to well over 65 000 ton. Then came a period of twenty year with an accelerated growth rate, and in the early 1850ies the production cut the one hundred ton line.

During the period 1856-1886 there are no good statistic over the wrought iron production. It is therefore very difficult to calculate the growth rate in Sweden. I am at presently occupied with a very time consuming attempt to calculate the production of one region for this period. It is therefore hard to say anything about the trends. This is very unlucky as it was the early years of the Lancashire process and at the same time the period of competition with the emerging steel processes. In 1887 the wrought iron production was very close to 250 000 ton, but the trend was then already going downwards.

Anyhow it lasted as long as until 1895 before the production of steel caught up with the wrought iron production, and at the verge towards the first world war the manufacturing of wrought iron still made up 20% of the total production of iron and steel. Compared with the Bessemer steel production the wrought iron production was bigger until the middle of the 1920ies, and they were both closed down in Sweden about the same time. In 1964 manufacturing of wrought iron came to and end when they closed down the forge in Ramnäs. A year later 'the Bessemer era' in Sweden ended when the Bessemer section of the Hagfors steelwork was closed down. Of the methods used during the 19th century it was only the open-hearth method that existed in Sweden after 1970.

The introduction of the new process and the division of labour[11]

The basic difference between the German process and the Lancashire process is that in the former both the melting/refining and the reheating procedures took place in the same hearth. In the Lancashire method these two parts of the process had been divided into separate units, the melting, or Lancashire, hearth, and the reheating furnace. In the German process only one hammer was used for both squeezing the iron after the refining and the manufacturing of the bars, while the new process made use of more hammers, one big and heavy for squeezing, one lighter for the first shaping of the bars and one even lighter for the final treatment of the bars.

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[10] Based on statistics provided by Hildebrand (1987), Attman (1986) and Rydén (1990).

[11] This section is based on Rydén, Göran (1984) *Gammelstilla Stångjärns-smedja. En manufakturindustri*. Uppsala Papers in Economic History, Research Report No 3, Rydén (1990) and ongoing research. See also Fahlström, J.M. (1960) Lancashiremetoden och den svenska järnhanteringen, in *Historisk Tidskrift 1960*.

This meant that the Lancashire forge was a far more complicated plant than the German forge ever was. Three things accentuated this. First the Lancashire method was introduced at the same time as the production regulations were abolished. This meant that the ironmasters were allowed to increase their production level, with an enlarged size of the forges as a result. Secondly there was a builded-in technical bias towards making the forges bigger than before. One reheating furnace was capable of serving at least four or five Lancashire hearths, and this came to be the minimum size of the new erected forges.[12] Thirdly the introduction of the Lancashire process coincided with the diffusion of steam power in Sweden. The new method could with advantage use the new source of energy, first by installing steam hammers and later as driving force for rolling mills.

The introduction of the new refining method at plant level caused, of course, some trouble. First it was the question of recruiting. With the general increase in production level there was a big rise in demand for new forgemen. Secondly it was some questions of how to organize the production. In this paper I will only deal with the second of these problems.

The basic work organization in the German forging method was a work team, or a *'hammer crew'* (*"Hammarlag"*) as it was called, consisting three forgemen. They were called master forgeman (*"Hammarsmedsmästare"*), forge hand (*"Mästersven"*) and apprentice (*"Koldräng"*). They worked in an inner shiftsystem from sunday evening to saturday evening, performing all tasks included in the process, even auxiliary tasks. The master did his ten to twelve hours shift while the forge hand had his rest. The apprentice was working for the first half of that shift, he then went for a rest. During the second shift the forge hand had the responsibility for the work while the master rested. This meant that during the whole week the master and the hand worked in a shift system of ten to twelve hours with a rest period of the same length of time. The apprentice worked five to six hours and then rested five to six hours.

This organization had existed at least since the middle of the 17th century, and it was therefore quite natural that it was used even after the introduction of the Lancashire process. There were, though, some changes. The most important one was that of the builded-in technical division between the two parts of the process, melting/refining and reheating. This meant that one 'hammer crew' had to become two, one responsible for the work in the hearth and one responsible for the reheating furnace.

Very soon it was also decided that the informal shift system between the master and the forge hand should be formalised. The Lancashire forgemen came to work six hours and then rest for six hours.

During the 1850ies and the early 1860ies the 'hammer crews' of the Lancashire hearths had the following structure: The master and the forge hand worked every other shift for six days. For their help they had one apprentice each. It very

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[12] There was of course the opportunity of changing a German forge to a small lancashire forge with only two lancashire hearths and no reheating furnace. The blooms were then transported to a bigger forge with a reheating furnace. This became more common in later stages of the development in connection with the introduction of rolling mills.

soon became evident that this organization did not suit the new refining method, and after a minor technical change had been made it was necessary to employ one extra apprentice per shift. The forgemen then worked with two apprentices. Very soon the distinction between the master and the hand disappeared and they were thought of as equal, and the title became 'half-master'. Towards the end of the 1870ies the superiority of the forgemen over the oldest of the two apprentices were lost and the hammer crew changed into four 'quarter-master', or just 'melters', and two apprentices.

At the same time there was also a division of labour between the work at the hearths and at the melting hammer. One hammer could serve about five hearths, and a special hammer forgeman was appointed. He was supported by a boy who was responsible for the pace of the hammer. The auxiliary tasks, as charcoal carrying and cinder removal, were also separated from the rest of the work and delegated to special workers.

In the reheating unit a 'hammer crew' adopted for the new method was found at an earlier stage. From the beginning there was a division between the forgemen working by the furnace and by the hammers, and there was faster development away from the older distinction between the master and his forge hand. In the early 1870ies we find two welders working by the furnace, together with two boys, one of each at each shift. By the hammers, sex hammer forgemen and four boys worked in two shift.

The division of labour in the Lancashire forge was initiated by the technical differences that existed between the German process and the Lancashire process. It was not possible to adopt the older 'hammer crews' for the new technic. The first reason for that was purely technical. The process of wrought iron manufacturing from pig iron had been divided into two major parts, the melting/refining and the reheating/bar-iron making. This required two separate 'hammer crews' or work teams. A second reason for the decomposition of the older 'hammer crews', or rather the hierarchial bonds that existed between different forgemen in the teams, has more of social connotations. It soon became evident that the new process differed from the preceding one in important features, the forge was no longer a small workshop of up to ten workers but a workplace for often five times that many, the production level of the forge was no more dictated by the state but by the performance of the workers themselves, the forge had developed from a rather simple workshop in technical terms to a more complicated unit etc. All this meant that the production had to be organized at a more efficient level, and the division of labour was the tool used for this purpose.

This development was also of benefit for the technical change. As Adam Smith, Charles Babbage and Karl Marx have underlined it was easier to generate technical change in a process that was divided into smaller segments. This also happened. The best example was, of course, the introduction of rolling mills instead of the manufacturing of bar-iron under hammers.

The introduction of rolling mills changed, of course, the organization of the production. These new mills could be constructed so that they could serve a lot more hearths than the older hammering departments. The division of labour was from the beginning very far going. Already during the 1850ies a rolling mill team, including the men at the reheating furnace, consisted of more that 30 men working two shifts. All of them had different tasks to perform.

Trying to summarize the development of the Lancashire process it is evident that two features were of special importance in the progress beginning in the older refining technics and ending in the emerging steel processes. These were the segmentation of the wrought iron production into two distinct parts and the continuing division of labour. Together these features created the necessary conditions for a further development of the industry.

During the 1820ies the average forge employing the German process consisted of two hearths and one hammer. Two 'hammer crews', of together six persons worked there. They produced about 150 ton of bar-iron a year. 40 years later this forge could have grown to a big workshop with up to six Lancashire hearths, steam hammers, one or two reheating furnaces and rolling mills. Up to about one hundred workers could have been employed and the production could be somewhere around 3000 ton.

I will now end this paper by giving you a very brief view of the connection between the Lancashire process and the German process and the introduction of steel on the micro level. A lot of research remains to be done in this area, but some main trends are clearly visible.

Tracing the division of labour one further step back: Technical development in the German process[13]

The introduction of the Lancashire process started in the western counties in Sweden. It was in Värmland that the new method first made its breakthrough. One reason for that was no doubt the fact that Ekman was doing his research in Värmland, but there is also one other possible cause for this. The wrought iron manufactured in this county was said to of a very poor quality. According to the metallurgists in the Ironmasters Associations staff the forgemen used a very bad adaptation of the German process, and it was totally impossible to make them change.

In the county of Gästrikland, on the east coast of Sweden, the Lancashire method was introduced 10 year after Värmland, but the quality of their wrought iron was of a very high quality. It was in fact even possible to sell some of it to the steel producers in Sheffield. In Gästrikland there was a clearly visible technical change in the German process during its last years of existence. They started to rebuild the hearths in a manner clearly preceding the Lancashire hearths, using hot air in the bellows and preheated the pig-iron and charcoal. More hammers, and of new constructions, were also used in the forge. Lastly there was a change in the construction of the bellows, more powerful blowing machines were used.

In connection with these technical modification of the forging method there was also a very important change in the 'hammer crews' and in the actual working procedure in the forge. Towards the end of the 1830ies the traditional 'hammer

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[13] Based entirely on Rydén (1990).

crew', consisting of three workers, was enlarged with a forth member. He was called 'hammerhand' (*"räckardräng"*), and placed between the forge hand and the apprentice in the hierarchy.

With the older 'hammer crews' the forgeman doing his shift had the responsibility for the whole process, he was actually doing almost everything at the same time. During the first half of the shift the forgemen should melt pig-iron, weld blooms and draw them out to bars. He was helped by the apprentice, but he could not devote enough time to the melting procedure. The introduction of the extra man changed this, and in the new work organization in the German forge more forgemen worked side by side at the same time.

It is possible to see this as the starting point of the gradual segmentation of the two parts of the process of wrought iron manufacturing. Earlier the forgeman had done these parts simultaneous, but after the change he could devote his skill at each of them at a time.

I think that the internal development of the German process in the east part of Sweden during the 1830ies and the 1840ies both can explain why the introduction of the Lancashire process lasted so long, and at the same time pin-point the fact that there is more of continuity in the technical development of the Swedish iron industry than earlier historians have thought.

The introduction of steel[14]

When it comes to the introduction of steel on plant level we do not have much to go on as the research in this field is much in its beginning. There is of course studies on a macro level, but as was noted above these have a tendency to underline the aspect of discontinuity, the iron industry became 'fully developed' with the introduction of modern steel processes. My aim has been to emphasis the aspect of continuity and in doing so I have taken the study of technical change from the macro level down to the micro level, and related it to the actual work procedure in the forge.

Even if the first successful production of Bessemer steel can be dated back to 1858, it lasted well into the 1860ies before any new steelwork were erected, and it was only in one work, Sandviken, that any progress was made. The expansion for the new method came instead during the boom in the early 1870ies.

If one study the steelwork in Sandviken during its first two decades it is striking how low the production of Bessemer ingot was. It lasted until 1880 before more than 8000 ton was produced. At that time new Lancashire forges had been erected with more that ten hearths and with a production level of more than 8000 ton. So there was, in this sense, not any big difference between the two methods. If one compare the number of workers there is of course some contrasts, in a forge with ten hearths about 75 workers were employed while the Bessemer department in Sandviken employed some 30 workers.

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[14] See Attman (1986) and Hedin, Göran editor (1937) *Ett Svenskt Jernverk. Sandviken och dess utveckling 1862-1937.*

The most important feature in the aspect of a more continuous development is the fact that the rolling departments were exactly the same. This is the extension of my point made above, the development of the iron industry was dependent on the division of the process of wrought iron manufacturing into one refining procedure and one reheating and shaping procedure. In fact most of the early rolling mills were used for both iron and steel rolling.

One last example can illustrate this further. The biggest rolling mill in Sweden during the 1860ies and well into the 1870ies was Smedjebacken. It was a kind of co-operative mill of four different ironwork companies producing Lancashire blooms. When, during the 1890ies, it was decided to change to steel production an open-hearth furnace was build in Smedjebacken in connection with the rolling mill, and the four founding companies were slowly going out of business.

SUMMARY

This leaves me with the more than easy task of trying to summarize what I have said so far. First I want to underline that the results presented in this paper are highly preliminary. Much research in this area remain to be done. On some points I have leaned on very sketchy sources.

I have in this paper tried to highlight a more continuous view on the technical development of the Swedish iron industry. Sofar Swedish historian have had a very old fashioned idea about the industrial revolution,[15] they have studied it from a macro perspective and underlined some distinct breaks in the development. This has made them argue that the iron industry went through a marked shift after the introduction of the modern steel processes.

I have here put forward some ideas of how to analyze this development in a different way, by pin-pointing the fact that industrial change also can be studied on a micro level. My results generate a different pattern of development. I have showed that the technical progress seen on this level point towards a more continuous evolution.

The lancashire process, as I see it, was the necessary bridge between the old wrought iron industry and the modern steel production. The two most important features of this process were, first, the segmentation of the older process into two parts, melting/refining and reheating/shaping of the bars, and, secondly, the continuing division of labour. These features made a further development possible. I think that one could say that the puddle process filled the same position in most other countries.[16]

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[15] See for instance a very new book on the technical history of Sweden: *Svensk Teknikhistoria* (1989) edited by Rydberg, Sven.

[16] See for example Nuwer, Michael (1988) From Batch to Flow: Production Technology and Work-Force Skills in the Steel Industry, 1880-1920, in *Tecnology and Culture vol 29 nr 4*, for an interesting discussion about the change from puddling to steel in the American industry.

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Abstract of my paper.

INDUSTRIAL REVOLUTION OR TECHNICAL EVOLUTION

- The Swedish Iron Industry During the 19th Century

In my paper I will address the question whether there was a striking technical breakthrough in the process we often call the industrial revolution. In the traditional view of this process the technical aspect has been emphasised very strongly, and for some writers it has almost been the one and only aspect of change. I will discuss the technical development in the Swedish iron industry during a period of change, that is from the end of the napoleonic wars up to the closing years of the century. I will dwell mostly upon the period preceding the introduction of the modern steel processes.

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Traditionally the industrial revolution has been analyzed in terms of a rapid technical change in some of the leading branches of the economy. In Sweden, historians have often pointed towards the lumber industry and the impact the increasing export of wood products had on the society. The development is said to have begun with the introduction of steam power in 1849, and the 'take-off' took place sometime after 1870.

The same historians have had very little to say about the impact coming from the iron industry, and this is a bit strange as this branch has had a very important position in the development in Sweden. It was by far the largest sector of the economy, besides agriculture, from at least the 16th century up to the end of the 19th century.

The importance of the iron industry has clearly affected the different disciplines of history, especially economic history. For a long time, up to the beginning of the 60's, a lot of case studies were directed towards the iron industry, but unfortunately very few of them had anything to say about the process of industrialization. They were most often written as histories of specific firms. There was, though, an active interest in the technical development of the firm.

For my period of interest it can be concluded that during the last quarter of the 19th century there was a rapid technical change. As in the rest of Europe, and in the US, there was an introduction, and expansion, of the modern steel processes. The Bessemer method came first, in Sweden during the

1860's, while the open-hearth method lasted a bit longer; in Sweden the expansion came as late as in the 1880's. This has been treated as the industrial revolution of the iron industry.

In the literature, there is also often a discussion about the introduction in Sweden about 1850 of a new refining method, the lancashire process. This process expanded very rapidly through out the country. In this discussion few connections have been made, however, to the overall technical development or to the process of industrialization.

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In my research I have a different approach to the process of industrialization. I want to insert the view of a rapid and swift change with a model that emphasizes continuity more. This does not mean that the aspect of discontinuity is totally abandoned. Instead the process of industrialization is seen as being far more complicated than earlier historians have thought. This approach has recently been given the label 'combined and uneven development'.

In my paper I will discuss the question of technical change in this new framework for studying industrialization. I will relate this to the aspect of work, as I think it is impossible to deal with one of them without dealing with the other. Surprisingly little has been done in this field, at least in the English-speaking world. As Patrick Joyce has argued recently, we still know very little about the history of work. This means that we also know very little about the technical development at its base level, at the work place.[1]

My general interest is to analyze the gradual technical development in the Swedish iron industry during the 19th century. In this paper the aim is more narrow, and I just want to present some thoughts on how to relate the introduction and expansion of the lancashire process to the processes preceding it and succeeding it.

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[1] Patrick Joyce, Work, in The Cambridge Social History of Britain 1750-1950. Volume 2: People and their environment, 1990, pp 131-194, see especially pp 169-184.

André GRELON

Intervention au Workshop - Barcelona 13.07/15.07.91

(en alternance avec Cl. Fontanon)

LE CONSERVATOIRE NATIONAL DES ARTS ET METIERS

Les racines:

Pour marquer combien le Conservatoire aurait eu des origines illustres, certains n'ont pas hésité à aller rechercher le parrainage de Descartes. Entre autres nombreuses choses, le savant philosophe s'intéressait en effet aux arts et métiers, et en 1648, il évoque la création d'un établissement spécial destiné aux artisans, avec des salles consacrées chacune à un corps de métier, remplies de tous les instruments nécessaires, où l'on ferait faire des démonstrations par des professeurs: ceux-ci "devraient être habiles en mathématiques et en physique, afin de pouvoir répondre à toutes les questions des artisans, leur rendre raison de toutes choses et leur donner du jour pour faire de nouvelles découvertes dans les arts".(1) En réalité, ce projet ne voit jamais le jour du vivant de Descartes. Mais cette idée est intéressante à double titre: elle rappelle d'abord qu'à cette époque, la science est une. Le philosophe qui avait chez lui un laboratoire de physique et une salle de dissection anatomique, ne professait point de mépris pour les techniques, bien au contraire: sa perspective est fusionnelle. Le paradigme de la science pure ne naîtra que bien postérieurement, dans le dernier XIXème siècle. Par ailleurs, la suggestion de Descartes montre que commence à se préciser cette idée d'un enseignement ad hoc permanent dans des lieux spéciaux, plutôt qu'une formation sur le tas, idée qui sera reprise, développée et appliquée au XVIIIème siècle.

Vingt ans plus tard, le ministre Colbert qui veut passionnément développer les manufactures en France, ouvre un *Cabinet des Machines* dans le cadre de l'Académie des Sciences, afin que les Académiciens puissent analyser les procédés des artistes et les perfectionnent: on y montre des cabestans, des machines hydrauliques pour élever les eaux. En 1699, un règlement royal stipule que désormais, "L'Académie examinera, si le Roi l'ordonne, toutes les machines pour lesquelles on sollicitera des privilèges auprès de sa Majesté. Elle certifiera si elles sont nouvelles et utiles et les inventeurs de celles qui seront approuvées, seront tenus de lui en laisser un modèle."(2) Les collections de l'Académie croissent tout au long du XVIIIème siècle: on y trouve des machines agricoles, des mouvements d'horlogerie, des grues, des serrures, des tours, des métiers à tisser, des machines à couper les pierres, etc. Pour informer le public du type et des caractéristiques de ces machines, l'Académie entreprend au milieu du XVIIIème siècle -avec une sage lenteur- de rédiger un recueil, *Le Recueil des Machines*, (auquel travaille entre autres Vaucanson) décrivant les machines et inventions qu'elle avait approuvées depuis l'origine de la règlementation. Le cabinet et ce recueil attirent la sympathie du milieu artisan pour l'Académie des

Sciences. Une partie de ce fonds (soit 441 pièces) partira au Conservatoire des Arts et Métiers lorsqu'il sera installé dans ses murs.

Vaucanson, l'inventeur célèbre, inspecteur des manufactures royales, s'était installé à la fin de sa vie à l'Hôtel de Mortagne, dans un faubourg parisien, demeure dans laquelle il avait rassemblé les machines les plus diverses dont beaucoup étaient de son invention. À sa mort en 1783, sa fille légua cette collection au roi, au nom de son père. Le roi Louis XVI accepta ce legs qui devint le cabinet des machines du roy. Le contrôleur général des Finances joue un rôle dans cette décision royale: l'administration du Commerce ne tient pas à ce que ces machines soient abandonnées. Plus, il s'agit d'établir à terme un établissement où non seulement seraient déposées les inventions les plus utiles à l'industrie, mais aussi d'exposer au public à jour fixe les machines (par exemple celles utilisées en Angleterre et en Hollande), voire de les construire sur place. Les ouvriers de Vaucanson seront donc réemployés à cette fin. Mais ils devraient en outre former des élèves. Ainsi voit-on en germe s'élaborer l'idée du Conservatoire qui sera exposée onze ans plus tard à la Convention. Le cabinet des machines est confié à Vandermonde, mathématicien, théoricien de la musique, membre de l'Académie et commissaire auprès du Bureau du Commerce. C'est Vandermonde qui, avec Berthollet et Monge, publiera en 1786 le fameux *Mémoire sur le fer considéré dans ses différents états métalliques*.

Le XVIIIème siècle est aussi une grande époque de publications consacrées aux métiers. La première en date est la collection de monographies de l'Académie des Sciences, consacrée aux *Descriptions des arts et métiers*. L'origine en remonte à une injonction de Colbert, non suivie d'effet jusqu'à la fin du siècle. Mais à partir de la réorganisation de 1699, l'Académie publie régulièrement une impressionnante série qui se poursuivra jusqu'à la Révolution, soit au total 27 volumes, desquels seront tirés 94 recueils consacrés chacun à un métier particulier. Vandermonde s'occupe de ces publications.

Il n'est sans doute plus besoin de rappeler la publication, sous la direction de Diderot et d'Alembert de *L'Encyclopédie*. Cette entreprise participe, avec d'autres ouvrages du même type comme l'*Encyclopédie méthodique* parue en fin de siècle, de ce véritable engouement pour les Arts et Métiers. Cet engouement se manifeste aussi par la fondation de "musées" consacrés à ces questions, entreprises commerciales dont l'existence est éphémère, à l'exception du *Musée de Monsieur* fondé par Pilatre de Rozier sous la protection du frère du roi et qui en 1785 prend le nom de *Lycée*: il connaît un authentique succès et se présente en fait comme un véritable centre d'instruction avec une collection de machines, et où les plus grands savants comme Monge et Fourcroy viennent y enseigner l'usage des machines nouvelles et des nouveaux procédés de travail. En 1792, le *Lycée*, du fait de ses origines, devient suspect et un *Lycée des Arts* concurrent voit le jour: il recueille la plupart des professeurs de l'ancien établissement.

Par ces quelques indications, on peut mieux mesurer combien, à la différence de ce qui a été dit parfois de façon un peu naïve au moment de la célébration du bicentenaire de la Révolution, le Conservatoire s'insère dans un vaste mouvement, amorcé dès le milieu du XVIIème siècle et qui n'a cessé de s'amplifier: l'institution n'est donc pas née toute armée de la seule pensée féconde des révolutionnaires. Les hommes qui l'inspirent, ceux qui l'animeront et la feront vivre, ont déjà largement oeuvré sous l'Ancien Régime. Lorsque Grégoire présente le projet de Conservatoire des Arts et Métiers à la Convention, il s'appuie sur cet ensemble de réalisations nées dans le siècle. Il est écouté et approuvé par des députés qui, baignés dans cet atmosphère d'intérêt permanent pour les sciences et les arts, comprennent parfaitement l'objet du débat et l'utilité d'une telle réalisation.

Le projet de Conservatoire s'insère du reste dans une vaste délibération menée par les Conventionnels sur les questions d'éducation nationale et sur la nécessité de réorganiser un enseignement dans tous les domaines, réflexion qui avait été alimentée entre autres par les analyses de Condorcet ou par les *Réflexions sur l'instruction publique* de Lavoisier (24 juillet 1793). Il n'est pas indifférent de noter que le projet de décret pour l'établissement du Conservatoire est présenté le 29 septembre 1794, c'est-à-dire le lendemain de la création par la même assemblée de l'Ecole Centrale des Travaux Publics qui prendra par la suite le nom d'Ecole polytechnique. Ainsi l'Etat immédiatement après s'être occupé du recrutement et de la formation de ses cadres civils et militaires, se penche vers la question de l'instruction des industriels et des artisans.

Quelles sont les fonctions dévolues à la nouvelle institution? Elles sont indiquées dans les deux premiers articles: "Il sera formé à Paris, sous le nom de Conservatoire des arts et métiers,(...) un dépot de machines, modèles, outils, dessins, descriptions et livres dans tous les genres d'arts et métiers. L'original des instruments et machines inventés et perfectionnés sera déposé au Conservatoire." (art.1) Il faut rassembler en un même lieu les diverses collections composées au fil du temps et les mettre sous une responsabilité unique.
Mais il ne s'agit pas seulement de conserver, comme le précise l'article 2: "on y expliquera la construction et l'emploi des outils et machines utiles aux arts et métiers". Pour se faire, le Conservatoire sera doté d'un personnel permanent: trois démonstrateurs et un dessinateur. Il ne faudrait pas en rester au titre de la fonction qui pour nous en cette fin du XXe siècle n'a pas une grande signification. Les trois démonstrateurs nommés sont trois savants: on y retrouve Vandermonde -qui a déjà en charge l'Hôtel de Mortagne et les collections du cabinet du Roy - , Le Roy, académicien, ancien membre de l'administration du Commerce sous l'ancien régime, qui mourra rapidement et sera remplacé par Joseph Michel de Montgolfier, l'aérostier, directeur d'une importante manufacture, et Nicolas Conté qui a inventé le procédé qui porte son nom pour remplacer la plombagine venue d'Angleterre pour les crayons. Quant au dessinateur, Beuvelot, il est membre de la commission des Arts dans la section des plans de machines de guerre et fortifications. La question du dessin des machines est dès cette époque primordiale.

L'organisation du Conservatoire ne s'effectuera que progressivement. Il va tout d'abord trouver un patron: ce sera Claude-Pierre Molard qui, adjoint de Vandermonde à l'hôtel de Mortagne, prend sa place au Conservatoire au décès de celui-ci; rapidement, il y joue un rôle prépondérant: un arrêté ministériel le nomme administrateur de l'établissement en 1800. Il faudra ensuite chercher un local: ce sera en définitive (après 5 ans d'attente) dans l'ancienne abbaye de Saint-Martin des Champs que l'on devra aménager pour placer les collections et pouvoir y faire des enseignements. Le Conservatoire est ainsi situé au coeur de Paris et surtout en plein centre d'un quartier artisanal et industriel. Il faut inventorier et classer les machines et objets industriels divers venus de fonds différent, ce qui n'est pas une mince affaire quand ils se comptent par centaines. Mais il faut aussi souvent les remettre en état (c'est le cas en particulier des collections de l'Académie des Sciences). Toutefois l'atelier devrait également en principe participer à l'enseignement pratique et aussi construire les modèles approuvées par le Conservatoire. Ce n'est qu'en 1810 que cet atelier sera réellement organisé. A cette époque, les meilleurs élèves de l'Ecole d'arts et métiers de Chalons sont envoyés au Conservatoire y parfaire leur instruction dans le cadre de cet atelier.

On doit aussi noter la création d'un bureau des dessinateurs qui tracent les plans des machines du Conservatoire, mais aussi - en principe- devraient réunir les dessins de toutes les machines connues concernant les arts et métiers. Enfin, les dessinateurs doivent enseigner les règles du dessin concernant les objets d'art mécanique. C'est ainsi que naîtra l'école de dessin du Conservatoire qui prendra ensuite son autonomie. Quant au bureau de dessin, il disparaîtra avec la nouvelle orientation du Conservatoire lorsque seront créées les premières chaires du haut enseignement.

Le Conservatoire dispose d'une bibliothèque. Ses premiers fonds proviennent des bibliothèques conventuelles, devenues nationales. Le bibliothécaire doit en outre assurer des traductions d'ouvrages en langues étrangères, utiles aux arts et métiers. En 1813, la bibliothèque possède déjà 8000 ouvrages.

Mis en place, le Conservatoire devient rapidement un lieu d'expériences et il sert de jury pour le bureau consultatif des Arts et Manufactures qui siège au ministère de l'Intérieur et qui doit veiller au développement de l'industrie. Et dès leurs créations, le Conservatoire entretient des liens étroits avec la Société d'Encouragement à l'Industrie nationale et la Société d'Agriculture. Mais outre son rôle de laboratoire d'essais et d'expert technique, l'Institution va rapidement développer un véritable enseignement. Le plus important est celui de l'école de dessin, mise en place dès le début du siècle et ouverte officiellement comme *Ecole gratuite de dessin appliquée aux arts* en 1806. Les élèves sont âgés de 14 ans au moins et doivent connaître un peu d'arithmétique. Ils sont choisis par les maires des arrondissements de Paris parmi les "fils d'artistes" qui montrent des dispositions. Le programme est celui d'une école technique (arithmétique, géométrie, géométrie descriptive, statistique, et une grosse partie de dessin technique - dessin d'architecture, de machines, lavis, dessins pour étoffes brochées, dessin d'ornement-). Les études durent trois ans. Il semble bien qu'en réalité, l'instruction soit à peu près totalement focalisée sur le dessin au détriment des autres matières. Mais l'école a du succès avec une centaine d'élèves par an, à partir des années 1820. Elle perdra de son efficacité à partir des années 1860: l'enseignement ne s'est pas adaptée aux nouvelles demandes industrielles, le dessin technique est professé dans d'autres établissements. Elle fermera ses portes définitivement en 1874.

On peut mentionner également une école de filature dirigée par des techniciens anglais, thomas Fergusson puis Jacques Milne. Il y a peu d'élèves (une quinzaine au maximum dans la meilleure année). Ouverte en 1804, l'école fermera en 1814, victime des circonstances économiques. Il faudra attendre 1866 pour voir réouvrir une école de filature en France: ce sera à Mulhouse, par les soins de la Société industrielle mulhousienne, et non de l'Etat.

Mais dès cette époque, des idées d'un enseignement d'un niveau plus élevé circulent. Molard réfléchit à l'idée d'une instruction plus large incluant la mécanique, la construction des outils, la chimie appliquée. (3) Après 1814, l'enseignement y est critiqué par La Rochefoucault qui est inspecteur des écoles d'arts et métiers et du Conservatoire. En fait, le Duc souhaiterait que l'institution parisienne donne une formation complémentaire aux élèves diplômés de Chalons et d'Angers, dans le but de former des directeurs instruits et non plus des ouvriers. Curieusement, ce voeu de La Rochefoucault, non exécuté de son vivant, sera finalement réalisé sous une autre forme au XXe siècle, les élèves des centres régionaux de l'ENSAM achevant leurs études à Paris pour y recevoir leur diplôme d'ingénieur. Le point de vue de l'inspecteur du Conservatoire rend compte des problèmes qui commencent à se poser à l'industrie française, par manque d'un encadrement et de dirigeants suffisamment éduqués. La réponse sera donnée d'une part par l'Ecole Centrale des Arts et Manufactures, fondée en 1829. D'autre part, le Conservatoire, poussé par des hommes comme Arago et Charles Dupin, va s'orienter vers un enseignement beaucoup plus élevé. Ce sera l'ordonnance du 25 novembre 1819 qui crée au sein de l'établissement une haute école d'application des connaissances scientifiques au commerce et à l'industrie avec trois chaires: une de mécanique offerte au baron Dupin, une de chimie appliquée aux arts donnée à Nicolas Clément-Desormes, une d'économie industrielle pour Jean-Baptiste Say. Par ailleurs, un cours de physique expérimentale est fait par Charles depuis 1816 pour quelques élèves, trois mois par an, jusqu'au début des années 1820. En 1829, le haut enseignement sera complété par une chaire de physique attribuée à Pouillet. C'est une nouvelle étape pour le Conservatoire: désormais, c'est le haut enseignement qui va imprimer sa marque sur l'institution. Cette orientation ne sera pas démentie jusqu'à nos jours.

(1) Adrien Baillet, *La vie de Monsieur Descartes*, p.434, Paris, 1691. Cité par J. Fayet, in *La Révolution française et la Science*, Paris, Marcel Rivière, 1960, p.285
(2) Fayet, p.290
(3) Dominique De Place, *L'incitation au progrès technique et industriel en France, de la fin du XVIIIe siècle à la Restauration, vue à travers les archives du Conservatoire des Arts et Métiers*, Paris, EHESS, 1981, p.143

2) L'entre-deux-guerres

En 1918, Maurice Soubrier, Polytechnicien et alors professeur suppléant d'électricité industrielle au CNAM écrit ceci: "Le Conservatoire National des Arts et Métiers offre une formule très nette, très personnelle de liberté et de haut enseignement qui peut et doit être étendue à toutes les sciences industrielles. Ce magnifique établissement est appelé à jouer un rôle considérable dans les nouvelles méthodes économiques d'après-guerre. M. Blondel, l'éminent membre de l'Institut, propose d'en faire l'Institut National des Sciences industrielles. Ce serait en effet sa véritable destination."(1)

En réalité, les voeux de M. Soubrier n'ont été que très imparfaitement réalisés sur les trois points qu'il énonce: un enseignement libre que l'on suit pour sa seule culture scientifique et technique; le développement des nouvelles méthodes économiques; sa transformation en Institut national de sciences industrielles. Examinons les successivement.

A) Alors qu'il est émerveillé par le nombre et la qualité de travailleurs absolument libres qui viennent suivre les cours uniquement pour s'instruire et se perfectionner, en dehors de leurs obligations professionnelles, l'entre-deux-guerres va être au contraire marquée par la création d'un diplôme d'ingénieur CNAM qui permettra aux élèves des cours du soir de rentabiliser les nombreuses heures passées à suivre ces enseignements. en réalité, la question du diplôme empoisonnait le Conservatoire depuis la fin du XIXème siècle. A cette époque, les universités régionales avaient non seulement enseigné pour les grades universitaires qu'étaient la licence et le doctorat, mais elles avaient obtenu par décret de 1897, le droit de délivrer des diplômes qui leur fussent propres. C'est ainsi que nombre de diplômes d'ingénieurs universitaires avaient été créés. Après bien des discussions, le Conservatoire avait institué en 1905 un diplôme couvrant plusieurs enseignements suivis par le même élève: mais cette création n'avait pas eu le succès escompté. Pourtant les élèves salariés estimaient qu'il leur fallait un diplôme monnayable. Dans les années qui suivent la guerre, le pays fait le bilan de ses pertes en hommes et l'on prend conscience de la nécessité de reconstituer, voire d'augmenter la couche des spécialistes techniques. C'est une opportunité pour créer un diplôme d'ingénieur du CNAM: les conseils de la maison proposent cette décision au ministre qui l'entérine par décret du 8 août 1922. Mais les conditions d'obtention sont extrêmement difficiles et entre la date de création du diplôme et la guerre, 28 élèves seulement deviendront ingénieurs CNAM.

Par ailleurs, la crise des années trente verra une évolution de la population des auditeurs: dans la deuxième décennie de l'après-guerre, ils sont plus âgés, plus tournés vers des cours de sciences appliquées aussi. Ils cherchent à se donner des qualifications complémentaires pour être plus monnayables sur un marché du travail particulièrement déprimé. Il est vrai que dans cette période d'intense chomage, les entreprises continuent de se plaindre de ne pouvoir recruter assez de personnel qualifié. Les jeunes femmes qui commencent à fréquenter les amphithéatres suivent, elles aussi, des cours appliqués, en chimie, en filature et en tissage. Les employées suivent plutôt les cours économiques et sociaux comme celui sur les assurances sociales. ici aussi, on est loin d'une fréquentation qui serait uniquement motivée par le désir de compléter sa culture scientifique et technique. (2)

Enfin, sur ce point, cette période est marquée par un bouleversement très important dans l'organisation du Conservatoire. Il s'agit de la création des premiers instituts spécialisés, au sein de la maison. Ces instituts ont une vocation de recherche appliquée sur des domaines pointus, mais ils ont aussi pour fonction d'enseigner ces spécialités à des élèves qui viennent y chercher un diplôme particulier et qui payent pour être inscrits, alors que le Conservatoire, depuis la fondation de la petite Ecole, puis du haut enseignement, s'était toujours enorgueilli de diffuser un enseignement gratuit. Le premier de ces instituts ouvert en 1922 porte sur les techniques sanitaires, l'INTEC fondé en 1931, forme aux techniques comptables. En 1932, c'est l'Institut scientifique et technique de l'alimentation et en 1939 ouvre l'Institut de topométrie et Ecole supérieure des géomètres et topographes.

B) Entre les deux guerres, les créations de cours et ouvertures de chaires ne sont guère nombreuses. La première décennie est vierge de toute création, ce qui est quand même paradoxal dans la mesure où cette période se caractérise par une transformation des paradigmes à l'oeuvre dans les différentes sciences. Dans le domaines des sciences physiques, les années trente verront toutefois ouvrir quatre enseignementsdans des domaines importants: la métrologie en 1932 (par Pierre Fleury); le Conservatoire retrouve là une de ses missions les plus importantes depuis ses origines; en outre, le CNAM a été chargé par la loi du 2 avril 1919 de conserver les étalons nationaux du système métrique. La photogrammétrie en 1937) (Roussilhe)et une chaire de moteur à combustion interne (1938, Max Serruys). Enfin, sur les injonctions de Jean Perrin, un cours de téléphonovision par Eugène Huguenard en 1938 (ce que nous appellerions aujourd'hui *télévision*).

Dans le secteur des sciences économiques et sociales, des chaires importantes sont créées qui verront un auditoire attentif et nombreux. C'est la création d'une chaire consacrée aux assurances sociales (1932), dans le contexte d'une action gouvernementale en faveur des assurances sociales, chaire financée par les fédérations des caisses d'assurance sociale. Malheureusement "le climat politique ayant considérablement évolué, une opposition contre le développement des assurances sociales se manifesta si violemment que le gouvernement décida de supprimer cette chaire" [au bout de trois ans].(3)

En 1932 également, une chaire d'Histoire du Travail avait été recréée en faveur de Charles Spinasse (qui sera ministre sous le gouvernement Léon Blum); il était suppléé par un syndicaliste, Georges Lefranc, qui se focalisait sur l'histoire du travail au XIXe siècle. Cette chaire a une importance historique dans la mesure où elle fut reprise par le célèbre sociologue du travail Georges Friedmann qui enseigna pour la première fois en France cette discipline.

Deux autres disciplines font également leur entrée durant cette période: elles sont significatives d'un nouveau regard porté dans l'entreprise sur les problèmes humains du travail. La première est la première chaire d'Organisation Scientifique du Travail (1929), offerte à Louis Danty-Lafrance qui avait été un des principaux promoteurs de la méthode taylorienne dès la guerre de 1914. La seconde porte sur la Prévention des accidents du travail et elle est ouverte la même année.

C) Il faut enfin dire un mot des changements institutionnels importants pour le Conservatoire. La fin de la guerre de 1914 avait vu se dérouler un important débat sur les problèmes de l'enseignement technique et de nombreuses publications avaient été consacrées à cette question. La Société des Ingénieurs Civils de France avait ouvert une large discussion parmi ses membres. Il s'agissait de repenser l'enseignement technique secondaire et supérieur. Dans l'esprit de ses partisans, le Conservatoire devait apparaître comme le sommet d'un enseignement technique pyramidal, comme une véritable "Sorbonne technique". L'enseignement technique était alors entièrement sous la tutelle du ministère de l'Industrie et du Commerce. Mais en 1920 eut lieu une vaste réorganisation gouvernementale. L'ensemble des enseignements techniques fut dévolu au ministère de l'Instruction publique qui doubla ainsi de volume, même si les enseignements techniques conservaient une sorte d'autonomie par l'attribution d'un sous-secrétariat d'Etat. Dans ces conditions, la place du Conservatoire devient difficile à cerner. Les liens organiques avec le ministère de l'Industrie sont rompus: ainsi l'Office national de la Propriété Industrielle qui dépendait du CNAM, reste sous tutelle du ministère du Commerce. Il en est de même du sevice des poids et mesures. Certes le Conservatoire peut faire valoir qu'il est un des plus anciens établissements d'enseignement supérieur en France. Etablissement d'enseignement supérieur, il l'est à n'en pas douter, étant donné la qualité de ses professeurs, mais les cours qu'il distribue ne sont en rien comparables à ceux des autres institutions d'enseignement supérieur dépendant de l'Instruction publique: on a vu plus haut qu'une des premières conséquences de ce transfert au ministère de l'Instruction publique fut la création d'un diplôme d'ingénieur du CNAM. Il faut donc que le Conservatoire s'invente une nouvelle légitimité: ce sera plus facile après la seconde guerre mondiale avec le développement de la Promotion Supérieure du Travail puis des législations sur la formation permanente. Les récentes décisions gouvernementale sur la création de nouvelles filières d'ingénieurs permettent aujourd'hui au CNAM de jouer un rôle pilote dans cette nouvelle organisation.

(1)Maurice SOUBRIER, *Les Industries électriques d'hier et de demain. L'enseignement de lélectricité industrielle*, Paris, Dunod et Pinat, 1918, p.155
(2)Claudine Fontanon, André Grelon, *Le Conservatoire des Arts et Métiers et ses auditeurs entre les deux guerres (1920-1939)*, Madrid, 1988 (XVIe Symposium ICOHTEC)
(3) *Cent-cinquante ans de haut enseignement technique au CNAM*,

1820-1970, Paris, CNAM, 1970, p.130

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LA SCIENCE AU SERVICE DE L'INDUSTRIE: LE CONSERVATOIRE NATIONAL DES ARTS ET METIERS

Au terme d'une période de pré-industrialisation active et dans la lignée des encyclopédistes, la nécessité d'un catalogue raisonné des techniques en usage apparait clairement en France. En 1794, la Convention fonde à cette fin le Conservatoire des Arts et Métiers: cette institution devra présenter des outils, machines et collections d'échantillons aux artisans, industriels et ouvriers et proposer des démonstrations utiles aux arts et aux métiers. En 1799 est annexée en outre une école élémentaire de dessin (dessins de figure, d'ornement et géométrie descriptive) qui connait un certain succès auprès des populations ouvrières. Cette école, devenue progressivement obsolète, sera supprimée en 1874.

Mais ce qui fonde l'originalité du Conservatoire, c'est le développement d'un haut enseignement scientifique au service de l'industrie. Dans son principe, cet enseignement ne se veut pas descriptif ou démonstratif, il ne prétend pas offrir une formation professionnelle pratique. Au contraire, il veut montrer comment la science peut expliquer les processus industriels et par là, permettre aux entrepreneurs de comprendre les principes de leur activité et d'améliorer ainsi leurs procédés et leurs produits. Ainsi verra-t-on s'ouvrir progressivement des chaires dans tous les domaines de l'économie industrielle et agricole - la science ayant une visée universelle - qui devront respecter cette problématique. Les cours professés seront publics, gratuits, accessibles à un auditoire industriel (horaires du soir après le travail), mais l'enseignement ne sera sanctionné par aucun diplôme.

Dès la Restauration, les quatre chaires fondamentales sont instituées: mécanique et géométrie, chimie, économie industrielle et physique appliquée aux arts. L'enseignement essaimera sur ces bases.

Si l'on examine les périodes de création des nouvelles chaires du Conservatoire, on peut se faire une idée de l'évolution des besoins industriels à ces différents moments. L'institution est en effet un miroir des attentes de l'époque et des tendances du développement des activités économiques. Mais par l'ouverture d'enseignements dans de nouvelles spécialités, le Conservatoire entend non seulement répondre à ces demandes, mais surtout en marquer l'orientation en offrant aux acteurs industriels les bienfaits de la science positive qui seule peut permettre de dépasser l'empirisme grossier. Il existe donc une dialectique subtile entre la demande virtuelle du monde économique et la réponse de la communauté savante qui, pour se situer en aval, n'entend pas moins mettre la science aux postes de commande.

L'analyse des vagues de création de chaires met bien en évidence les moments d'impulsion industrielle comme les nouvelles directions que prend l'économie. Ainsi en est-il de l'année 1839, en pleine monarchie de Juillet qui fut une période faste pour l'industrialisation: une deuxième chaire de chimie est instituée, une de géométrie descriptive, une de mécanique, pas moins de deux chaires d'agriculture et une de législation industrielle. Les créations de 1852 signalent l'intérêt pour l'industrie du nouveau régime qu'est le Second Empire: c'est du reste à la même époque (1854) que seront instituées de nouvelles facultés des sciences et, en leur sein, des cours publics de sciences appliquées. On pourrait aussi noter à la fin du siècle l'ouverture d'un cours de Droit commercial (1880) qui correspond à une période de prise de conscience de la nécessité de développer les compétences en ce domaine, et qui verra également une floraison d'écoles de commerce dans l'ensemble des régions de France. L'étude des créations des années 1900 comme des années 1920 montrerait le remarquable développement des études économiques et sociales appliquées (assurances sociales, histoire du travail, géographie industrielle, organisation du travail, etc.).

A partir du Second Empire et sous l'impulsion de son Directeur, le Général Morin, le Conservatoire a également développé un certain nombre de services d'expertises économiques et spécialement industrielles qui ont complété son action d'enseignement au service du monde des entreprises: la création du Laboratoire expérimental de mécanique en 1852 illustre bien cette nouvelle fonction que le Conservatoire entendait désormais jouer. Il en est de même du Laboratoire de métrologie, des travaux de la Convention internationale du mètre à partir de 1869, du dépôt des marques de fabriques, du dépôt des brevets d'invention français et étrangers tombés dans le domaine public, etc.

Ainsi le Conservatoire des Arts et Métiers constitue-t-il un lieu d'observation tout-à-fait adéquat de l'évolution des interactions entre sciences et industries pour le chercheur. Ce champ n'est encore qu'à peine exploité. Les travaux qui ont été menés sur cette institution sont peu nombreux et anciens. Aujourd'hui, nous appuyant sur le renouveau des recherches en histoire des sciences et des techniques et sur l'essor des études en matière d'histoire industrielle qui ont avancé de nouvelles hypothèses explicatives du cas français d'industrialisation, nous nous proposons d'explorer ce terrain qu'est le CNAM en mobilisant la communauté des chercheurs. Nous souhaitons en effet que soient analysées les orientations et évolutions des disciplines enseignées au CNAM depuis le XIXème siècle ,que soit réalisée une prosopographie du corps enseignant et qu'une sociologie historique des auditeurs du Conservatoire puisse être mise en oeuvre. Il s'agit là d'un programme de travail sur plusieurs années dont les hypothèses seront débattues au sein d'un séminaire que nous ouvrirons cet automne et dont les résultats seront exposés dans une série de publications et en particulier dans un dictionnaire biographique des professeurs du Conservatoire rassemblant les études de spécialistes en histoire des sciences, des techniques et des industries.

Electrical research and academic engineering

Anna Guagnini

It is obviously unnecessary to warn this audience about the ambiguities of such an easy expression as "science-based industry" ... Nobody takes it to mean exactly what the phrase seems to imply - at least for the period before the first world war. But, however cautious we are, innocent phrases like this inevitably carry weight, in a sly sort of way ... It is all too easy to assume that the changing character of - say - organic chemicals and electric industry (the classic examples of science-based industry) - it is too easy to assume that the changes in these sectors were the result of the adoption of the approaches and methods that we see being used at the time in academic science. However, our contention, in this paper, is that more careful consideration should be given to what was done in practice, and in places other than the laboratory - academic or industrial.

My reflexion, and, in this paper I am talking about electrical industry, was stimulated by the comparative perspective we have tried to develop over the past few years, and by our unease about an assumption that has run through a lot of work on industrial technology in the period before the and immediately after the first world - an assumption that seems particularly tenacious whenever international comparisons are attempted. The assumption, broadly stated, is that in the age of science-based industry a strong, and preferably expensive commitment to research and development is an essential ingredient of a nation's technological prowess. The corollary is that technological success and, by a deceptively easy extension, economic success have come to be seen as dependent on a capacity for autonomous innovation - or, at least on control over innovation. As a result, a serious commitment to innovation, typified by the presence of research facilities, has assumed an exaggerated, almost symbolic importance, especially when it is applied uncritically to the period before the first world war. And, inevitably, this organized commitment to innovation has come to be regarded as one of the main touchstones dividing the countries we traditionally see as the technological pacemakers (most notably Germany and the U.S.A.) from those which are usually portrayed as limping along in their wake.

Now . . . our scepticism does not concern the fact that some countries performed better than others in electrical technology: that, needless to say, we accept. Our scepticism concerns rather the tendency to invoke research as a main source of innovation, and even more so the tendency to equate research with practices which have only become a routine part of science-based industrial activity since the first world war.

Of course Thomas Hughes has highlighted the variety of social, political, and demographical factors that affected the development of electric supply systems in different national contexts. His analysis has left us with little doubts that technological factors were only part of the complex interplay that led to such a diverse outcome in countries such as Germany, Britain, and the U.S.A. Ulrich on the importance of commercial factors

First part

The first part od my paper deals with the notion of the extended laboratory that, in our view, was a distinctive feature of the period before the first world war.

Our criticism of the image of research as an activity necessarily geared to the quest for novelty has certainly overtones that will be immediately familiar to this audience. In obvious ways, the criticism draws part (though only part) of its strength from the exploding revisionist literature on laboratory practice that has circulated in recent years. One pertinent conclusion that emerges from Leonard Reich's history of research at the American company General Electric, for example, is that the very term "research" is itself obfuscating. Reich describes a company laboratory at the beginning of this century that was far more concerned with testing and patent protection than with the quest for novelty. The laboratory justified its existence by standardizing, enhancing reliability, and the examination of external patents that might be purchased with a view to creating a kind of protective belt around their range of product from which rivals would be virtually excluded. Our scepticism about the nature of research has also been fed by a parallel revisionism directed at academic rather than industrial laboratories

David Cahan Crosbie Smith and Norton Wise on measurement as the key to the develcoment of closer relations between physics and industry, and to the growth of physics laboratories. (see bibliography)

point to an emphasis on painstaking precise measurement that characterized both research and teaching in physics in the later nineteenth century   There is no doubts that one of the reasons for the close relationship between science and technology in the field of telecommunications and electric light and power in the period 1820 to 1880 was the close resemblance between the practices, methods and instruments of the laboratory, and those of industry   [example]

As we have insisted, however, our unease about the rather exclusive preoccupation with laboratory-based innovative research as a mainspring of technological success stems only in part from these historiographical trends. For this new trend of analysis has undoubtedly had the effect of highlighting the importance of a kind of research not deliberately aiming to novelty, and the extent of the involvement of sciences in industry But even when that modification is made, the laboratory still retain, firmly, the central position they hold in the current accounts of the development of research, applied or industrial. This is where we believe it is necessary to go further in the analysis of the relation between the 'location' of science, research, and industrial innovation.

In other words ... if we want to examine the progress made by electrical industry as a whole before the first world war, is this image of research sufficient, or appropriate? Could it be that, by laying emphasis on the close relation between scientists and electrical industry but nevertheless taking an essentially academic image of research, we are restricting the concept of research too much to be adequate for the understanding of the transformation of electrical industry? Do we really believe that, in the first decade of the century, the presence - or the absence - of research facilities, whether they are of the routine kind testing and essaying, or of the more innovative kind, are distinctive (exclusive) signs of the presence of science in industry?

In voicing these reservation, we should not wish to deny innovative laboratory-based research the success that it had, in a number of important cases, already before the first world war. There is no doubt that scientists, often actively involved as consultants for major industrial firms and electricity supply companies, played a vital role in the development of transmission technology and the design of electric machinery. (Edward Ayrton and Guido Semenza)

Moreover, they remained centrally involved in the work on standardization. And this was issues of vital economic as well as technological importance in the development of electrical industry. There is also no way denying the importance of major, though in our view untypical, instances of new departures, such as the metal filament lamp at General Electric, that emerged from the first in-house laboratories. However, these instances should not be allowed to obscure the less spectacular character of most of what was done in the overwhelming majority of companies in the fast as well as in the slow lane of electrical industry. Here, the case of AEG, a large and consistently profitable firm that made its way on the basis of next to no fundamental innovation generated "in house", is an outstanding example that contrast sharply with the far greater reliance on independent research in Siemens and Halske and even, on a smaller scale, Schuckert - before its amalgamation with Siemens.

The point I am trying to make here is that the academic ideal of research, however revised, can divert attention from the innovation that could and did take place in the workshop (or, more precisely, that the revisionist literature would benefit from the development of an strong reassessment of the industrial end of research in the admittedly misty,but nevertheless vital pre-laboratory period. Here, the innovation was typically of a far less spectacular kind and often of an adaptive rather than a fundamentally novel character. But it provided another channel by which knowledge not only entered industrial practice, but actually developed within industrial practice, often producing more immediately profitable results. Indeed, it is tempting to suggest that the key to the technological success of countries in the fast lane of electrical industry may have less to do with the very visible world of the laboratories than with the far obscurer mechanisms for the transfer and adaptation of scientific knowledge through experimentation conducted on the shop floor or at an installation.

The force of this suggestion lies in the location of the cutting edge of electrical technology in the quarter of a century or so before the first world war. The location was unequivocally in the growth of the industrial use of electricity, and in the exploitation of high-voltage polyphase alternating current. It was a world of large generators, long-distance transmission lines, electric traction, and, above all, the slow but inexorable process of electrification of industry. In all these areas, there were major new departures, but they were seldom ones that originated in the laboratory, at least in the laboratory as it is usually conceived. The laboratory that mattered for the pioneers of high-voltage A.C., and for those who endeavoured to replace D.C. with A.C. at the turn of the century was the workshop or the site. Here, the activity was scientific to the extent that it involved experiment, theoretical insights, sophisticated mathematical techniques, and the systematic analysis of production methods.

Examples

Sebastian Ziani de Ferranti (1864-1930) was apprenticed at Siemens, in 1886 was appointed chief engineer of the Grosvenor Gallery electric power station in London, and set up to renew it completely - and successfully. He transformed it into the world's greatest station, with alternators driven by 10,000 hp engines and transmitting at 10,000 volts (the maximum at the time was 500 hp). One year later, in 1887, he embarked in the planning of an even more daring venture, when he became the director of the Deptford power station (for the London Electric Supply Corporation). There, he rushed head long in an exceedingly bold and unprecedented scheme, experimenting with high voltage, alternating current system, with relatively long distance distribution, and machinery of gigantic size. The output was to be 120,000 hp (Edison's 1882 Pearl Street station had a capacity of 750 hp. Everything had to be designed from scratch, not only the huge alternators and the   but also the switches and the cables. And all was carried out without instruments to test the work in progress, nor a theory to guide the design. So much so that the only way of assessing the voltage of the generators was to connect them to a line of electric lamps and see how far the power could sustain it. No one - not even Ferranti - knew exactly what the reaction of the machinery could be, so that this huge and very expensive plant assumed, itself, the character of an experiment. The problem was that the experiment failed, not because of mistakes in the design, but rather because it was impossible to control the behaviour of this large scale experiment as if it were in laboratory: everything was designed to operate at the limit of its anticipated performance, perfection was a necessary condition for its success. Accidents were not allowed - but they happened. First a fire caused by a mistake in operating a plug switch. Then a failure in one of the transformers provoked the overloading of the other transformers (already loaded to the maximum), and burned them all out one after another. Then, when in 1891 the station, albeit reduced in size, began operating, chain of power interruptions revealed failures in various parts of the system when in action. By 1898, the company had lost at least 400 000. It was an economic and technological catastrophe that should have warned off anyone tempted to dabble in innovative entreprises in electrical industry.

Moreover, while laying the cables from the Deptford power station to London Ferranti carried out tests on sections and discovered an entirely unexpected phenomenon. The voltage of the cable remote from the station exceeded the generated voltage. (by adopting the usual system of connecting the number of electric laps that were expected to be lighted at the voltage of the generating machines, and finding that others had to be added to prevent burning them out - 8500volts at Deptford, 10000 at Grosvenor Gallery) Ferranti effect, due to the interaction of the induction of the transformer windings and the capacitance of the cable.

John Hopkinson carried out the research that led in 1886 to the publication of his paper on <u>Dynamo electric machines</u> (Proc. Royal Soc. 40 (1886), p. 326) at the works of Mather & Platt in Manchester. His work led to the patenting of what became the most efficient dynamo of the 1890s (the Edison-Hopkinson model). He continued to act as a consultant. But the lack of market led to a steady decay of the concern with electricity.

And it was in the rather unglamourous environment of Maschinenfabrik Oerlikon that Charles E. L. Brown, technical director of the electrical machinery section of that firm, experimented the use of oil-insulated transformers to step up voltage, and tested the machinery that was to make a sensational demonstration in long distance high voltage alternating current transmission at the Frankfort Exhibition of 1891 that transmission line insulators could work at such intensityand in a rather messy and seemingly modest environment.

The case, recently described by Ulrich Wengenroth, of of the exceedingly complex tasks that were involved in adjusting A.C motors to the requirements of a textile mill is typical. As Wengenroth shows, the gearing and linking mechanism that were required in order to ensure a uniform speed irrespective of the number of machines in use were not fundamentally novel. But the quest for a solution called for precise measurements of efficiency and a degree of mechanical ingenuity and flair which can too easily be eclipsed by the the fact that it was not carried out in the kind of environment usually associated to research activity.

The workers of this laboratory, however, were not the physicists but electrical engineers, a very different breed who combined scientific competence with experimental interest focussed firmly on the machines and installations themselves. The fruits of their efforts were at times highly innovative. But more frequently they were improvements of a less spectacular kind in quality control, in the reduction of production costs, or in the harnessing of electric power in new industrial contexts.

Second part: the teaching and research institutions

By drawing attention to the engineers, the last thing I want to do is to suggest the existence of a profound dichotomy between science and practice, but rather to highlight the growth of a body of highly qualified technical experts. In the early 1880s, it was electrical engineering that began to emerge as the fastest growing sector of engineering schools throughout Europe. And it was the product of these new schools who gradually overtook the "men of practice" and physicists in staffing this industry.

This process was one that occurred almost simultaneously in different countries. Its pace of expansion was diverse, but one feature is common: by the end of the century there was no shortage of graduates with degrees in electrical engineering.

Initially courses of electrical technology were launched as part of the syllabuses leading to degrees of general or, more often, mechanical engineering. In fact, it is important to remember that, in many - and significant - cases, they were still subsection of mechanical engineering in the early years of the twentieth century. This was the case in particular of the German high technical schools and of the Eidgenossische Technische Hochschule of Zurich. Elsewhere, advanced courses of electrical technology were set up, often privatly funded, to provide instruction to students who had already completed a course of instruction in engineering. This was the case of the Montefiore Institute, opened in 1883 in Liege. Entirely supported by a wealthy Belgian entrepreneurs, a partner in the

Societe Vieille Montagne, Europe's largest zinc works, this school offered a one-year full time course of instruction in electrical technology. The entrants were graduates of mining, mechanical, and civil engineering, with substantial component of graduates of military schools. It is interesting to notice that although one of its aims was to respond to the demand for competent electrical engineering by "recycling" graduates who had completed their studies in other technological sectors, it was also meant to favour the application and diffusion of electricity in their various compartments. Very similar was the structure of the advanced schools of electrical technology that were attached in the mid-1880s to the engineering schools of Milan And Turin, and of the Ecole Superiore of Electricite opened in Paris in 1894.

It would be impossible here to examine in detail the variety of these courses and their development, but there are tow points that I want to stress. First, even when (and where) electrical engineering became a separate degree course, a close link between mechanical and electrical engineering remained one of the main features of the generation of electrical engineers who took part in the transformation and steeping up of power generating plants, and in the electrification of industry. Secondly, and with regard to the standard of their preparation, <u>everywhere</u> electrical engineering degree courses attracted the best students - and the most ambitious - if anything because the pressure soon became such as to impose competitive criteria for admission.

Another prominent feature of the electrical engineering courses was their success in attracting funds for the equipment of their teaching laboratories. In fact, their involvement in the teaching of electrical technology, with its proximity to the theory and methods of physics, was one of their main arguments in support of their claim to a comparable "scientific" dignity as the science faculties. And support for the equipment of their laboratories came with relative relative ease and abundance.

Of course, some institutions more successful than others, and some governments more forthcoming than others in supporting the updating and expansion of their expensive equipment. However, we have to beware the contemporaries' obvious emphasis on laboratories. Not only the syllabuses were very similar in their theoretical contents, but the impact of laboratory work is to be assess with caution. Even in the case of the best equipped laboratory, graduates came to grips with the nitty-gritty of electrical machinery design, and of the applications of electricity to a variety of contexts, only in the works. A highly sophisticated kind of nitty-gritty, which required a sound understanding of the theory of electricity, but also one that could not be reproduced in the laboratory.

At it is precisely in facing these challenges that the relatively lower level of specialization of the mixed mechanical and electrical engineering courses might have been more profitable than the "intensive" laboratory training in electrical technology. The case, recently described by Ulrich Wengenroth, of the exceedingly complex tasks that were involved in adjusting A.C. motors to the requirements of a textile mill is typical. As Wengenroth shows, the gearing and linking mechanism that were required in order to ensure a uniform speed irrespective of the number of machines in use were not fundamentally novel. But the quest for a solution called for precise measurements of efficiency and a degree of mechanical ingenuity and flair which can too easily be eclipsed by the the fact that it was not carried out in the kind of environment usually associated to research activity.

Conclusion

We want to bring together here the two parts of the paper, i.e. the first section on research and innovation, and the second on education. We want also to give a flair of our compataive perspective.

If it is true that

1. A substantial amount of research was done at the shopfloor, and

2. Theory was available, and educated engineers abundant

then a reassessment of the roots of national diversity is necessary

The point we want to make is that in both cases, slow and fast, the low key kind of research was pursued, and, at least in some instance, very successfully. France and Italy, in the case of hydroelectric power stations, and of small companies that found suitable niches. The capability was there, but inevitably it was in the large works that the low-key research was most effective

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Wengenroth, Ulrich

Electrical research and academic engineering circa 1900

Anna Guagnini

There is no doubt that by the 1890s the development of the electrical industry rested on a sound understanding of the theory of electricity. The age of the practical man without a formal education was over. Nevertheless, we should beware of making too much of the role of scientific and technical education and research, and of focussing on the availability of these facilities as a key to success in manufacturing.

In this paper, I suggest that by using a narrow interpretation of a research environment, however modified by recent revisionist literature, we run the risk of underestimating the amount of knowledge that was developed at the shop-floor and site level, in a context that we do not usually associate with research activity. The workers in this kind of "laboratory" were not physicists but electrical engineers, who combined scientific competence with an experimental interest focussed firmly on the machines and installations themselves.

I suggest also that the very diverse patterns of performance in the electrical industry of the countries of Europe <u>before</u> the first world war depended more on the development of this kind of knowledge, and on the "low-key" route to technological change, than on the availability of highly educated manpower and research facilities, and major science-based innovations.

Susann Hensel

University and national economic development - demonstrated by means of some examples for the interactions between mathematics and technology in Germany in the 19th century

I want to contribute to this workshop with its broad topic by establishing the limits of my paper.
According to my special field - the history of mathematics - I will restrict myself to some relevant aspects from the point of view of mathematics. I am going to enquiry after relations between mathematics and technology and economic development in Germany. That will be possible here by means only of few historical examples.
Investigating the relations between mathematics, the development of productive forces, and the economic development of a country one has to pay attention especially to the interactions between mathematics and technological sciences: mathematics is not able to effect technology and production directly but only through the means of other sciences. In this case mathematisized theories of natural sciences and engineering sciences are to be considered as important mediators of the practical efficiency of mathematics.
First of all I want to mention some aspects of the economic development of Germany since the beginning and in particular the middle of the 19th c. which are relevant to my topic.
By the beginning of the 19th c. France and Germany were ecomically backward countries compared with England, the mother-country of the industrial revolution. Consequently they looked for ways to level their backwardness.
The scientific foundation of production and the overall technology was reckoned to be the most hopeful way to achieve this purpose.
In those times the high estimation of what mathematics and sciences could effect was a kind of analogical conclusion: Why shouldn't these sciences be able to promote technology and the economic development as well - with regard to their achievements

in the field of investigating nature, ~~heavenly~~ celestial mechanics in particular?

Such views caused a very new connection between educational and economic policy and led to new forms of the organization of education by the state. France with the more advanced economic conditions was the leading country in this regard. I want to mention the foundation of the Ecole Polytechnicque as an important result of the French revolution. In the German states they tried to master the increasing demands of the industrial revolution and of the English rivalry by means of the new founded polytechnical schools. Looking at the French example of the Ecole Polytechnicque leading scientists and civil servants made efforts to use the sciences to promote economy. But in the end German and Austrian polytechnics were only modifications of the French prototype. While the Ecole Polytechnicque continued to be the polytechnical school with the highest scientific level, polytechnics in the German speaking countries emphasized more the practical part of education. More precisely: After the French revolution of 1789 the leading and outstanding French scientists were concentrated at the Ecole Polytechnicque. In opposition to that, in the beginning German polytechnical schools had not yet been a home for leading mathematicians and scientists. German universities were still the traditional places for research and teaching.

Now I will concentrate on mathematics. While subjects with connections to practice like applied mathematics were still being taught by the beginning of the 19th c., such lectures vanished out of the calendars up to about 1860. That development was forced by the increasing influence of Neohumanism. Among the university professors dominated the view that dealing with the "pure science" had to be their first and very task.

A sign of that tendency was the development of mathematics in the 19th century. Since the beginning of that century mathematics had been developed mainly as pure mathematics. Numerous famous mathematicians also dealt with extra-mahematical applications of mathematics like e.g. in astronomy, mathematical physics, and analytical mechanics. But technical applications did

not belong to the area of mathematicians' tasks.
But there was still another circumstance which also forced the overweight of "pure" mathematics. As part of the Prussian university reform process of 1810 the function of the teacher of mathematics and science became a profession. Thus educating teachers for secondary schools became the mathematicians' main task at universities.
Because of all these reasons there were only few or no relations between university and industry in Germany up to late 19th c.. In particular that was true of mathematics and most sciences. There was perhaps only one exception, namely the association of chemical science with chemical industry.
But now I will return to some economic aspects of Germany by the middle of the 19th c. and to related demands and challenges on mathematics and science. The rapid industrial development and further display of free competition capitalism resulted into the monopolic stadium of capitalism by 1870. Because of the relatively backward and still developing industry there were good possibilities for the bourgeoisie of achieving a change to modern industry by means of scientific-technical progress.
Other factors which forced that strategy were severe trade competition and difficulties in providing raw materials.
On the other hand, the new demands of the technical and industrial development made a totally different approach to the solution of these problems more and more necessary. This was especially true in the field of machine building, a core of the industrial development of Germany which I have chosen as one of my historical examples.
Since the 1860s increasing demands for largeness, velocity, safety, reliability and diversity of machines but also demands for low price and high efficiency made a scientifically based machine building more and more important. In this situation the need was felt for a science which would balance the lack of money and experience. Subsequently higher demands for technical education were formulated.
It was of great importance for the further development of technical sciences and the polytechnical schools that in the middle

of the 19th century a direction in mechanical engineering arose that aimed at a scientific mechanical engineering on theoretical grounds. The most important representatives of this direction were Ferdinand Redtenbacher, Franz Reuleaux, Franz Grashof, and Gustav Zeuner. Their main aim was to turn inventing and constructing into a deductive science in order to make engineering highly calculable and therefore manageable. It's interesting to look from this point at mathematics because one can stress some aspects worth mentioning concerning the relation between science and university and industrial and economic development.

The theoretical conceptions of the leading engineers were based on the methodical ideal [12] which derived from the natural sciences, in particular from the strong deductive and axiomatic method of mathematics. Mathematics played an outstanding role in the process of the scientific foundation of engineering. It was not only an auxiliary tool but also a methodical model. I want to point out some consequences of this direction for the development of mathematics at the polytechnics which are of interest for our topic.

To anticipate the results: The new challenges on the engineering sciences due to the display of the industrial revolution resulted into an important process of development and emancipation of the technical colleges. This process culminated with the right to grant doctorates for the technical colleges in 1899. That meant achieving the balance of the status of universities and technical colleges. This process implicated an important qualitative rise in mathematical education at the technical colleges, though connected with some heated debates on the role of mathematics for practice and its status at technical colleges. Here I can consider these relations only briefly.

For understanding the theoretical conceptions it was necessary to think mathematically, to know the method of mathematics. It was not sufficient to restrict oneself to the education of mathematics only on those topics immediately necessary for solving concrete problems. Mathematical thinking, mathematics as a thinking training - this was the new main aim of the education in mathematics. But - the level of mathematics was very low at polytechnics around the middle of the 19th c., as mentioned above. In order to reach their aim, Redtenbacher, Reuleaux and other leading engineers persued a policy by appointing mathematicians from universities to polytechnics. (The first example was the appointment of Alfred Clebsch at the Karlsruhe polytechnic.)

We have to consider another initiative important to the qualitative rise of mathematics at polytechnics. The polytechnics which later became technical colleges educated these staff needed both by the industry and the public service. Thus the associations of industrialists connected with the body politic exerted an important influence on the education of the prospective leading servants. The so developing scientific-technological corporation body, including both scientists of universities and colleges and representatives and scientists of industry, resulted into a close link between science and industrial capital. This exertion of influence was achieved by scientific and technical societies or associations founded under the direct assistance of industrial circles.

In this direction the "German Association of Engineers", founded in 1856, was of outstanding importance. Franz Grashof used his influence as its president to promote mathematics and science at German polytechnics. In 1865 the "German Association of Engineers" published the so-called "Principles of the Organization of Polytechnics" that documented the point of view of this association concerning the development of polytechnics. The main aim was developing polytechnics into colleges. Drawing, mathematics, and science should be the basis of education. The two latter should reach a level - so the "principles" - comparable with that at universities. The so-called "technicians' movement" in Germany striving for the emancipation of engineers compared with other academic groups was another factor promoting such science policy. In consequence of this politics a remarkable number of prominent mathematicians and scientists came from universities to polytechnics. The level of the holders of mathematical chairs became essentially higher. There were more and more research workers under these professors.

Since the last third of the 19th c. the mathematical education of engineers and that of teachers had become very alike concerning content, scope, and methods. On the other hand the special needs of ~~the~~ prospective engineers were neglected to a great extent in the mathematical teaching at the technical colleges. Mathematicians considering the characteristics of technical colleges in their teaching and research were rather exceptions up to the turn of the century.

Let's have a look at the technological disciplines. Their theoretical foundation, in particular that of technical mechanics and cinematics had make an important contribution towards scientific machine building and civil engineering. But it had also led to far away from the real problems of technical practice. The requirements of practice especially of the quickly increasing monopolized industry for the education of engineers collided more and more with an education essentially theoretical and oriented towards the methods of the university in the last decade of the 19th century.

The situation of the world market by the end of the century - the United States had become ~~the~~ Germany's strongest rival in trade competition - caused an urgent need for immediately efficient scientific solutions for ~~the~~ industrial practice. Since the end of the 1880s a methodical clarification and a new orientation including a reform of engineers' education had become absolutely necessary. The further development of technological sciences did not follow the theoretical way based on mathematics that was pointed out by Redtenbacher, Reuleaux, Grashof and others. Rather the experimental side was developed in form of the machine-laboratories which were founded and well equipped in the 1890s. This process was immediately determined by demands of industry that disposed of a remarkable experimental research-capacity in the beginning period of monopolization. The stimulus was given by the 1893 Chicago world exhibition. The impressions and experiences of German engineers in America became the beginning of a broad public discussion about the methods of engineering and education of engineers. It is worth mentioning again ~~is~~ that this discussion was organized by the German Association of Engineers expressing and supporting the special expectations and interests of industry. The core of the reform was the completion of the theoretical component by the empirical one by means of regular research and teaching in laboratories at technical colleges.

Numerous engineers of industry and technical colleges rejected the mainly theoretically oriented direction within the technological sciences. The collision of several interests had consequences especially for mathematics. There arose stronger and stronger contradictions between mathematicians and engineers in the century's last decade.

The group of engineers most consequently fighting for an education of engineers with immediate practical efficiency stood under the leadership of Alois Riedler, professor of machine building and rector of technical college Berlin-Charlottenburg.

Contemporaries called these vehement discussions and activities the "antimathematical movement". This was a synonym of criticizms of content, scope, and methods of engineer's mathematical education. A dramatic reduction of hours for mathematical teaching, its reduction to elementary mathematics and the consequent exclusion of higher mathematics from technical colleges and reducing to elementary mathematics were the most extreme demands. The demands for teaching only that what was immediately applicable in practice were not so much vindicated as such more essential changes in the mathematical teaching as:

- more exercises and applications of mathematical methods to examples connected with practice
- training the spatial ~~imagination faculty~~ representation
- teaching of graphical and numerical methods of solution
- the so-called strong foundation of mathematics as it is necessary for an exact dealing with higer mathematics, but to a legitimate limit for a prospective engineer.

Furthermore, the engineers criticized the universities' monopoly in educating teachers, and demanded to break it and educate all future professors for technical colleges at the colleges. The important influence on appointments of mathematicians should be taken away from the theorists and occupied by the technicians.

Some engineers would have liked engineers to be taught in mathematics by engineers.
Riedler was the protagonist of those demands. A remarkable number of engineers from industry and technical colleges as well as industrialists agreed with him.
On the other hand some progressive engineers strove for using new mathematical methods in the technological sciences. (Prospective geometry became the basis of Culman's graphical statics. Grashof and August Föppl were the pioneers in using partial differential equations and vectors analysis in engineering. Steinmetz used the complex numbers for describing the laws in alternating current circuits. Eigenvalue problems were solved for preventing resonance catastrophes. Linear algebra was first calculating electrical networks.)
Of course such engineers didn't support the mentioned extreme demands of the especially practically thinking engineers.
It had been due to the influence of the German Association of Engineers that very extreme demands could be prevented, which would not have been useful to the further development of mathematics at technical colleges. The German Association of Engineers manifested its intermediate position to the mathematical teaching in the so-called 1895's Aachen resolution. Mathematical teaching should be improved by more exercises and application of mathematical methods.
However, through the question of mathematics teachers' education **universities** had been taken into consideration. As a matter of fact, the education of teachers of mathematics at universities was not sufficient for future mathematicians at technical schools or colleges. E.g., there was not provided for descriptive geometry, which played an important role at technical colleges.
But the impulses and demands for changing the education in mathematics and physics and for their opening to the requirements of industry did not first and only come from the antimathematical movement. In the last third of the 19th century the understanding that the traditional places of higher teaching couldn't further close over against the challenges of pracitce was awaken

at the universities as well. In particular, mathematicians and scientists made several efforts to bring mathematics and physics at universties into closer connections with technical applications both in research and teaching.
As known, the most important figure in this development from the side of mathematics was Felix Klein at Göttingen university. He made Göttingen a centre of applied mathematics and technological sciences. His efforts and results in that direction had been appreciated by Renate Tobies. Here I want to point out only some aspects which are relevant to this topic.
Klein was one of the few university mathematicians who acknowledged relatively early the one-sidedly introverted development of mathematics and - furthermore- that mathematics need outside impulses for their fruitful display.
Moreover, Klein was one of the scientists who realized early enough that the economic development of monopoly forced an efficient exhaustion and influencing of the existing scientific potential. His great aim was to bridge the gap between humanistic and realistic education caused by the separate development of universities and technical colleges in the "general interest of culture". After failing his plans to unit university and technical college, especially since 1893 Klein had been striving for closer relations between mathematics and physics and technology at Göttingen university.
With the institute for Applied Mechanics established in 1897 essential facilities and conditions were to be provided for that aim. Karl-Heinz Manegold e.g. described that.
With regard to the relationship between science and industry I give only one example.
It has been proved that the rates of increase of production rose more slowly and the profit rates decreased during the time between the middle of the 1870s and the 1880s. Therefore the monopoly tried to increase the profit rates both by scientific foundation of production and by influencing higher education.
On the other hand, the impressive development of modern industry (in particular of the chemical, electrical, and the precision optical one) by using scientific results undermined the ideal of

"pure science" - more and more. That also led to a broader concept of "culture" widened by and by from the intellectual area to the material-technical one.
Felix Klein had pointed out this intention in relation with the Göttingen Association for the Promotion of Applied Physics and Mathematics founded by him. He wrote that the universities should be worried about their leading role within culture, which would be impossible to maintain, if they intentionally concerned themselves with pure science completely separat from the demands of practice.
In his book "State, society, and university in Germany 1700 - 1914" (1980) E. McClelland writes that the Göttingen Union for Applied Physics and Mathematics was one result of the interest among industrialists in more industry-related research. In relation with mathematics this was a novelty.
When by the end of the 19th c. monopolies of chemical and electrical industry concerning fields of research had tried to control mathematical works in general remained outside the considerations of those social forces. Because of the characteristically indirect influence of mathematics on production at first representatives of monopoly were not willing of supporting and promoting works whose utility and benefit were not immediately recognizable.
The Göttingen Association in 1898 founded as Göttingen Association for the Promotion of applied Physics and in 1900 widened to mathematics was <u>one</u> form of the promotion of applications of mathematics to technology and of the reformation of mathematical teaching in all its forms, gained momentum thanks to the initiative of F. Klein.
A view over the members of the Göttingen Association shows that also in those who possessed the productive capacities an interest to promote the mentioned areas had arisen. Besides 42 professors of mathematics and science who taught at Göttingen university, 50 financially strong persons, among them people like Krupp von Bohlen und Halbach, Emil Rathenau, Werner von Siemens, Anton von Rieppel and others, took part in the activity and support of the Göttingen Association. The president of the

Association was Henry Th. von Böttinger, a member of the board of directions of the Bayer chemical concerns, while Felix Klein served as vice-president. The founding papers of the Göttingen Association show the main reason for industry to take part in this form of supporting science. They considered a change in teachers' training as a decisive factor that could lead to positive long-term results for industrial production. Because of the dynamic which the development of mathematics and physics had achieved for themselves both at universities and at technical colleges, the representatives of industry preferred to control and influence the education of its prospective human potential by themselves.

In 1912 Anton von Rieppel, founding member of the Göttingen Association and industrialist of the bridge and steel industry, said in a paper:

"... in his lecture Klein presented uns with the following goals for our organization: 1) above all to effect a better training for future teachers; 2) to promote more research in the direction of the applied sciences; and 3) to redirect university politics along lines that have more to do with practical everyday life than has been the case up till now. We reached agreement above all on the first point, as experience had taught us that young engineers lost considerable time in their graduate studies due to a deficient prior education that was divorced from practice. Often they were forced to recoup knowledge that could easily have been provided to them by the secondary schools. This system, in our opinion, only forces engineers to delay their careers, and the founding idea of the Göttingen Association was to help improve these conditions."*

These words prove again that by the turn of the 20th c. especially the demands of engineers, engineer scientists, and industrialists promoted a development towards an application-related teachers' education for the field of mathematics and physics.

The new examination regulations for prospective teachers of secondary schools in Prussia issued in 1898 were a first advance in this direction. Felix Klein had promoted this new order and he had added a considerable contribution to its formation and

* Niedersächsische Staats- und Universitäts-bibliothek Göttingen Handschriftenabt. [illegible]

execution. The novelty was that the reforms created a special teaching certification in applied mathematics - which was later adopted by many of the German states. To receive the new teaching certification one could choose between courses in descriptive geometry, technical mechanics and geodesy (from 1911 on also in ~~the theory of probabilities~~ [insurance mathematics]).

In the introduction of that teaching certification conditions and facilities were provided to establish essential institutes and chairs for applied mathematics at universities. But there were several difficulties in establishing "applied mathematics", technical applications like technical mechanics in particular, at universities. Only in Göttingen and Jena all parts of applied mathematics could be provided to the students. In this direction I agree with McClelland's view of the Göttingen association, that it "was rather an exception, given the opposition of the German professiorate to smuggling vulgar applied research into university institutes". (p. 303)

Later, in 1909, the industrialists of the Göttingen Association, especially Krupp, promoted the research works of Ludwig Prandtl concerning the measuring of the air resistance. In 1909 Göttingen as the first German university got a teaching assignment (Lehrauftrag) for scientific aeronautics filled by Ludwig Prandtl.

With the support of the Göttingen Association F. Klein succeeded in establishing several institutes for applied research at Göttingen university (applied mathematics, applied electricity, geophysics, later an aerodynamics testing center (1907/08) and a laboratory for testing wireless telegraphy (1909).

The promotion of science in the scope of the Göttingen Association was only <u>one of the ways</u> followed by the bourgeoisie to realize its interests in the field of science as well as giving new facilities to scientists to get means for research and teaching.

At last I point out another example for the widespread system of foundation in the German Reich - the case of the Carl Zeiss-Foundation Jena. I'd like to mention that foundation because it can be reckoned as a model for the ties between science and

university on the one side and technology and industry on the other. Moreover, the Carl Zeiss Foundation was of great importance for the development of mathematics at Jena university.
Ernst Abbe himself, the promoter of the Carl Zeiss Foundation, personified the very close (intimate) connection of science with industry in the case of the Jena foundation.
From 1893 to his death in 1905 Abbe belonged to the teaching staff of Jena university. He taught in several fields of experimental and theoretical physics, mathematics, and astronomy. Since 1870 he was extraordinary (associate) professor, since 1878 ordinary honorary professor. Besides, since 1866 he had been working in the precision optical workshop of Carl Zeiss. With the ratification of articles of partnership with Carl Zeiss in 1876 he became a (at first a sleeping) partner of the business.
Since 1878, when Abbe had to take over the affairs of the faculty of mathematics and physics owing to the sickness of the professor of mathematics and physics, Karl Snell, he had influenced the development of mathematics and physics at Jena university considerably. But in the following years this influence still increased.
Abbe had perceived the signs of the times very clearly: The industrial revolution had come to a close in the classical trade branches ; after a short crisis ("Gründerkrise") the so-called period of promoterism flew into a long-term period of the so-called "Great Depression" which stimulated technical innovations due to the detoriorating conditions of capital utilization. An increase was to be expected especially in such branches which depended on scientific-technical innovation in a high degree. Besides the chemical and the electrical industry, the precision optical industry belonged to those "modern branches of industry".
The experience of his former work at Carl Zeiss' workshop made Abbe aware of the important role of mathematics and physics for the development and production of optical precision instruments. From there resulted his strong interest in promotion of the institutions for mathematics and physics at Jena university.

But there was still another circumstance. Indeed, the university had delivered the decisive impulses for industrialization by means of its need for optical instruments and of Abbe's fundamental achievement, his theory of microscopes. But the small financial means of the university sponsored by the minor states of Thuringia set significant limitations to the display of science. The town Jena itself didn't provide the necessary conditions to govern the development of the concerns, productive forces, and population. Moreover, there were the limitations set by the private capital form of an enterprise.

Given this background and with long sight Abbe developed the idea to take the Zeiss concern and the half of the Schott concern out of their pure private form of possession, put them into close link with the university, and allocated social tasks to them. This idea resulted in the establishment of the Carl Zeiss Foundation founded by E. Abbe after the death of Carl Zeiss in May, 1889. According to the founding document of 1889 the goal of the foundation was to promote the traditional Jena "branches of scientific industry" as well as the corresponding mathematical and scientific studies at Jena university. The complementary regulations of 1896 and 1900 broadened the support by the university as a whole though with emphasis on (natural) sciences and social care for the Carl Zeiss workers, the town and their inhabitants.

The foundation had to ensure the future of the concerns of Zeiss and Schott by the continuous cooperation with university which had to guarantee the necessary stock of scientific results and the competitive security.

Once Abbe characterized the close ties and the reciprocal dependence between the factories of the Carl Zeiss foundation and the university mediated by the Foundation with the following words: "extensive care for the welfare of all those who contributed or will contribute to gain that means - and furthermore the <u>promotion of that sciences</u> on which ground the concerns had grown and to which I owe my own way upwards. ... According to the intentions mentioned above Jena university alone has the natural candidacy for the revenues from those concerns. It is the real "nourishing mother" of them; if the university didn't exist there would exist no one of these concerns."

It has to be pointed out that even in the case of the Carl Zeiss Foundation the objective interest of the industrial entrepreneur in applied mathematical and physical researches coincided in a perhaps uníque way with the efforts of the appointed professor of mathematics, physics, and astronomy for the extension and completion of the concerning university institutions as well as with the orientation by the state to promote applied mathematics by the turn of the century.

A considerable completion of the university institutions for mathematics could be achieved by means of the university funds of the Carl Zeiss foundation, comparable only with the efficiency of the Göttingen Association.

In 1900 the states of Thuringia issued examination regulations for probátionary teachers for secondary schools analógical to the Prussian model of 1898. Due to the initiative of August Gutzmer, appointed as extraordinary professor for mathematics to Jena in 1899 and by means of the Carl Zeiss Foundation it was soon possible to create that institutions and chairs necessary for the teaching in applied mathematics according to the examination regulation. E.g. there were provided the conditions for the teaching in descriptive geometry, the means for an extraordinary professorship for applied mathematics and technical physics, and for the establishment of an institute in 1902/03 as well.

That means, Jena was the first German university after Göttingen which possessed teaching cápacities in all signed objects of applied mathematics. The further development of the institutions of applied mathematics at Jena university was characterized by a close connection with the Carl Zeiss Foundation. The foundation exerted an increasing influence on a great part of the university businesses and granted its financial support only under certain conditions. One can say the Carl Zeiss Foundation created such close connections between university and the Jena specific interests of industry as nearly no town possessed. Compared with the Göttingen Association the ties between science and industry were much stronger in Jena. Not only the person of Ernst Abbe was a reflexion of that but also several other scientists who were collaborators of the Zeiss concern and at the same time members of the university. To this group belonged Rudolf Straubel (1864-1943), since 1897 extraordinary professor for physics at the university, from 1901 to 1933 honorary professor and since 1901 scientific collaborator at Zeiss, from 1903 to 1933 he worked also in the management of Zeiss. Hermann Ambronn (1856-1927), another example, directed the department for microscopy of the Zeiss concern from 1897 to 1907, got an extraordinary professorship at Jena university and his own institute there in 1902. August Köhler (1866-1948) was a scientific collaborator at Zeiss and the leader of the microphotographical department of the Institute for microscopy at the university.

Susann Hensel (Jena)

"University and economic development - demonstrated by means of some examples for the interactions between mathematics [illegible] technology in Germany in the 19th century

Summary

Investigating the relations between mathematics, the development of productive forces, and the economic development of a country, one has to pay attention especially to the interactions between mathematics and technological sciences: Mathematics is not able to effect technology and production directly, but only intermediately by other sciences. [illegible] theories of the natural sciences and of engineering [illegible] are to be considered as important mediators of the practical efficiency of mathematics.

In my following talk I shall proceed from the different development of mathematics in France and in Germany since the beginning of the 19th century. Concerning Germany, both the new position of mathematics in society during the first decades of the 19th century and the Newhumanism are relevant factors. The education of teachers for secondary schools became the mathematicians' main task at universities. Therefore pure mathematics was cultivated. The educational ideal of the Newhumanism to cultivate science without any connection with practical reality promoted this process of the development of pure mathematics and of the neglect of applied mathematics. The divergent and completely different development of universities on the one hand and of polytechnics on the other was an expression of this development.

Thus, up to the late 19th century there were only few or no relations between university and industry in Germany. This was especially true of mathematics but also of the natural sciences. There is perhaps one exception, namely the interactions between chemical science and chemical industry.

Moreover, it will be mentioned that due both to the industrial revolution since the middle of the 19th century and to the severe international trade competition totally new technical and

conomic demands on science [illegible].
hoosing the example of engineering [illegible]
cientific foundation of technology [illegible]
he efforts of the leading polytechnicians of [illegible]
he fact that the scientific foundation should [illegible]
theoretical approach. They aimed at a deductive [illegible] of invention and construction in order to make engineering highly calculable and thereby governable. [illegible] methodical ideal of the engineering sciences which derived from the natural sciences and especially from the strong deductive and axiomatic method of mathematics.

This direction within the technological sciences had consequences both for the development from [illegible] to polytechnical colleges and for the level of mathematics at the latter compared with that at universities.

On the other side we will look at the [illegible] and physics at universities around [illegible] where some progressive mathematicians [illegible] realized the gap between the [illegible] mathematics and made efforts to abolish it step by step.

Besides, the paper points to two [illegible] worth mentioning if we examine the relations between [illegible] at universities and the economic development.

The first example is the Göttingen Association for the [illegible] of Applied Physics and Mathematics. Here [illegible] for the first time [illegible] such a form – the interests of [illegible] mathematicians and of entrepreneurs and industrialists in an effective and modern education in mathematics and physics [illegible] at high-schools and universities coincided.

The second example to be mentioned is the [illegible] Foundation. It could be considered just as a model example for the association of science [illegible] hand with technology, industry, and economic development on the other.

IDEOLOGIES FOR PROGRESS

Ulrich Wengenroth (Technische Universität München)

It remains one of the major problems for the history of technology in Germany to assess the importance of science and scientific thinking for the high rate of technological progress prior to World War I. Especially if compared to England, the then leading industrial nation, it is striking to see how much better German industry managed to benefit from inputs from science at large or more particular the universities both traditional and technical.

Many explanations have been given for this phenomena, the most common of which were:
a) entrepreneurial failure on the side of British industrialists who lacked the innovative spirit of their German counterparts and failed to see the importance of scientific research and laboratories in industry;
b) a superior system of higher technical education, esp. the great number and scholarly competitiveness of technical universities in Germany.

If one looks into recent industry studies, however, one feels less comfortable with these at first sight very plausible explanations. Many revisionists studies in entrepreneurial history have shown convincingly that it is very difficult to make a strong case for entrepreneurial failure on the British side when it comes to making use of or engineering technological progress. The biggest case of "decline", the British steel industry, has been demolished by about half a dozen major studies over the last 15 years. More than that, most major innovations in steel metallurgy with something approaching a scientific background did come from Britain in this period while German steel industrialist were complaining in World War I that their engineers and scientists had had no good idea of any importance since the turn of the century.

The superiority of higher technical education and the great numbers of engineering degrees lose a lot of their glory when one learns that these young academic engineers had a career as civil servants rather than in industry. And again, if compared to England, research in individual companies was not so strikingly different in its scale that this could have been the reason for 50% higher rates of growth in industry at large. Even if one looks at the model-cases like the German dye-stuffs industry one has to learn from Carl Duisberg, head of the Bayer company, that in their laboratories was not a single flash of genius to be found - rather very down to earth routine work.

Still, it remains evident and needs an explanation why German industry fared so much better when it came to developing an industry that had a large interface with science or could make use of the methodology of scientific research. The respect of the early 20th century world for the high scientific standards of German industry cannot simply be dismissed as a myth.

One of the efforts to shed more light on this problem was the creation of a graduate college in Munich to investigate into the interface between science and technology in late 19th and early 20th century in Germany. Some of the case studies have come close to an end by now and they seem to converge on the view that the importance of hard scientific fact for the development of technologies as different as refrigeration, gyros, bridge construction and wind turbines was very limited and certainly of less importance than one would gather from the available literature let alone from autobiographies. More than that, a substantial number of flaws and ambiguities in the theories and calculations employed were found. The same is true for my own research in steel metallurgy. In some cases one is impressed by the number and magnitude of errors a theory can have without the technological process thus described to fail.

If the successful invention and diffusion of a new product or process technology was not closely related to the validity of the scientific explanation behind it, what then was the important contribution scientific thinking had to make to industrial success through innovativeness? To answer this question one has to find out who was behind the effort to enrich practice with theory and for which purposes.

Browsing on the trade journals (not scientific journals!) of the second half of the Nineteenth century we find relatively more "scientific" explanations in continental journals then in British journals. The effort to quickly reach a more abstract level of reasoning seems to have been stronger on this side of the Channel. In the case of steelmaking e.g., where travelogues from Britain remain to be the most valued source of information well into the 1880s authors feel ever more compelled not only to report the "secrets of manufacture" but to analyse what they have seen and to "scientifically" explain to the reader what has supposedly been poorly understood in England itself.

In this process travelogues become expertises, the respectability of which is demonstrated by abstracting from the case one has seen and disclosing the scientific principles which alone can be transfered safely. Like the well-known drawings of the earlier decades now science has become the tool to analyse a process or an artifact to make it transferable to the continent. After many failures to simply translocate British technology, the ability to "scientifically" explain a process is becoming the proof that it has been understood well enough to justify the expenses of introducing it at home. The "secret" which made every investment a risk is lifted by reassuring science. Those who own the "secret" on the other side do not need the science.

"Scientific analysis" in this perspective becomes the tool of a backward industry in need of government-support to quickly catch up with advanced engineering practice and routine in the Workshop of the World. Unlike traditional travelogues which sometimes read like novels, "scientific analysis" is based on both a formular language which makes it easier to communicate widely without personal contact and the assumption that every reasoning along scientific lines is true. Using the restricted code of scientific language helps very much to create a common language among engineers, civil servants and university experts who have to cooperate to help an infant industry to develop. "Science-speak" becomes something like the corporate identity of those engineering the catch-up process.

This common language helped to break down the barriers which in other places (esp. England) kept civil servants, university scientists and engineers apart and eased a flow of information people and mutual support especially among the latter two groups. In using the same tool to overcome their inferiority vis-a-vis the English dominance in industry they forged an alliance that did not exist to a similar extent in Britain. When industries appeared that needed substantial imports from the academic world, than this alliance would have to have a head-start. Whether the form into which information was cast was always correct or not was of secondary importance only as long as information flowed freely.

The assumption that everything that was expressed in "scientific terms" was true created a very efficient ideology for progress which came into existence in the second half of the 19th century in German industry and is lasting until today.

TH Darmstadt: Anteil der Ausländer unter den Studenten der Elektrotechnik (in Prozent)

Wintersemester	Ausländeranteil
1902/03	53
1903/04	57
1904/05	62
1905/06	65
1906/07	72
1907/08	70
1908/09	64
1909/10	65
1910/11	60
1911/12	62
1912/13	55
1913/14	42
Durchschnitt	61

Quelle: HA Darmstadt; 7.2.1914 - Rektor an Min., Anlage.

Nachrufauswertung ETZ: Ausbildung und Studium von Berufseintrittskohorten - Industrie (absolute Zahlen)

		1874 und früher	1875-1879	1880-1884	1885-1889	1890-1894	1895-1899	1900-1904	1905-1909	1910-1914	zusammen
	Nachrufe insgesamt	71	19	37	51	73	59	65	38	20	433
	davon Industrie	31	14	25	37	57	46	45	28	15	298
Ausbildungsstätten	Praxis	14	4	3	6	5	2	-	1	-	35
	Technische Mittelschule	1	-	-	1	6	5	5	3	1	22
	Technische Hochschule	10	9	16	19	43	39	40	23	10	209
	Universität	4	1	6	13	8	1	4	1	3	41
	keine Angaben	2	-	-	1	-	-	-	-	1	4
Studienfächer	Elektrotechnik	-	-	8	7	19	15	19	6	3	77
	Maschinenbau	3	3	1	5	10	8	6	4	3	43
	Naturwissenschaft, Mathematik	4	2	7	14	9	-	3	2	3	44
	keine Angaben, Sonstiges	8	5	7	9	18	18	23	14	5	107

Nachrufauswertung ETZ: Ausbildung von Berufseintrittskohorten - Industrie (absolute Zahlen und Prozent)

	vor 1879		1880-1894		1895-1914	
Praxis	18	40%	14	11%	3	2%
Technische Mittelschule	1	2%	7	6%	14	10%
Technische Hochschule	19	42%	78	61%	112	81%
Universität	5	11%	27	21%	9	6%
keine Angaben	2	4%	1	1%	1	1%
zusammen	45	100% (99)	127	100%	139	100%

Table 3: The Training of Technical Employees in the Berlin Industry, 1907/08 (data in percent, the absolute figures in parenthesis)

	All Engineers	Higher technical training ('Technische Hochschulen')	Medium level of technical training (and self-educated engineers*) ('Technische Mitte schulen', 'Fachschulen')
Entire Industry	100% (3265)	26,40% (862)	73,60% (2403)
Machine Building Industry	100% (1840)	19,24% (354)	80,76% (1486)
Electrical Industry	100% (1209)	34,16% (413)	65,84% (796)

* only 4,5%

Source: Jaeckel, pp. 1, 4, 36.

Hochschullehrer für Elektrotechnik 1882–1914. Verteilung auf Berufungs-Kohorten und Statusgruppen (in absoluten Zahlen)

Statusgruppen	1882–1891	1892–1901	1902–1914	zusammen
Ordinarien	8	11	11	30
Extraordinarien	3	7	2	12
Dozenten	4	7	5	16
zusammen	15	25	18	58

Hochschullehrer für Elektrotechnik 1882-1914. Ausbildungsstätten und Studienfächer von Berufungs-Kohorten (in absoluten Zahlen)

		1882-1891	1892-1901	1902-1914
Ausbildungs-stätten	Praxis	-	-	1
	Technische Mittel-schule	-	-	1
	Technische Hoch-schule	9	21	16
	Universität	12	7	3
Studien-fächer	Elektrotechnik	-	19	11
	Maschinenbau	6	9	12
	Physik	12	7	1

Durchschnittliche Industrietätigkeit (in Jahren) von Hochschullehrern der Elektrotechnik 1882-1914. Berufungs-Kohorten, Ordinarien sowie Extraordinarien und Dozenten

	1882-1891	1892-1901	1902-1914
Ordinarien	1,1	6,0	9,4
Extraordinarien und Dozenten	0	3,6	5,4
zusammen	0,6	4,6	7,8

Diplomprüfungen und Doktorpromotionen an den deutschen Technischen Hochschulen 1902/03 - 1910/11

Fächergruppen	Diplomprüfungen	Doktorpromotionen	Promotionsquote (Prozentsatz der Doktorpromotionen auf die Diplomprüfungen bezogen)
Architektur	1979	93	5
Bauingenieurwesen	2663	99	4
Vermessungsingenieurwesen	391	-	-
Maschineningenieurwesen	3764	242	6
Elektrotechnik	1491	130	9
Verwaltungs- bzw. Fabrikingenieurwesen	62	-	-
Schiffs- und Schiffsmaschinenbau	321	21	7
Chemie und Hüttenkunde	1678	663	40
Allgemeine Wissenschaften	11	40	(364)
zusammen	12360	1288	11

Quelle: ETZ 34 (1913), S. 301.

La creació de la Facultat de ciències i de les Escoles d'Arquitectura i d'Enginyers:

La reorganització de l'ensenyament universitari que va significar l'aparició de la llicenciatura en ciències és l'inherent a la llei de J. Pidal i Gil de Zárate de 1845. S'hi contemplava la llicenciatura en ciències i si a aquesta llicenciatura s'hi sumava la de lletres, llavors hom esdevenia llicenciat en filosofia. A més, es podia obtenir el doctorat amb dos anys més (de lletres o ciències). De la mateixa manera que en el cas de la llicenciatura, la concurrència del doctorat de ciències i de lletres significava el doctorat en filosofia. Al 6è i 7è d'ensenyament secundari, dit d'ampliació, després del qual hom podia examinar-se de llicenciatura i, doncs, equivalia a aquesta, eren obligatories les assignatures de Complements de Matemàtiques, Química general, Mineralogia, Botànica i Zoologia.;d'altra banda, els estudis del doctorat incloïen: Calculs sublims, Geologia, Astronomia, Mecànica i Història de les ciències.[1]

El 1857, d'acord amb la llei de Moyano, les dues seccions de la Facultat de Filosofia, ciències i lletres, esdevenien facultats; la de ciències, amb el nom de ciències exactes, físiques i naturals. L'any següent, concretament amb el R.D. del 7 de setembre de 1858, la Facultat de Ciències es dividia en tres seccions: físico-matemàtica, química i naturals.[2] Un cop assolida la llicenciatura hom podia emprendre els estudis necessaris, de dos anys de durada, per tal d'aconseguir el títol de doctor, grau, el de doctor, que tanmateix només podia aconseguir-se a Madrid: un tret que palesa a bastament la política centralista de la burgesia liberal (més o menys liberal) al poder aleshores. Val a dir que endemés de les Facultats de Lletres i Ciències completaven l'ensenyament universitari les de Farmàcia, Medicina i Dret.

Vegem amb cert detall el pla d'estudis que acabem d'esmentar:[3]

GRAU DE BATXILLER

Cursos	Assignatures
1è	Algebra
2n	Física, Geometria i Trigonometria, Química
3r.	Història natural, Exercicis gràfics

GRAU DE LLICENCIATURA

	Secció de físico-matemàtiques	Secció de químiques	Secció de naturals
Cursos	Assignatures	Assignatures	Assignatures
4t.	Geometria analítica Geometria descriptiva	Química inorgànica Exercicis pràctics	Fisiologia vegetal Organografia
5è	Càlcul diferencial i integral	Química orgànica Exercicis pràctics	Zoologia (vertebrats) Fitologia i Geografia vegetal
	Geografia astronòmica, física i política	Geometria analítica	Zoologia (invertebrats)

GRAU DE DOCTORAT

Cursos	Assignatures	Assignatures	Assignatures
6è	Mecànica	Anàlisi química	Ampliació de mineralogia i geognosia
	Geodèsia	Exercicis pràctics	Anatomia comparada
7è	Astronomia física i d'observació	Anàlisi química Exercicis pràctics	Geologia Paleontologia

Aquest pla d'estudis de 1858 va regir, ultra petites variacions, fins a final de segle.

Tanmateix, quan el nou edifici de la Universitat va esser construit, va aixoplugar així mateix les Escoles d'Arquitectura i d'Enginyers.

La carrera d'enginyer industrial havia estat creada per R.D. del 4 de setembre de 1850 essent Seijas Lozano ministre de Comerç, Instrucció i Obres Públiques. A tal fi es crearen les Escoles de Barcelona, Madrid, Vergara i Sevilla. Els dos primers nivells s'impartien arreu però el tercer, dit superior, només a l'*Instituto Industrial* de la capital.[4] Nogensmenys, aquesta situació canviaria el 1857 quan foren autoritzades les altres Escoles a impartir el títol superior, trencant així el monopoli que en un principi havia estat concedit a la de Madrid.[5] A Barcelona aquesta mesura es faria efectiva a partir de 1860. Set anys més tard desapareixien totes les Escoles citades anteriorment més les recentment creades de València i Gijón, excepte la barcelonina, la qual restaria com a única Escola d'Enginyers Industrials de l'Estat fins a finals de segle.

Pel que fa a l'Escola d'Arquitectura, tenia els seus orígens, com la d'enginyers, en la Junta de Comerç. Quan la Junta va desapareixer i el 1851 va néixer l'Escola Industrial Barcelonesa (més tard Escola d'Enginyers Industrials) es creà l'Escola de Mestres d'Obres que va ser dirigida per Casademunt i Elias Rogent fins a la seva desaparició el 1869. Tot seguit es fundà l'Escola Politècnica Provincial que incloïa una Escola d'Arquitectura.Quan la Politècnica va desapareixer el 1871, l'Escola d'Arquitectura va passar a anomenar-se Escola Provincial d'Arquitectura i el 1874 va aixoplugar-se al nou edifici de la Universitat. L'any següent es convertia en escola Superior d'Arquitectura.[6] La independència d'aquesta Escola es fa palesa puix no figura en les estadístiques de les Memòries de Secretaria de la U.B. ni d'aquells anys ni dels següents; en canvi, sí que hi figura l'Escola d'Enginyers Industrials. Si al que acabem de dir hi afegim que l'Escola d'Arquitectura és objecte d'un estudi específic en un altre apartat d'aquest catàleg, resta justificat que, si bé centrem l'atenció en la Facultat de Ciències, fem així mateix determinades referències a l'Escola d'Enginyers la qual va aixoplugar-se també en el nou edifici i va compartir amb d'altres facultats - inclosa, és obvi, la de Ciències - molts avatars universitaris.

Per tal de donar una més concreta idea sobre els estudis científics i tècnics de l'època, i escollint el curs 1872-73 com el més proper al trasllat al nou edifici,[7] constatem 177 alumnes matriculats en la Facultat de Ciències sobre un total de 2.386 repartits de la següent manera: Dret (inclós Notariat), 614; Medicina, 1.093; Farmàcia, 269; Facultat de Lletres, 233; facultat de ciències, 177. A l'Escola d'Enginyers Industrials consten 56 alumnes matriculats. Pel que fa al nombre de professors (catedràtics, auxiliars i ajudants) es repartien així: Facultat de ciències, 12; Facultat de Farmàcia, 7; Facultat de Medicina, 23 més un director i un ajudant per al Museu anatòmic i un ajudant d'escultor; Dret, 15; Escola d'Enginyers Industrials, 11.[8]

Uns anys més tard (Memoria que acompanya al discurs de l'apertura del curs acadèmic 1876-77), el nombre d'alumnes no ha variat pas substancialment a la Universitat però s'ha doblat a l'Escola d'enginyers: Dret(inclós Notariat), 665; Medicina, 1.020; Farmàcia 228; Lletres, 76, Ciències, 159; Escola d'Enginyers Industrials, 105.[9]

Els estudis mèdics i farmacèutics:

Si bé la unió de la cirurgia i la medicina es va realitzar el 1827 quan el Col.legi de Cirurgia va convertir-se en Col.legi de Cirurgia i Medicina, hom pot dir que la Facultat de Medicina no va retornar a Barcelona fins al 1843 en transformar-se, el Col.legi suara esmentat, en Facultat de Ciències Mèdiques la qual incloïa també els estudis farmacèutics els quals previament s'havien impartit al Col.legi de Sant Victorià creat el 1815. Un procés, el de la reinstauració de la Facultat de Medicina a Barcelona, que deu molt a Pere Mata, el metge positivista català que féu vida, tanmateix, a Madrid.

A partir d'aquest moment hi hagué continuitat. Nogensmenys, la Facultat de Medicina va romandre al carrer del Carme fins al 1906 en què es traslladà a l'Hospital Clínic, mentre que la Facultat de Farmacia, creada explícitament com a tal el 1845, en efectuar-se el canvi d'edifici s'allotjà en el nou de la plaça Universitat compartint un espai no massa gran amb l'Escola d'Enginyers. Era el curs 1874-75. És interessant recordar que el primer degà d'aquesta Facultat fou Tomàs Balvey, el qual havia estat catedràtic de matèria farmacèutica (1830) i havia fundat, el 1832, un laboratori de productes químics i farmacèutics conjuntament amb dos companys de professió.[10]

Antonio Sanchez Comendador, llavors catedràtic de Matèria Farmacèutica Vegetal, va aprofitar el nou estatge per pintar a les parets un resum dels conceptes de la matèria amb tant d'èxit que el fet fou copiat per altres facultats. D'altra banda, les úniques catedres de la Universitat que disposaven d'un museu addicional que permetia de dur a terme un ensenyament pràctic eren les de Matèria Farmacèutica Vegetal i Matèria Farmacèutica Animal (a part els laboratoris de química dels quals en parlarem més endavant). En el curs 1875-76 la facultat de Farmàcia comptava amb sis càtedres; la de química orgànica, que s'oferia Gairebé com una novetat ~~per primer cop~~ als estudiants catalans, l'ocupava Julián Casaña, el qual fou així mateix rector de la Universitat. Josep Arqués i Anna Carmona, que han efectuat recentment estudis molt documentats sobre la història de la Facultat de Farmàcia,[11] ens ofereixen també l'anècdota: els catedràtics de Farmàcia donaven la classe amb la vestimenta acadèmica tradicional. Cal suposar que no eren els únics.

Pel que fa a la medicina, cap al 1868 irromp en escena amb empenta una nova generació de professors; són els fundadors de revistes com ara la *Gaceta Médica Catalana*, creadors d'institucions entre les quals no podem deixar d'anomenar l'Academia i Laboratori de Ciències Mèdiques, o organitzadors de congressos com el de Frenopatologia de 1883 o el de Medicina de 1888. D'aquest darrer, que marca un punt àlgid de la medicina catalana, en fou cap destacat Joan Giné i Partagás, traductor de Virchow i estudiós de les malalties venèries, ultra haver estat destacat degà de la Facultat. Sense espai per estendre'ns en relatar els origens del que seria l'escola catalana de Medicina, recordem tanmateix B. Robert, catedràtic de Patologia Mèdica i acèrrim partidari de la medicina interna i Jaume Pi i Sunyer, catedràtic de patologia General que orientaria R. Turró pels viaranys de la recerca mèdica i biològica.[12]

conjuntament amb B. Robert

Tal mateix

La llibertat de càtedra:

El centralisme a què hem fet referència més amunt arribava al punt de publicar llistes d'obres obligatòries per a cada assignatura en el benentés que, com a màxim, el professor encarregat d'impartir una determinada matèria podia escollir entre dues o tres opcions. Aquestes listes començaren a publicar-se des de la llei de 1845 pel que fa a l'ensenyament universitari i des de 1850 per al tècnic.

Per a aquest darrer, hem examinat amb cura les de l'any 1861[13] en el R.D. del 15/X/1861 on s'especifiquen els llibres de text obligatoris per a enginyers industrials, agrònoms i arquitectes. Per als agrònoms, de 12 obres especificades, 6 són franceses(50 %); per als enginyers industrials, de 22 obres, 18 són també franceses (82 %); i per als arquitectes n'hi ha 17 sobre 29 (58,6 %), quelcom que palesa un model francés clar en l'ensenyament tècnic.[14]

Si atenem ara l'ensenyament universitari i ens centrem en la llista del mateix any per a la Facultat de Ciències, podem copsar que s'hi recomanen, ultra tres llibres de Física amb nocions de química per a l'ensenyament mitjà, tots d'autors espanyols, nou de química, inorgànica i orgànica, tres dels quals són d'autors espanyols, cinc de francesos i un del famós químic alemany

Liebig. Una proporció, pel que fa a les altres franceses, per a la química, del 55,5 %. Val a dir que en el cas de la química l'indiscutible model francés de mitjan segle XIX serà substituït progressivament per l'alemany.[15]

Si hi afegim que la llei Moyano contemplava l'existència d'un **Consell d'Instrucció Pública** presidit pel Ministre o persona per ell delegada, que nomenava rectors, degans i directors d'Escoles Superiors i que, endemés, va sostraure totes les atribucions als claustres d'universitat (l'ordinari format per catedràtics i l'extraordinari que el composaven tots els doctors) fins al punt de deixar-lo convertit en un organ l'única missió del qual era reunir-se amb motiu de determinats actes públics i solemnes,[16] es compren que existís un cert malestar en el sector més progressista del professorat; un cop abans de 1973 i un cop després, la resposta d'aquest professorat més conscienciat, més modern, es fa palesa ~~amb~~ en les anomenades qüestions universitaries.

La primera va esclatar el 1865 quan Castelar fou amonestat per defensar els "textos vius" enfront dels "textos morts" que eren els obligatoris. De resultes de la virulenta controvèrsia que va seguir, **Sanz del Río, exponent del krausisme a Espanya,** i el mateix Castelar foren expedientats; com que el rector , Juan Manuel de Montalbán, es negà a actuar contra els seus companys fou separat del càrrec. Seguiren el camí de l'expedient i l'arraconament Salmerón i Giner de los Ríos, entre d'altres.[17]

La revolució de 1868 va dur la calma en proclamar la llibertat de càtedra. Foren, els del sexenni, sis anys de normalitat pel que fa a la debatuda qüestió. En canvi la Restauració significava el retorn a les llistes obligatories de llibres de text així com a la obligatorietat de presentar els programes de l'assignatura al ministeri per tal d'obtenir-ne l'aprovació (R.D. del 26/II/1875). La reacció contra el Decret, signat per Orovio, s'inicià a Santiago; seguiren les protestes de Castelar, F. Giner de los Ríos i Salmerón, essent els dos darrers confinats a Càdis i Lugo respectivament. Hi hagué ressò al País Valencià i a les Illes però no a Barcelona, malgrat que hi hagués estudiat un home tant representatiu del moviment reprimit com

Giner de los Ríos. Certament, el krausisme no havia envaït la institució docent catalana la qual seguia fidel a les ensenyances de R. Martí d'Eixalà i del seu successor X. Llorens i Barba defensors de l'anomenada escola escocesa.

S'ha d'afegir que la qüestió es va diluir en un clima de major comprensió i de tolerància que, contemplà la restitució dels professors expedientats als seus llocs de treball, a partir de 1881'. Havien guanyat els krausistes.

El trasllat de la Universitat a l'edifici actual als voltants de 1873 - no totes les facultats ho feren al mateix temps ni el mateix any - es va fer en un context somort i sotmès als avatars polítics. **Tanmateix, i malgrat l'existència d'alguns homes molt vàlids, la Universitat de Barcelona no es va distingir, durant la segona meitat del segle pel seu progressisme militant.**

Tot seguit pot ser interessant d'examinar com i de quina manera, i amb quant de retard, s'introduïren les grans teories científiques de l'època en aquest àmbit universitari concret i determinat.

Dues aportacions científiques de l'època:[18]

A) *La taula periòdica dels elements*: **Dimitri Ivanovitch Mendeleiev (1834-1907) i Julius Lothar Mayer (1830-1895) donaren cim als treballs que precediren els seus en la llarga carrera de trobar una classificació dels elements químics.** Mendeleiev ho féu un xic abans i, doncs, la seva taula de classificació, avui coneguda amb el seu nom a tot el món, és la que va adoptar-se definitivament. Val la ~~insistir~~ pena de remarcar que existien **precedents valuosos**: l'acceptació de la teoria de Dalton; la de la hipòtesi d'Avogadro en el sentit que les mol.lècules dels gasos són diatòmiques; la introducció de símbols per tal d'identificar els elements; l'actuació decisiva de Cannizaro dirigida a calcular els pesos atòmics basant-se en les hipòtesis d'Avogadro i d'Ampere (Congrés de Karlsruhe, 1860).

Tampoc els intents de classificació no havien mancat; és inevitable l'esment de les tríades de Dobereiner (1817) i la de les octaves de Newlands (1866), molt més propera a l'adoptada finalment per Mendelejev **Antecedents sobre els que no ens estenem per manca d'espai però que no fan més que demostrar, un cop més, que el problema era ja a l'ambient, tot amarant la comunitat científica**, i que la troballa final no surt pas del no res, per generació espontània; les gestacions de les descobertes científiques són lentes i el resultat final no és res més que el remat final d'aquelles.

El 1869 Mendelejev, que tot sigui dit havia assistit al congrés de Karlsruhe, un dels més importants de la història de la química, publicava per primera vegada el resultat dels seus estudis. Convençut de la periodicitat ~~va~~ Havia ordenat els elements pels pesos atòmics creixents i ~~va~~ s'havia adonat d'aquesta manera que la periodicitat de llurs propietats es presentava ~~de manera~~ periòdicament cada set elements:

Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19
Na=23	Mg=24	Al=27,4	Si=28	P=31	S=323	Cl=35,3
K=39	Ca=40	......	Ti=50	V=51	etc.	

Tanmateix, molts pesos atòmics eren equivocats ; Mendelejev en va corregir alguns. D'altra banda, quan en la seva classificació no trobava l'element que per raó de les propietats li calia, deixava el lloc buit. Cal pensar que en un moment de confusió teòrica notable tal decisió era d'una gran valentia i palesava una confiança molt gran en la seva teoria i en ell mateix. Tanmateix, ben aviat arribaren les primeres confirmacions: el gal.li i l'escandi, els quals foren col.locats en els buits que els eperaven. La teoria, sobre la qual els químics s'havien preguntat fins a quin punt no era un mer artifici pedagògic per tal de recordar millor els elements i llurs propietats, car no pot oblidar-se que tant Mendelejev com Mayer eren professors, va guanyar credibilitat i s'imposà. Es pot assegurar que el 1875 la taula periòdica havia convençut els més repatanis.

Obviament podriem estendre'ns molt sobre la classificació periòdica dels elements; tanmateix, el que ens interessava d'antuvi era situar la seva genesi temporal. Ara ens resta, de la manera mes breu possible, remarcar-ne la importància.

La nova i definitiva classificació va obligar - ultra les aportacions de Mendelejev en aquest sentit - a revisar els pesos atòmics i a ajustar-ne el valor; va servir per detectar analogies insospitades entre els elements que composaven els grups, almenys en alguns d'aquests; finalment, plantejava un interrogant crucial: **perquè les regularitats** observades? Totes i cada una d'aquestes qüestions, en especial la darrera, serien punts de partida per a un novedós desenvolupament de la química i àdhuc de la física puix caldrà cercar un model d'atom per a trobar les explicacions adients. Un cop més pot detectar-se com problemes concrets, en el cas que ens ocupa una classificació, esdevenen baules importants en la història de la ciència.

Es obvi que a la segona meitat de segle XIX ens trobem davant de nombroses aportacions científiques de pes. Podriem esmentar-ne moltes però recordem a tall d'exemple la teoria **electromagnètica de Maxwell** o bé, un xic abans, l'establiment de la ciència de la calor, és a dir, **la termodinàmica**. L'elecció de en aquesta ponència dues (la taula periòdica i el darwinisme) no respon a criteris d'importància sinó d'estratègia - es tracta de dos temes de moda i sobre els quals s'estan fent recerques novedoses - i alhora d'espai. El que ens interessa, però, és, un cop triats els temes, examinar-ne els retards amb què les noves teories es difongueren a Catalunya per tal de poder valorar la modernitat i l'esperit d'innovació i renovació dels científics que a la segona meitat del segle dinou treballaven al Principat i, especialment, a la Universitat de Barcelona.

→ cursiva i minúscula

B) EL DARWINISME: És ben sabut que el viatge que va efectuar el *Beagle* al voltant del món (1831-1836) va influir poderosament en Charles Darwin que havia embarcat com a naturalista de l'expedició. Dotat d'un acusat esperit crític d'observació, Darwin va acumular una valuosa informació (no tan sols visual sinó que va confegir així mateix diverses col.leccions) que li serviria de base per a la confecció de l'obra que escriuria al cap de més de 20 anys.

Nogensmenys, els antecedents no poden ésser oblidats. Els estudis de la terra, la geologia, havien deixat expedit el camí en el sentit concret que la terra tenia més dels 6.000 anys que podien deduir-se d'una interpretació literal de la Bíblia; en aquest context, l'obra de Charles Lyell, *Principles of Geology* (1830), un dels llibres que Darwin va emportar-se per al viatge, va tenir una influència decisiva en el nostre home. Emperò, a més, hi havi antecedents sobre l'evolució de les espècies animals; per citar-ne dos, les idees del seu avi Erasmus Darwin i la teoria de Lamark (J. Baptiste Monet, cavaller de Lamark). No és el moment d'entrar en detall però cal dir que tampoc aquí no falta l'ambient propici per abordar la qüestió. Darwin va saber concretar les respostes a les preguntes que molts es plantejaven. Ben sabuda és la història de A.R. Wallace que, independentment, va arribar a les mateixes conclusions que Darwin. Fou així com la primera publicació de l'obra cabdal de Darwin va ésser acompanyada de la comunicació sobre el tema de Wallace. *On the Origin of Species* no sortiria fins a l'any següent (1859).

Tampoc no ens estendrem a donar detalls de la teoria darwiniana de l'evolució. Sí que volem dir, però, que trencava amb la tradició i, doncs, que el xoc amb qui la representava, l'església, era inevitable. El mateix Darwin n'era conscient i a l'*Origen de les espècies* no parla per res de l'home; l'obra sobre l'evolució de l'home sortiria a la llum pública dotze anys més tard amb el Títol *The Descent of Man* (1871) on mantenia la idea, ara sí, que pel que fa a l'evolució no hi ha diferencies entre les espècies animals i l'home. La lluita fou molt dura però a la fi la teoria de l'evolució, que ha arribat als nostres dies, amb totes les addicions que el procés científic li ha afegit, s'imposà.

Cal entendre la inèrcia i les dificultats que trobà el darwinisme fins que no va ser acceptat - encara avui el creacionisme treu el cap esporadicament - per tal de comprendre'n la problemàtica de la difusió a casa nostra.

No hi ha cap dubte que ens trobem enfront del **procés de substitució d'un vell paradigma per un altre de nou. I tal com diu** [redacted] **aquests processos no es fan pas sense greus tensions internes que afecten la comunitat científica com la societat.** En el cas que ens ocupa, les teories de l'evolució que precediren les de Darwin la consideraven, l'evolució, com un procés que es dirigia cap a una fita. En canvi, per a molts l'abolició d'aquest tipus teleològic de l'evolució era el més important i alhora desagradable suggeriment de Darwin. En el fons el que es qüestionava era l'accepció tradicional del concepte progrés.

La química a Barcelona als voltants de 1873:

A Barcelona existia, al segle XIX, una tradició en el conreu de la química que datava de 1805 quan Francesc Carbonell i Bravo (1768-1837) va inaugurar l'Escola de Química de la Junta de Comerç, un centre que va gaudir d'una merescuda fama en el primer terç del dinou. Carbonell i Bravo que va introduir els corrents de la química moderna a casa nostra va tenir deixebles tan notables com Josep Roura, primer director de l'Escola d'Enginyers barcelonina i, no tan significat com l'anterior, el seu fill F. Carbonell i Font (1792-1854) traductor de les *Lecciones de Química General* de J. Girardin.

La Universitat de Barcelona va heretar el renom de l'escola de química suara esmentada. J. Agell i Torrent (1809-1868), que va estudiar a les Escoles de la Junta de Comerç i arribà a ésser catedràtic de química de la nostra primera institució, és qui representa el nexe d'unió entre les generacions de Carbonell i Roura amb les posteriors universitaries, és, forçosament, objecte de la nostra atenció José Ramón de Luanco (1825-1905), asturià que exercí la docència a Oviedo, Santiago, Madrid, Saragossa i finalment s'afincà a Barcelona. Fou l'autor d'una coneguda obra a l'època, *Compendio de las lecciones de química general* que va veure tres edicions (1878, 1884 i 1893) - sobre la que tornarem més endavant - i un bon pedagog que es va cansar de demanar laboratoris per als ensenyaments pràctics sense els quals, deia, no pot existir un ensenyament correcte de la matèria.

El 1879, E. Mascareñas (1853-1934) va guanyar la càtedra de química inorgànica la qual va regentar fins a la seva jubilació esdevinguda el 1924. L'Escola de què parlàvem continua amb el seu deixeble J. Pascual i Vila (1895-1979), l'obra docent del qual pertany ja al segle XX.[19]

Mascareñas, com abans Luanco, s'escarrassà demanant mitjans per tal de bastir bons laboratoris tant per a poder realitzar-hi pràctiques com per a dur-hi a terme una recerca adient. Fou, però, endebades. Sobre l'estat dels laboratoris tenim notícies a bastament. El mateix Mascareñas, en el discurs inaugural del curs acadèmic 1899-1900, després de recordar l'excel.lent organització i equipament de les universitats alemanyes - a finals de segle el paradigma de l'ensenyament, molt especialment en la branca química tal com hem assenyalat més amunt -, remarca el lluny que es troben d'aquell model les universitats espanyoles especialment pel que fa a les ciències físico-químiques, necessitades d'un ensenyament pràctico-experimental que exigeix laboratoris ben equipats amb productes, instruments i aparells útils i moderns.[20] Després passa a constatar *el lamentable estado de las ciencias experimentales en nuestro país, y del punible y vergonzoso abandono en que yacen de largo tiempo acá...*[21] Al mateix discurs recorda conceptes semblants que el Dr. Magí Bonet i Bonfill escrivia el 1855 i repetia el 1878. Però el que és realment significatiu són les dades econòmiques que ens proporciona Mascareñas:

> *Para tener idea de la escasez de los recursos que se conceden a la enseñanza experimental en España baste decir, que las cátedras de Química mineral y orgánica de la Facultad de Ciencias de la Universidad de Barcelona reciben, cada una, la mezquina consignación trimestral de noventa pesetas, ó sean treinta pesetas al mes, con destino al sostenimiento del laboratorio, enseñanza experimental en la cátedra y prácticas de los alumnos. Consecuencia de esta falta de recursos és también la carencia absoluta de Bibliotecas especiales para los laboratorios, en donde se hallen las revistas, publicaciones extranjeras y obras más importantes, necesarias para la consulta de profesores y alumnos, y tan indispensables para hallarse al corriente del movimiento científico como para emprender la investigación de trabajos originales.*[22]

Podriem fer desfilar nombrosos testimonis per aquestes pàgines; tanmateix, en ésser les opinions idèntiques es farien repetitives. Serveixin com a exemple els mots de Mascareñas.

No obstant, és obligat preguntar-se com s'introduiren els corrents cientifics moderns en la Universitat de Barcelona; concretament: com i quan es va introduir la taula periòdica de Mendeleiev?

Un professor de la Universitat de Madrid, Muñoz de Luna, va assistir al congrés de Karlsruhe (1860), fet que fa pensar que no podia deixar de coneixer els treballs de Mendeleiev i Mayer sobre la classificació periòdica dels elements; no obstant, podem comprovar que a la seva obra *Elementos de Química General* (1877) no en fa cap al.lusió. Tampoc a Barcelona, el seu company J.R. Luanco, al seu *Compendio de lecciones de química general*, no en fa cap esment en les dues primeres edicions de 1878 i 1884, però si que la cita - tanmateix, tangencialment - en la darrera de 1893.

Nogensmenys, hem de remarcar que és Mascareñas a *Introducción al estudio de la química. Compendio de lecciones explicadas en la Universidad de Barcelona* (1884), qui presta atenció de manera seriosa per primera vegada a la taula de Mendeleiev en un text universitari.[23]

Cal recordar que tradicionalment hom cita els discursos d'ingrés a l'Acadèmia de Ciències (de Madrid) dels catedràtics de química Santiago Bonilla i José Muñoz del Castillo (1898 i

1901, respectivament) com els primers documents científics espanyols que contenen cites explícites de Mendeleiev i Mayer, una asseveració que, doncs, és obligat de rectificar.[24]

Com una prova de l'esperit científic progressista de Mascareñas ~~cal recordar~~ és obligat assenyalar que en el discurs inaugural del curs **1899-1890**, ja esmentat, s'estranya que des de 1857 a 1880 hi hagués hagut una assignatura a la facultat de Ciències que tractant de l'estudi de la calor, la llum i l'electricitat es digués encara ***Flúidos imponderables***... ¿ No reflecteix, tot el que duem dit sobre aquest professor barceloní, un esperit crític que s'avergonyeix del tradicional endarreriment científic a Espanya i alhora denota un home de ciència professional, al dia, entestat en no perdre el tren? L'estudi crític de l'obra de Mascareñas és un dels buits que cal omplir rapidament si volem entendre tant el desenvolupament d'aquesta branca de la ciència a casa nostra com l'ambient científic que existia a la Universitat de Barcelona i al Principat en general.

Precisament perquè no s'ha de tenir cap dubte sobre el fet que la història de la ciència a casa nostra és gairebé tota per fer - tanmateix, hi ha excepcions valuoses -, desitjariem que les noves generacions s'hi interessessin progressivament i anessin aclarint punts, omplint buits i interpretant el nostre passat científic. Nosaltres avui no hem fet més que apuntar el camp de la química i encara en un aspecte concret. Obviament n'hi ha d'altres, no cal precisar si tant o més interessants. La questió es fer entendre que conèixer el passat - quin sigui -, no ès pur sentimentalisme, és senzillament, repassar la lliçó de la història.

Sobre la introducció del darwinisme a Catalunya:

Si bé la difusió de les teories evolucionistes de Darwin i del positivisme a Espanya han estat objecte d'atenció per part d'alguns estudiosos que hi han centrat llur atenció - entre d'altres, T.F. Glick i D. Nuñez -,[25] en canvi quan es tracta d'analitzar el problema a Catalunya o bé ens trobem amb tòpics que arrenquen de la qualificació que Vicens Vives fa de la burgesia catalana, a la qual titlla d'immobilista, tòpica i amb repugnància per qualsevulla novetat intel.lectual o artística,[26] o bé constatem un buit pel que fa al tema. Creiem que això no pot ser així, tan simple, atès que l'entorn social dinàmic català havia de menar forçosament per altres viaranys. Estudis recents han donat la raó a la nostra intuició: J. Arqué[27] i A. Vives[28] han estudiat seriosament dos moments de la història intel.lectual catalana i ens han aclarit moltes coses.

D'antuvi, no podem deixar de comentar, encara que sigui breument, els esdeveniments ocurreguts a l'Ateneu Barcelonès. A començaments de 1877, Pere Estasen va iniciar un curs, ~~sobre~~ *Lecturas sobre el positivismo*, el qual va ser interromput a la cinquena conferència per la Junta Directiva de l'entitat. El cicle que el mes d'abril va començar Bartrina sobre l'*América Precolombina* va patir la mateixa sort amb l'única diferència respecte a l'anterior que fou després de la primera conferència que va ésse prohibit. No caldria afegir que tant Estasen com Bartrina es declaraven darwinistes i positivistes. L'afer, que no relatem amb detall perquè fer-ho ens obligaria a sortir de la visió general que ens hem proposat, va generar una pregona reacció del sector republicà existent a l'Ateneu. La politització, doncs, va esdevenir realitat.

Val a dir que els elements que abandonaren l'Ateneu Barcelonès arrel de la intransigència inicial de la Junta fundaren una nova institució, l'Ateneu Lliure, que tot presentant-se com la rèplica de l'Ateneu històric, va iniciar les activitats el 1878. **Tanmateix, el sector moderat republicà, reformista, va aconseguir a la llarga gaudir d'un cert pes específic a l'Ateneu Barcelonès i arribà a controlar les decisions de la Junta.** N'és prova fefaent el que homes com **Estasen, Gener, Sanpere i Zulueta** tornessin a donar conferències als locals de l'Ateneu Barcelonès. Hom pot detectar a partir de

1880 una clara tolerancia que va contribuir, sens dubte, a que l'altre Ateneu, el Lliure, no gaudís d'una vida gaire llarga.[29]

En examinar i matisar la idea tòpica que fa referència al conservadurisme intel.lectual de la burgesia catalana en els anys setanta del dinou, hom constata, doncs, l'existència d'un sector republicà **que va reaccionar davant la intransigència i la immobilitat d'un altre sector conservador** tot i aconseguint **alguns resultats positius per a la llibertat de pensament i d'expressió. L'actuació** d'aquest sector liberal, no podria considerar-se com ~~la~~ una versió catalana de les qüestions universitaries esdevinguda, però, per raó de les pròpies caracteristiques de la societat catalana, fora de les aules?

Anys més tard foren també els republicans qui protagonitzaren i polititzaren un afer que, aquest sí, va tenir lloc en les aules universitaries. Cal, tanmateix, explicar-lo abans d'extraure'n concretes valoracions.

Ens situem ara a la darrera dècada del segle passat. Tot i admetre, i saber, que a la Universitat hi havia qui era més o menys proper a les teories darwinistes i positivistes, cal ser conscients que la nostra primera institució docent no havia donat pas excessives proves de liberalisme científic. En aquest marc general, que admet no obstant excepcions, és indubtable que la batalla decisiva la va lliurar **el jove catedràtic aragonés d'Història Natural** que va prendre possessió de la càtedra **barcelonina el 1889, Odón de Buen,** llirepensador, amic de Ferrer i Guardia i republicà notori (fou regidor de l'Ajuntament de **Barcelona i posteriorment senador**). L'any següent de la seva arribada publicà un llibre de text que tocava punts intocables i indiscutibles per a l'església catòlica, concretament ~~aquell~~ el que es referia a l'home com a producte de l'evolució.

La resposta no es féu esperar i la Sagrada Congregació de l'Index condemnava, el juny de 1895, el *Tratado Elemental de Zoología* i el *Tratado Elemental de Geología* de l'esmentat catedràtic. Coherentment des del seu punt de vista, el bisbe, en rebre la notícia de la prohibició, va declarar les dites obres no vàlides per a l'ensenyament; com a conseqüència, dispensava els alumnes d'anar a classe del Dr. de Buen i demanava alhora, en darrer terme, que la classe fos impartida per un altre professor, tanmateix catòlic. A la vista dels esdeveniments, el rector, Julian Casaña, **decidí "treure de circulació les obres de l'esmentat senyor (el catedràtic de l'assignatura, Odón de Buen) en compliment d'aquella superior disposició".**

A partir d'aquest moment l'afer es polititzà; les forces republicanes fent costat al catedràtic; les dretes, al bisbe i al rector. Els aldarulls estudiantils se succeiren i el Govern s'espolsà les responsabilitats endosant-les a les autoritats eclesiàstiques i universitàries personalitzades en les persones del bisbe i del rector. Aquest va convocar el Consell Universitari el qual, en una primera reunió donà suport al rector, però més endavant va canviar de parer i, **després de l'autodefensa del mateix de Buen, el deslliurà de qualsevulla reponsabilitat.** L'afer arriba a la fi quan el 7 de gener de 1896 Odón de Buen rempren les classes i el rector accepta una càtedra a la Universitat de Madrid gairebé creada per a ell per tal de trobar una sortida a un assumpte que havia agafat una volada insospitada.[30]

De Buen, a més dels càrrecs polítics ja citats, va ser nomenat director del Laboratori de Biologia Marina de Mallorca, creat el 1906, i així mateix director de l'Institut Espanyol d'Oceanografia. Hom pot comprendre per tot el que diem, que la polèmica havia finit amb un triomf del catedràtic darwinista i de les forces més progressistes. **A partir d'aquest moment el darwinisme no seria ja qüestionat, almenys publicament en el camp científic i universitari.**

L'assumpte s'havia escolat de manera molt diferent a com ho havia fet, per exemple, al País Valencià, on es va poder comptar amb la tasca del llirepensador positivista, el metge Peregrí Casanova (1849-1919), deixeble de Haeckel, del qual va traduir *La Biología General*, una obra positivista per excel.lència des de la primera a l'última pàgina, i amb qui es cartejava.[31]

No ens ha pas d'estranyar que a cada lloc la història de la difusió de les idees científiques sigui diferent car el coneixement científic ha d'ésser considerat com un conjunt de coneixements que interactua constantment amb l'entorn socio-econòmic que l'envolta. I és indubtable que en aquell moment Catalunya, amb una burgesia decidida a industrialitzar i modernitzar el país, es distingia d'altres regions de l'Estat. Una cosa és la universalitat de la ciència occidental - tanmateix, podriem fer crítiques a la dita universalitat en el sentit d'imposició a d'altres cultures - i una altra és el desenvolupament científic d'una societat determinada en un moment concret en què la difusió d'aquelles idees universals resten sotmeses a interelacions/influències polítiques, socials, econòmiques i culturals que fan que el seu descabdellament, el de les idees científiques, sigui diferent en la mesura que ho és la societat suport.

Ja hem dit que la nostra història científica és plena de buits (valgui la contradicció). Anar-los omplint és la tasca urgent que cal dur a terme puix serà en la mesura que els emplenem que podrem millorar les valoracions serioses, amb fonament, confegides sobre el nostre passat universitari i, doncs, científic. Un repte que sols pot ser enfrontat amb garanties si es reconeix a la història de la ciència el rang que li pertoca i que de fet ja gaudeix en altres indrets.

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NOTES

1.- *Decretos de S.M. la reina Doña Isabel II, dados en su real nombre por su augusta Madre la Reina Gobernadora y reales órdenes, resoluciones y reglamentos generales expedidos por la Secretaría del Despacho Universal, por D. Josef María de Nieva,* t. XXXIII, Madrid 1845, pp. 474 i ss. Obres més generals que fan referència als temes que es tracten: RIERA, S., "Les ciències físiques, químiques i matemàtiques" a *L'Aportació de la universitat catalana a la ciència i la cultura*, Barcelona, L'Avenç 1981, pp. 125 a 127; PESET, J.L. i altres, *Ciencias y enseñanza en la revolución burguesa*, Madrid, Siglo XXI, 1978, pp. 42 i 43.

2.- "Ley de Instrucción Pública (9 de setembre de 1857)" a *Colección legislativa referente a los Ingenieros Industriales*, Barcelona, Asociación de Ingenieros Industriales, 1886, pp. 53 i 54.

3.- PESET, op. cit., p. 44.

4.- *Colección legislativa...*,op. cit., pp. 9 a 19.

5.- *Colección legislativa...*, op. cit.,p. 59.

6.- *Catàleg de l'Exposició commemorativa del centenari de l'Escola d'Arquitectura de Barcelona 1875-76/ 1975-76*, Escola Superior d'Arquitectura de Barcelona, 1977, pp. 15 a 18 i 35 a 37. També el documentat article de S. TARRAGÓ a G.E.C.

7.- VERGÉS,F., *Discurso inaugural. Apertura del curso académico de 1872 a 1873 en la Universidad de Barcelona*, Barcelona, Tomás Gorchs 1872, pp. 11 a 13 i 50 a 53.

8.- Pel que fa al nombre de professors de l'Escola d'Enginyers: CASTELLS,P., *Reseña histórica*, Barcelona, Escuela especial de Ingenieros Industriales 1943, p. 23. A la llista consultada del personal docent no hem comptat els traslladats a la Universitat de Barcelona ni aquells en l'expedient dels quals no consta la data de cessament malgrat que un d'ells, P. Bori y Riu, ho féu, amb molta probabilitat, ja passada la data de referència.

9.- VIDAL I VALENCIANO, L., *Discurso inaugural. Apertura del curso académico de 1876 a 1877 en la Universidad de Barcelona*, Barcelona, Tomás Gorchs y Cª 1876, pp. 10 i 11, 14 i 15.

10.-CARMONA, A.M., *La nova ciència farmacèutica catalana. Influència i incidència científiques*, Discurs llegit a l'acte de recepció celebrat el dia 4 de juny de 1987 a la Reial Acadèmia de Farmàcia de Barcelona, Barcelona 1987, p. 23.

11.-Cal citar: ARQUÉS, J., *Cinc estudis històrics sobre la Universitat de Barcelona (1875-1895)*, Columna, Barcelona 1985; CARMONA,A.M., *De l'Apotecari al Farmacèutic. Els farmacèutics catalans dels segles XVIII i XIX*, Publicacions i Edicions de la Universitat de Barcelona, 1983; CARMONA,A.M., "Evolución de la enseñanza de la Farmacia en España y en otros paises" a FOLCH JOU,G. (dirigida per), a *Historia General de la Farmacia. El medicamento a través del tiempo*, vol. 2, pp. 685 a 698.

12.-Vegeu: CASASSAS, O., *La medicina catalana del segle XX*, Llibres a l'abast, edicions 62, Barcelona 1970; COMENGE I FERRER, Ll., *La medicina en el siglo XX*, José Espasa editor, Barcelona, s.d.; RIERA I TUèBOLS, S., *Sintesi d'Història de la ciència catalana*, La Magrana, Barcelona 1983, pp. 256 a 264 i 270 a 282.

13.-*Gaceta de Madrid* (20/X/1861).

14.-RIERA I TUèBOLS,S., "Industrialisation et enseignement tecnique (1850-1914)" a *Industry, knowledge and education in moderne Europa*, Cambridge University, en premsa, pp. 6 i 7.

15.-*Gaceta de Madrid* (27/IX/1861) i (20/X/1861)

16.-PESET,M. i PESET, J.L., *La universidad española (siglos XVIII y XIX)*, Taurus, Madrid 1974, pp 476 i 477.

17.-Pel que fa a les qüestions universitàries: CACHO VIU,V., *La Institución Libre de Enseñaza, I. Orígenes y etapa universitária (1860-1881)*, Ediciones Rialp, Madrid 1962. En especial capítols III al VIII; JIMENEZ,A., *Historia de la universidad española*, Alianza Editorial, Madrid 1971. Concretament, cap. 6.

18.-No explicitarem un llista de referència bibliogràfica per dos temes ben coneguts dels quals qualsevulla obra general d'història de la ciència en proporciona abundant bibliografia. No obstant, no volem deixar de citar, per a aquells que vulguin aprofundir, sense esser-ne experts: HOLTON,G., *Introducción a los conceptos y teorías de las ciencias físicas*, editorial Reverté, Barcelona 1979, cap. 20 i 21, pel que fa a la taula periòdica. Quant al darwinisme: FARRINGTON,B., *El evolucionismo*, Editorial Laia, Barcelona 1967.

19.-Per a l'escola de química de la Universitat de Barcelona, RIERA I TUèBOLS, S., *Sintesi...*, op. cit., pp. 239 a 241, 282 a 284 i 319.

20.-MASCAREÑAS,E., *Discurso inaugural leido en la solemne apertura del curso académico de 1899 a 1900 ante el claustro de la Universidad de Barcelona por el Doctor...*, Imprenta Moderna de Guinart i Pujolar, Barcelona 1912.

21.-MASCAREÑAS, E.,op. cit., p. 34.

22.-MASCAREÑAS,E., op. cit., n. 11, p 43.

24 ~~23~~.-ARAGON DE LA CRUZ, "Evolución histórica de la clasificación de los elementos", *Anales de la Real Academia de Ciencias Exactas, Físicas y Naturales de Madrid*, 1981, pp. 185 a 315, en especial 307 i 308.

23 ~~24~~.-RICOL,P., *La introducció de les noves teories químiques de finals del XIX a la Universitat de Barcelona*, tesi de llicenciatura, Departament d'Història Contemporània de la Universitat de Barcelona, inèdita. Ricol aporta interessants dades que rectifiquen les opinions que fixaven l'entrada a Espanya de la taula periòdica just a finals del XIX.

25.-GLICK,T.F., *Darwin en España*, Edicions 62, Barcelona 1982.; NUÑEZ,D., *El darwinismo en España*, Madrid 1977.

26.-VICENS VIVES,J., *Industrials i polítics*, editorial Vicens Vives, Barcelona 1972 (1958), concretament p. 286.

27.-ARQUÉS,J., *Cinc estudis...*, op. cit.

28.-VIVES,A., *Positivisme i Evolucionisme a Catalunya*, tesi de llicenciatura inèdita llegida al Departament d'Història Contemporània de la Universitat de Barcelona, 1987.

29.-VIVES,A., op. cit., concretament cap. IV.

30.-ARQUÉS,J., *Cinc estudis...*, op. cit., en concret, l'estudi primer: "Darwinisme i antidarwinisme a la Universitat de Barcelona; la suspensió d'Odón de Buen de la seva càtedra", pp. 21 a 66.

31.-GLICK,T.F.,*Darwin...*, op. cit., especialment cap. 1 i en concret pp. 17 a 20.

INDUSTRIALISATION ET UNIVERSITE À L'ESPAGNE A LA FIN DU XIXème SIECLE

En el contexto de una industrialización que había empezado a finales de la tercera década de siglo a través del sector textil, la Ley de Pidal y Gil de Zárate de 1845 organizaba la enseñanza de la ciencias en España. Por primera vez se contemplaba la licenciatura en ciencias; si a ella se sumaba la licenciatura en letras, podía llegarse al titulo de licenciado en filosofía.

Por la Ley Moyano (1857), la sección de ciencias de la Facultad de Filosofía se convertía en Facultad de Ciencias con el nombre de Ciencias Exactas, Físicas y Naturales. Al año siguiente, la recién nacida Facultad de Ciencias se dividía en tres secciones: Físico-matemàtica, Química y Naturales. Una vez conseguida la licenciatura, con dos años más de estudios se alcanzaba el título de doctor, el cual, todo sea dicho, sólo podía obtenerse en Madrid, una prueba más del centralismo existente.

Mientrastanto, en 1850 (R.D. del 4 de septiembre) se había creado la carrera de ingeniero industrial, en tres grados o niveles. Su clara finalidad, la de ser el soporte de la industrialización. Dimos cuenta de ello extensamente en nuestras anteriores comunicaciones (Lancaster 1985, París 1987), hoy recogidas en un libro en proceso de edición (Cambridge University). No insistiremos.

Poco después de este largo proceso de creación de Facultades y Escuelas de Ingenieros, estallaba en España la cuestión de la "libertad de cátedra" cuando algunos catedráticos y profesores defendieron la libertad de enseñanza, negándose a seguir las instrucciones, referentes a programas y libros de texto, que aún emanaban del Ministerio. Esta controversia se extendió durante las décadas de los años sesenta y setenta. Al fin, los liberales vencieron; por lo menos en este punto.

Serenados los ánimos, parece que los tiempos favorecían el cultivo de las ciencias. Con todo, hay que recordar que España no era un país puntero ni en el campo de la ciencia ni en el de la tecnología. Mas bien al contrario. Es por ésto que son meritorios los esfuerzos, que los hubo, para intentar alcanzar el nivel europeo.

Tres son los campos en que dicho esfuerzo tuvo algún brillo y continuidad: el campo de la electricidad, el de la química y el de las teorías darwinistas. De la introducción de la electricidad tambien hablámos en nuestras anteriores comunicaciones; hoy nos interesa remarcar la atención prestada a la química, especialmente en la Universidad de Barcelona. Por lo que se refiere a las teorias darwinistas, caen fuera del alcance de nuestras metas. Por el momento.

En Barcelona existía una tradición en la química que provenia de la Escuela de Química fundada por la Junta de Comercio en 1805, de la que fue director F. Carbonell. Un discipulo suyo, J. Roura, fue el primer director de la Escuela de Ingenieros de Barcelona. J. Agell, J.R. de Luanco y E. Mascareñas, constituyen los eslabones de una escuela, en el sentido de personalidad y tradición, que llega hasta los principios del siglo actual.

Como detalle, anotemos que fue Mascareñas en 1884, en su obra *Introducción al estudio de la química*, quien prestó atención por primera vez a la tabla de los elementos de Mendeleiev. El retaso en este caso no era mayor de diez años. Cabe añadir que todos los químicos mencionados reclamaron la modernización de la enseñanza de la química con el establecimiento de laboratorios dignos. El modelo francés de principios de siglo se despalaza visiblemente, a finales de la centuria, en el campo de las ciencias físico-matemáticas especialmente, hacia el modelo alemán.

Como conclusión, puede asegurarse que si bien la ciencias puras no tuvieron un papel tan relevante como el de las aplicadas, una afirmación que debiera matizarse, por lo menos se comprendió que la modernización del país implicaba su cultivo (el de las ciencias puras) como base del anhelo industrializador que se vivía, aunque ello sólo era posible de momento en Cataluña y en el País Vasco.

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