THE TEACHING OF CHEMISTRY AT THE GERMAN POLYTECHNIC SCHOOLS, 1803-1860*

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Historians of German chemistry are aware of the polytechnic schools mainly from their role in the *second* half of the nineteenth century. From studies by Manegold, Burchardt, Meyer-Thurow, Johnson and Scholz we know quite a lot about the polytechnic schools and their chemistry programmes at that time.[1] By contrast, it is hardly possible to sketch from the literature a clear picture of German polytechnic chemical education in the *first* half of the nineteenth century. Even the history of German polytechnic education in general is poorly documented as far as the first half of this period is concerned. The studies that are recognized as being the best overviews of the polytechnic school system - an article by Franz Schnabel from 1925, and Karl-Heinz Manegold's book *Universität, Technische Hochschule und Industrie*[2] - appear to present a rather anachronistic picture with respect to the first half of the nineteenth century when one carefully compares their statements with available primary sources. In fact, both authors were strongly influenced by the rhetoric of late-nineteenth century spokesmen of the *Technische Hochschulen*, who looked back on the first half of that age from the perspective of their struggle for *Gleichberechtigung*. Examples are the emphasis on the importance of mathematics for the teaching at the polytechnic schools, and the assertion that there was a strong continuity between the Parisian *École polytechnique* and the German polytechnic schools. These were crucial issues for late-nineteenth century polytechnicians like Franz Grashof and Franz Reuleaux. Schnabel and Manegold have mainly emphasized the same points, and have underestimated, by doing so, the important continuities between the first German polytechnic schools and older eighteenth century German institutions, like *Realschulen*, evening- and Sunday lectures, engineering courses at the universities, and (even) pharmaceutical boarding schools.[3] As a consequence, both authors have failed to recognize that the years around 1830 were a watershed in the history of German polytechnic education. The periods before and after 1830 had a very different character; with different aims, curricula and institutional dynamics.[4]

The aim of this paper is to present a short sketch of the main episodes in the teaching of chemistry at the German polytechnic schools. It tries at the same time to do justice to the rich diversity of polytechnic schools which were in existence in the

Mitteilungen, Gesellschaft Deutscher Chemiker / Fachgruppe Geschichte der Chemie
(Frankfurt/Main), Bd 13 (1997) ISSN 0934-8506

first part of the nineteenth century. A diversity which partly resulted from the lack of political integration of the German speaking countries at that time. Three periods will be described. During the first period, 1803-1830, polytechnic schools were founded in many German states. They were set up for the training of artisans, manufacturers and, sometimes, engineers. Chemistry was an important part of the curriculum but there were no specific courses for (technical, or industrial) chemists. During the second period, about 1830-1845, the previous 'horizontal' diversity within the polytechnic schools system gave way to a 'vertical' division between lower and higher technical schools. From that time on artisans and manufacturers no longer trained at the same institutions. The education of the manufacturers and 'higher technicians' (*höhere Techniker*) was concentrated in those polytechnic schools that succeeded in raising their teaching standards. Other polytechnic school were down graded to a second rank. In the third period, 1845-1860, a further process of differentiation took place. The general course for (future) manufacturers was split up into two specialized curricula for two new types of professionals: the mechanical engineer and the industrial chemist. For the first time, specific courses for chemists were designed. This signalled an important stage in the emergence of the chemical profession.

The first polytechnic schools, 1803-1830

Between 1803[5] and 1830, more than a dozen polytechnic schools were founded in Germany, Austria and the German speaking parts of Switzerland, by states, towns, economical societies (*Gewerbevereine*) and private entrepreneurs. Several other serious attempts to found such schools failed, mainly for financial reasons. The overall picture presents an impressive record of the strength of the polytechnic movement in early-nineteenth century German society, and of the strong will to modernize education and to improve the training of artisans and manufacturers (table 1). Particularly active reform periods were the years 1803-1809, when educational modernization was the main drive - partly following French institutional examples like the *écoles centrales* and the *École polytechnique*,[6] and the years 1815-1818 and 1825-1830 when, after the end of the French wars, British products flooded the German markets, and the founding of these schools was seen as one of the best means to meet that competition and to raise the level of the national industry, trade and agriculture.[7] During the economically difficult years between 1818 and 1825, when state budgets were under severe pressure, initiatives to found schools mainly came from private persons. Several of the schools in table 1 were rooted in older eighteenth century institutions (eg. Prague, Vienna, Stuttgart and Erfurt).

Mitteilungen, Gesellschaft Deutscher Chemiker / Fachgruppe Geschichte der Chemie
(Frankfurt/Main), Bd 13 (1997) ISSN 0934-8506

Table 1: *Polytechnical schools in German speaking countries: founding dates, plans to found a school, and reorganisations, 1803-1829*[a]

Year	Town	State	Name
1803	Prague	Austria	*Polytechnisches Institut*
1808	Karlsruhe	Baden	'Polytechnische Lehranstalt'
1808?	Würzburg	Tuscany (1814 Bavaria)	*Polytechnische Schule* (1831?)
1808	Augsburg	Bavaria	*Real-Institut* (1816)
1809	Nuremberg	Bavaria	*Real-Institut* (1816)
1815	Vienna	Austria	*Polytechnisches Institut*
1817	Prague	Austria	*Polytechnisches Institut* (r)
1817	Berlin	Prussia	'Mathematisch-techn. Lehranstalt'
1817	Stuttgart	Württemberg	'Polytechnische Schule'
1817?	Düsseldorf	Prussia	*Polytechnische Anstalt* (1837?)
1818	Freiburg i/B	Baden	*Polytechnisches Institut* (1822)
1818	Erfurt	Prussia	'Mathematisch-naturwiss. Institut'
1821	Berlin	Prussia	*Technische Schule*
1822	Augsburg	Bavaria	*Polytechnische Lehranstalt* (1823?)
1823	Nuremberg	Bavaria	*Polytechnische Schule*
1823	Berlin	Prussia	'Polytechnisches Institut'
1825	Karlsruhe	Baden	*Polytechnische Schule*
1826/7	Berlin	Prussia	*Gewerbe-Institut* (r) (was *Technische Schule*)
1827	Munich	Bavaria	*Polytechnische Central-Schule*
1827	Graz	Austria	*Joanneum* (r)
1828	Dresden	Saxony	*Technische Bildungsanstalt*
1828	Luzern	Switzerland	*Polytechnische Lehranstalt* (ca. 1830?)
1829	Munich	Bavaria	*Polytechnische Central-Schule* (r)
1829	Nuremberg	Bavaria	*Polytechnische Schule* (r)
1829	Leipzig	Saxony	*Polytechnische Schule*
1829	Stuttgart	Württemberg	*Vereinigte Real- und Gewerbeschule*
1829?	?	Mecklenburg	'Polytechnisches Institut' (ca. 1830?)

Note: Names of schools that have actually been founded are in italic. In the other cases the attemps to found a school failed. An (r) behind the name of a school means that the school was reorganized in that year and/or that the name of the schools was changed. If a school closed down before 1860, the name of the school is followed by the year of closure between brackets.

In the first period, between 1803 and 1830, diversity within the group of polytechnic schools was very large. There were great differences between, for instance, the Vienna polytechnic institute, the Bavarian *Real-Institute*, the *Technische Schule* of

Mitteilungen, Gesellschaft Deutscher Chemiker / Fachgruppe Geschichte der Chemie (Frankfurt/Main), Bd 13 (1997) ISSN 0934-8506

Berlin, and the polytechnic school of Dingler in Augsburg. All the schools in table 1, however, were considered by contemporaries to be polytechnic schools of some kind. They exercised a mutual influence over each other, and it is necessary to pay attention to all of them to understand the character of the German polytechnic schools during the first three decades of the nineteenth century. During those years the polytechnic concept was a rather wide and vague notion, merely consisting of the entire set of mathematical, natural science and technical subjects, or disciplines. The distinguishing mark of the polytechnic school system of that period was the central place given to these disciplines in the school curricula.[9]

Table 2: *Characteristics of four types of polytechnic schools, 1803-1829*[10]

school type	general education		vocational training		examples
	full-time eng./man.	part-time manuf.	engin.	manuf.	
Real-Institute	x				Augsburg (1808) Freiburg (1818)
Bavarian-type		x			Augsburg (1822) München (1827)
Prussian-type				x	Berlin (1821)
Vienna-type	x	(x)	x	x	Vienna (1815) Prague (1817) Karlsruhe (1825)

Note: eng./engin. = (state) engineers; man./ manuf. = artisans and manufacturers.

With respect to the early years, one can distinguish between four types, or models, of polytechnic schools (table 2). Some of the polytechnic schools were for the education of future manufacturers and artisans only, while others also had courses for the future members of the technical state services, for instance in the fields of mining, forestry and civil engineering. It is important to note that in those years, with the possible exceptions of the civil engineers, none of the polytechnic schools had curricula for the so-called technical professions (e.g. mechanical enigineers and technical chemists). Those professions did not exist at that time. A second difference between the schools was, that some schools offered full-time education, while others

Mitteilungen, Gesellschaft Deutscher Chemiker / Fachgruppe Geschichte der Chemie (Frankfurt/Main), Bd 13 (1997) ISSN 0934-8506

only organized Sunday and evening classes. A third difference is connected to the aims of the schools and their place in the entire educational and vocational training sytem. At some schools, artisans or engineers could get a proper vocational training, both theoretical and practical, while other schools concentrated on the teaching of general mathematical, physical, chemical and technical knowledge to lay a foundation for subsequent vocational training at another school or university, or as an apprentice. A fourth difference, which is not apparent from the table, has to do with school regulations. Some schools like the Bavarian *Real-Institute* and the Berlin *Gewerbeinstitut* had a class system in which all subjects were obligatory (so called *Jahresklassen*). At other schools, such as the one in Vienna, there was a much larger freedom of choice.[11]

On the basis of the table one can briefly sketch the main elements of the history of the concept 'polytechnic school' in Germany. After the educational reforms of the early 1830s, the first two (South-German) types of schools were no longer considered to belong to the category polytechnic - or by then 'higher technical' - school. So only the Prussian and Vienna types were left, both offering full-time education. Between 1850 and 1870 the polytechnic schools were reorganized once again. The outcome was a mix, or compromise, between the artisanal, highly disciplined Prussian system and the more flexible and more academic Austrian system.

Chemistry teaching

Chemistry was, along with technical drawing, mathematics and mechanical technology, one of the central subjects of early polytechnic school teaching. As stated before, the aim of giving lessons in chemistry was not to train future chemists, but to improve the chemical knowledge of future manufacturers, artisans or engineers. As at the universities, most of the teaching was given in the form of oral lectures accompanied by demonstrations. The time devoted to chemistry lessons varied from about two hours per week for a period of two years (or four for one year) in Berlin and Augsburg, to five (or more) hours a week for two years in Vienna and Prague (after 1817), and Munich (after 1829).[12] The chemistry course was mainly general chemistry, with a particular emphasis on technical subjects. To do justice to the technical orientation of the teaching, special textbooks were written, such as those by Neumann (1810), Prechtl (1813-15), Scholz (1824-25), Erdmann (1828), and Schubarth (1830-31), or translations appeared, like Engelhardt's version of Dumas' textbook on chemistry applied to the arts and manufactures.[13]

In addition to these lectures, most of the polytechnic schools held special practical courses in the laboratory. At the German polytechnic schools practical chemistry lessons were the rule rather than the exception, in a period when many universities had not (yet) adopted this teaching method. This should not be considered a first

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sign that professional chemists were going to be educated by these institutes, but one should understand this teaching practice primarily from the perspective of Enlightenment pedagogical thought. Practical training held a central place in the didactics of the eighteenth-century philanthropists that influenced early German polytechnic education.[14] So, at the polytechnic schools of Vienna, Karlruhe, Berlin, Stuttgart, Hanover and Dresden laboratory exercises were given from an early date. These exercises were not always obligatory for the students following the chemistry course. The founder of the Vienna polytechnic school, Johann Joseph Prechtl, considered laboratory training an essential part in the teaching of chemistry, but in practice the professors (Scholz and Meissner) did not permit all students to use their laboratories.[15] The character of the laboratory training differed considerably from the type of analytical chemical training offered during the late 1830s by Liebig in Giessen and Rose in Berlin. Like the exercises organized by Fourcroy during the first years of the *École Polytechnique*, one of the aims of the laboratory training was to repeat and reinforce the chemical training that was offered during the lecture course. In that sense it was merely a didactic aid.[16] In addition to that, there was the aim of a vocational training for occupations like that of the brewer, the dyer, the textile printer or the soap boiler. Thus, in the laboratories of the larger polytechnic schools, operations could be learned which were in used in practice. For instance, when the American chemist J.C. Booth visited the laboratories of the Vienna polytechnic school in 1834, he noted:[17]

> Visited the laboratory and was pleased to find the ideas I had conceived carried into effect. Here was 10 or 12 ovens on a large scale for performing operations, precisely as carried on in the large way - viz. a distillery, sugar-refinery & c. in which the students are exercised and thus made acquinted with theory and practice.

It was exactly this practice which was later severely criticised by Justus Liebig when he wrote that '*nichts nachtheiliger und schädlicher (ist), als wenn (man versucht) Seifensieder, Branntweinbrenner oder Schwefelsäure-Fabrikanten aus Kindern zu bilden*'.[18]

A central role in this early phase of German polytechnic chemical education was played by the director of the Vienna institute, Johann Joseph Prechtl. Between 1810 and 1815 Prechtl developed a novel scheme for chemistry teaching intended for the new Vienna polytechnic institute. This scheme gives us a clear insight into the thinking of that time and of the dilemmas that the early polytechnic school system faced.[19] Prechtl wanted to make his institute useful to Austrian economic development in its broadest sense and, like a true Enlightenment educationalist, he wanted to disseminate scientific knowledge to all classes of society. So, his institute had to be accessible for students of all categories: artisans, manufacturers, engineers, factory owners, landlords etc.. These students had very different educational back-

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grounds. To resolve this problem, Prechtl developed a scheme of two chemistry courses that could, in principle, be followed independently: a course of so-called *allgemeine technische Chemie*, which was in fact a course on general chemistry with special emphasis on the technical aspects, and a course on *spezielle technische Chemie*, in which special trades like dyeing and brewing were studied extensively. In Prechtl's utopia, on the one hand, students from good families, like some manufacturers, engineers and landlords, who had a good secondary education, could start with a study of the scientific principles in the course on *allgemeine technische Chemie*, and then study the applications in their second year, by following the course *spezielle technische Chemie*. On the other hand, artisans started immediately with the less abstract course on *spezielle technische Chemie*, in the hope that this would motivated them to strive for a deeper scientific understanding, and that they would therefore follow the course on *allgemeine technische Chemie* afterwards.

On this scheme Prechtl came into a protracted conflict with the professor of *spezielle technische Chemie*, Paul Traugott Meissner, who refused to implement Prechtl's ideas.[20] Meissner was strongly in favour of a hierarchy between general and technical chemistry, and he put a lot of general chemistry into his course. Nevertheless, Prechtl's division of the chemistry teaching into two different courses exercised quite some influence on polytechnic education elsewhere in Germany. It was copied for example at the schools in Karlsruhe, Munich and Hanover.

Some information is available on the student numbers in Vienna. Table 3 shows the numbers of students that followed the chemistry courses before 1830. Almost every year more than 70 students attended the lecture course on *allgemeine technische Chemie*. The number of students who seriously studied this subject and passed the examination was much smaller: around 25. Approximately the same number of students attended the course on *spezielle technische Chemie*. Of these a much higher percentage took part in one of the four different examinations that were held every year. In accordance with its orientation to discrete 'chemical trades', there was no general examination on *spezielle technische Chemie*, but four separate examinations on 'fermentation chemistry' (*Gährungschemie*), tanning (*Gerberei*), soap boiling (*Seifensiederei*), and dyeing (*Färberei*) respectively. This state of affairs underlines, more than anything else, the fact that Prechtl and his school did not intend to educate allround technical chemists. However, it is worth noting that there was a very small group of students who went beyond the minimal requirements laid down in the curriculum by doing all four the examinations in (special) technical chemistry (table 3, column 12). There we see the technical chemist '*in statu nascendi*'.

Mitteilungen, Gesellschaft Deutscher Chemiker / Fachgruppe Geschichte der Chemie (Frankfurt/Main), Bd 13 (1997) ISSN 0934-8506

Table 3: *Students at the Vienna Polytechnic Institute, esp. in chemistry, 1818-1830.*[21]

year	all direct.	technical departm.	general chem. lect.	general chem. exam.	special technical chemistry lect.	special technical chemistry exam.					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1818	403	105	42	16	16						
1819	515	195	83	17	22	21	13	5	11	10	3
1820	574	243	69	17	31	14	8	5	5	5	1
1821	692	346	101	38	26	19	7	2	7	5	0
1822	760	404	110	41	33	21	10	7	12	8	4
1823	780	430	143	41	31	18	11	5	9	6	3
1824	752	413	97	29	27	11	6	4	4	7	3
1825	761	422	98	27	23	16	10	6	11	14	6
1826	727	392	77	27	26	17	8	3	8	7	3
1827	741	393	73	22	21	17	10	7	10	12	6
1828	717	390	75	23	21	17	12	4	7	8	4
1829	747	395	74	17	25	15	8	2	6	5	2
1830	727	385	70	21	24	13	9	4	6	11	3

Note: The numbers in the columns 2 and 3 refer to regular (*immatrikulierte*) students only. The numbers in the columns 4 and 6 give the numbers of the students that followed the chemistry lectures (*Frequenz*). They include both regular and irregular students. Columns 5 and 7-12 give the numbers of the students that passed one or more of the examinations in chemistry. There were four different examinations in 'special technical chemistry': on the fermentation industries (beer brewing, wine, distilleries) (column 8), on tanning (column 9), on soap boiling (column 10), and on dyeing and textile printing (column 11). Column 7 presents the numbers of the students who passed an examination in one subject only. Column 12 gives the numbers of the students who passed all four examinations.

The reforms of the 1830s

After 1830 polytechnic education changed dramatically. Partly as a result of the political changes in the wake of the July Revolution of 1830, several German states reorganized their educational system. The *Wirtschaftsbürger* became a more and more influential class of society, and, in addition, their educational needs had to be fullfilled. New institutions were founded, like *Real-* and *Gewerbe-Schulen*, neatly separated from the schools for the *Bildungsbürger*. Then the struggle between the *Gymnasia* and the *Realschulen* really began.[22]

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The most important development in the technical or polytechnical school system was the introduction of a hierarchy between the lower and higher technical schools. A new type of school, aptly called the *'Höhere' Gewerbeschule* came into being, and schools of that type were founded in some lesser German states, such as Hanover (1830), Hessen-Kassel (1831) and Hessen-Darmstadt (1836). Reorganizations of most of the older polytechnic schools - Berlin (1829/32), Prague (1829/33), Karlsruhe (1832), Stuttgart (1832/38), Augsburg, Nuremberg and Munich (1833), Brunswick (1835), and Dresden (1835/38) - also contributed to the differentiation between lower and higher technical schools.[23]

Polytechnic education proper was henceforward separated from artisanal training. The teaching system which combined *populärwissenschaftliche* and *streng wissenschaftliche* elements, that had been so eloquently defended by Prechtl, was to end. According to influencial and prominent defenders of the new educational policy, such as Friedrich B.W. Hermann, Joseph von Utzschneider, Alexander von Humboldt, Eilhardt Mitscherlich, Karl Friedrich Nebenius and August Uhde the teaching at the reformed polytechnic schools should be *streng wissenschaftlich* only.[24] Viewed from a social perspective, this bifurcation of the educational system signalled the rise of the new class of professional technicians, like industrial chemists and mechanical engineers, separated from the lower grade technicians like artisans. In France the rise of this new class was for first time clearly proclaimed by August Comte and his compatriots of the Saint-Simonist school in the late 1820s. However, in Germany the emergence of this new group had barely begun by 1830. Despite that, these French ideas were assimilated by some educational reformers, with Alexander von Humboldt acting as an intermediary between France and Prussia, and the school reforms in their turn contributed to the rise of the new class.[25]

These reforms were not without their consequences for the teaching of chemistry at the polytechnic schools. However, in the short term no spectacular changes in the chemistry curriculum were visible. The raising of the scientific standards of chemistry teaching was a gradual process, which partly depended on the influx of new groups of students with an improved secondary school background in the natural sciences - a result of reforms of the secondary school system that parallelled the polytechnic reforms. The elimination of the artisanal courses from the chemistry curriculum was also a gradual process. Though some of the polytechnic schools made the transition between 1840 and 1850, the general change over was not complete before the 1860s.[26] An important influence on changes in the actual teaching practice was exercised by the chemistry teachers at the polytechnic schools. After 1830 a second generation of professors was appointed, who had studied in the 1820s and after. They had a much more thorough practical laboratory training, especially in analytical chemistry, compared to the chemistry professors of the first generation. Many of them had studied at the new polytechnic schools or at the

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philosophical faculties (table 4), where they had benefitted from opportunities to work in the laboratory. During the 1820s, as a result of reforms in pharmaceutical and medical education, most of the German universities introduced practical training courses in analytical chemistry.[27] While the first generation of teachers was technological in orientation and well integrated in local patriotic and technological societies (such as the *Polytechnische Verein im Königreich Bayern*, the *Gewerb-Verein im Königreiche Hannover* and the *Verein zur Beförderung des Gewerbfleißes in Preußen*), members of the second generation identified themselves much more with an international chemical community. Well known examples of chemists of this second generation were such figures as Anton Schrötter, Friedrich Wöhler, Robert Wilhelm Bunsen, and Karl Weltzien.

Table 4: *The educational background of the chemistry professors at the German polytechnic schools: a comparison between the first and the second generation*[28]

Education	**Professors appointed before 1830**(1)	**Professors appointed 1830-1851**(1)
Total number	22	34
Pharmaceutical	9 (41%)	12 (35%)
Medical	9 (41%)	12 (35%)
Scientific/technical(2)	8 (36%)	26 (76%)

Note: (1) = The sum of the percentages exceeds 100, because several chemists had (during the second period especially) more than one type of training. The few professors whose educational backgrounds are unkown have not been taken into consideration; (2) = i.e. educated at a 'philosophical faculty', a cameralist institute, or a polytechnical school.

The emergence of teaching programmes for industrial chemists

Under the influence of this new generation of chemistry professors, in combination with several important 'external' factors a fundamental change in the orientation and aims of polytechnic chemical education took place between 1830 and the 1850s. Chemical education was transformed from a training programme for specific occupations, such as brewing and soap boiling, into a system that produced industrial chemists.[29] The clearest signs of this change at the polytechnic schools are the formulation of well-defined curricula (*Studienpläne*) for future technical chemists and the creation of chemistry departments (*chemische Fachschulen*). At the universities a parallel, though somewhat less visible, development took place in the form of the creation of special practical courses for so-called 'advanced students'.[30] To a large extent, by these fundamental changes in polytechnic and university chemical education the profession of the chemist was created.

The reasons why at the individual polytechnic schools specific courses for technical chemists were created were diverse, and strongly dependend on the local context. There is not one set of causes that applies to every individual school. Nevertheless, a number of reasons can be mentioned that were prominent in several of the individual cases.[31]

In the first place, there were the consequences of the reorganizations of the technical school system in the 1830s, mentioned above. The separation of the training of artisans from that the manufacturers and the 'higher technician', together with the introduction of higher scientific standards to the polytechnic schools, set the stage on which disciplinary-oriented (e.g. chemical) courses for highly specialized individuals could develop. This was a general factor, which influenced the historical development of nearly all the polytechnic schools.

Secondly, as stated, the appointment of a new generation of chemistry teachers to the schools, with a new set of (disciplinary) norms and values, exercised an influence. Naturally, this influence was not equally felt at all the schools, because it depended on the educational background and personality of the new professor, and, significantly, on the moment at which a chemist from the second generation took the place of a previous professor. So, when Fehling succeeded Degen in Stuttgart in 1839 this made an important difference to the way chemistry was taught at the school, and this applied even more so when Schrötter succeeded Meissner in Vienna in 1845, and when Weltzien succeeded Walchner in Karlsruhe in 1850. It was this non-synchronous alternation of generations which partly determined the timing of institutional changes at the German polytechnic schools. In many cases, however, it was not so much the personal activity of the new professor that produced the institutional changes, but the (previous) strong determination of the school directors to appoint a chemistry professor that could meet the latest standards of the science of his time.[32]

A third cause of institutional change was the need to introduce courses in analytical chemistry; a need that came both from the metallurgical and (heavy) chemical industries, and from the recent scientific orientation of the polytechnic schools. After the polytechnic schools had raised their scientific aspirations in the 1830s, and by doing so had entered into competition with the universities, they had to face the fact that analytical chemistry, including the analysis of organic compounds, so superbly practiced and advertised by Justus Liebig, played an ever growing role in the chemistry teaching at the universities. However, in the traditional technology-oriented chemistry teaching of the polytechnic schools, courses of analytical

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(Frankfurt/Main), Bd 13 (1997) ISSN 0934-8506

chemistry were a *Fremdkörper*, and the introduction of such courses often had far-reaching consequences for the structure of the total chemistry-related curriculum. For example, the creation of a special curriculum for chemists (*Analytiker*) at the Vienna polytechnic school was a consequence of the introduction of a course on analytical chemistry by Anton Schrötter in 1845/46.[33]

Table 5: *The emergence of specific curricula for (technical) chemists at the German polytechnical schools*[34]

Polytechnical school	Start of chemical curriculum and/or new laboratory	Appointment of a second chemistry professor	Start chemistry department
Vienna	1845/52(1)	1856(2)	1865
Dresden	1846/51	1850(3)	1865
Karlsruhe	1847	1851	1847
Prague	1850	1864	1863
Berlin	1850	1850	1860
Hanover	1853/4(4)	1858	1880
Stuttgart	1854	1862	1862
Zurich	1855	1855	1855
Brunswick	1855	1862	1862
Darmstadt	1859?(5)	1863?	1868
Munich	1868	1868	1868

Note: The schools are mentioned in the chronological order of the start of special curricula for the chemical professions and/or the inauguration of a new analytical-chemical laboratory (colomn 2). Other relevant indicators are the appointment of a second professor of chemistry (column 3), and the creation of separate, independent chemistry departments (*chemisch-technische Fachschulen*). (1) in 1845 a special course for analytical chemists was created, in 1852 liberal study (*Lernfreiheit*) was abandened; (2) Also from 1816 to 1845 there were two chemistry chairs in Vienna; (3) One chemistry professor also taught physics; (4) A new technical-chemical course started 1853, a new analytical chemical laboratory opened 1854; (5) The *Höhere Gewerbeschule* at Darmstadt had a good chemical laboratory since 1845, but no specialised training of chemists seems to have taken place. In 1859 a semi-department (*Fachabteilung*) of technical chemistry was created

Lastly, a fourth reason for the creation of special curricula for technical chemists was formed by developments within civil and mechanical engineering, resulting in the creation of specialized curricula or departments (*Fachschulen*) in these branches. In historical studies of professionalization the causation implied by this type of

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mechanism is often overlooked, as a result of a too narrow focussing on the developments taking place in the discipline, or profession, studied. Within the framework of schools, however, different disciplines are mutually dependent, and because of this 'institutional coupling' within the schools, the creation of *Fachschulen* in other disciplines could influence the founding of a chemical department. For polytechnic chemistry teaching, this fourth factor was in many cases of great importance. Examples are the polytechnic schools in Karlsruhe, Dresden, Stuttgart, and Brunswick, where the creation of separate chemistry departments must be understood primarely as being a mere 'by-product' of the creation of a separate department of mechanical engineering. In all these cases the traditional 'industrial department' (*höhere Gewerbeschule*) of these schools was split into a *mechanisch-technische Schule* and a *chemisch-technische Schule*.[35]

For the reasons mentioned, between 1845 and 1868 all polytechnic schools started special courses for industrial chemists (table 5). Vienna took the lead, Dresden and Karlsruhe followed soon, and after 1850 the other schools started such courses as well. At some universities special courses for chemists were created at about the same time. However, because of the *Lehr- und Lernfreiheit* at the universities this change in the university curriculum was less visible compared to that at the polytechnic schools. Some universities (Giessen, Göttingen, Munich and Leipzig) created advanced laboratory courses earlier than the polytechnics did, but the time lag was very small, and, in general, the polytechnic schools were in advance of the majority of German universities with respect to the institutionalisation of the education of professional chemists.[36]

Conclusion

It certainly cannot be denied that the university developments in the field of chemistry exercised an influence on both polytechnic education and on the professionalization in the field of chemistry. Nevertheless, the (three-stage) institutional history of German polytechnic education clearly shows that some additional mechanisms were at work that had an impact on the formation of the chemical profession. In particular I would like to emphasize (1) the 'institutional coupling' between the technical disciplines at school level, which (partly) explains why several technical professions emerged at the same time, and (2) the political and social influences on the educational system in the 1830s, that deepened the gap between the artisans and the *höhere Techniker* in German society, and by doing so created the circumstances under which chemistry could development into a distinct profession.

Both 'mechanisms' are of a very general nature, but despite this they were crucial for both the rise and the special character of the chemical profession in Germany. The second factor especially, helps to explain why German chemists had a status and

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social position that differed considerably from their British (and to a lesser extent French) counterparts.[37] This improved insight in the social configuration in which the pursuit of chemistry developed into an occupation in Germany, has also consequences for the social history of German chemistry itself. The efforts of an influential figure like Justus Liebig can thus be understood in the context of the development of German secondary and higher education. By doing so, it becomes clear that had Liebig not been born, the professional chemist would nevertheless have emerged in Germany.

* Paper presented to the Meeting of the Fachgruppe Geschichte der Chemie of the GDCh in Jena, 18-20 March 1993. I thank James Small and Tony Travis for their comments on an earlier version.

1 Karl-Heinz Manegold, *Universität, Technische Hochschule und Industrie. Ein Beitrag zur Emanzipation der Technik im 19. Jahrhundert unter besonderer Berücksichtigung der Bestrebungen Felix Kleins*, Schriften zur Wirtschafts- und Sozialgeschichte, Bd. 16 (Berlin 1970); Lothar Burchardt, 'Die Ausbildung des Chemikers im Kaiserreich', *Zeitschrift für Unternehmensgeschichte* 23 (1978), 31-53; idem, 'Professionalisierung oder Berufskonstruktion? Das Beispiel des Chemikers im Wilhelminischen Deutschland', *Geschichte und Gesellschaft* 6 (1980), 326-348; Georg Meyer-Thurow, 'Zum unprofessionellen Umgang mit Professionalisierungsprozessen. Anmerkungen zu Lothar Burchardts Beitrag über die Chemiker im deutschen Kaiserreich', *Geschichte und Gesellschaft* 6 (1980), 586-597; Jeffrey A. Johnson, 'Academic, Proletarian, ... Professional? Shaping Professionalization for German Industrial Chemists, 1887-1920', in: Geoffrey Cocks and Konrad H. Jarausch (eds.), *German Professions, 1800-1950* (Oxford 1990), 123-142; Hartmut Scholz, 'Zu einigen Wechselbeziehungen zwischen chemischer Wissenschaft, chemischer industrie und staatlicher Administration, sowie deren Auswirkungen auf die Entwicklung der wissenschaftlichen Chemie in Deutschland in der Zeit des Übergangs zum Monopolkapitalismus', Dissertation B, Humboldt-Universität (Berlin 1989).

2 Franz Schnabel, 'Die Anfänge des technischen Hochschulwesens', in: *Festschrift anlässlich des 100jährigen Bestehens der Technische Hochschule Fridericiana zu Karlsruhe* (Karlsruhe 1925), 1-44; Manegold, *Universität, Technische Hochschule und Industrie*.

3 For a more detailled discussion, see Ernst Homburg, *Van beroep 'Chemiker'. De opkomst van de industriële chemicus en het polytechnische onderwijs in Duitsland (1790-1850)* (Delft 1993), esp. 100-113, 118-130, 153-157.

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4 Homburg, *Van beroep 'Chemiker'*, 223-251.

5 The polytechnical institute of Prague officially opened in 1806, the date most often mentioned in the literature as the start of German polytechnic education, but the school operated unofficially from 1803 onwards, the year when the first professors were appointed.

6 Cf. Gert Schubring, *Die Entstehung des Mathematiklehrerberufs im 19. Jahrhundert. Studien und Materialien zum Prozeß der Professionalisierung in Preußen (1810-1870)* (Weinheim/Basel 1983), esp. 37-46, 66-70, 85-100.

7 Cf. Johannes H. Voigt, 'Lehre zwischen Politik und Wirtschaft 1829-1864. Von der Real- und Gewerbeschule zur Polytechnischen Schule', in: J.H. Voigt (ed.), *Festschrift zum 150jährigen Bestehen der Universität Stuttgart. Beiträge zur Geschichte der Universität*, Die Universität Suttgart, Bd. 2 (Stuttgart 1979), 13-138, esp. 13-32; A. Lipsmeier, 'Technik, allgemeine Pädagogik und Berufspädagogik im 19 Jahrhundert. Ein Beitrag zur Geschichte der vergleichende Berufspädagogik', *Technikgeschichte* 36 (1969), 133-146, esp. 139-144.

8 The table is based on a great number of sources, such as commemorative publications on these schools, official school histories and several more general works on the German polytechnic school system. For a complete overview of all sources used, see Homburg, *Van beroep 'Chemiker'*, 398-423. The most important general works consulted, are: Friedrich Schödler, *Die höheren technischen Schulen nach ihrer Idee und Bedeutung dargestellt und erläutert durch die Beschreibung der höheren technischen Lehranstalten zu Augsburg, Braunschweig, Carlsruhe, Cassel, Darmstadt, Dresden, München, Prag, Stuttgart und Wien* (Braunschweig 1847); Carl Kořistka, *Der höhere polytechnische Unterricht in Deutschland, in die Schweiz, in Frankreich, Belgien und England. Ein Bericht an den h. Landesausschuss des Königreichs Böhmen* (Gotha 1863); Wilhelm Lexis (ed.), *Die Technischen Hochschulen im Deutschen Reich*, Das Unterrichtswesen im Deutschen Reich, Bd. IV.2 (Berlin 1904); *Die deutschen technischen Hochschulen. Ihre Gründung und geschichtliche Entwicklung* (München 1941); Wilhelm Treue, 'Die Geschichte des technischen Unterrichts' in: *Festschrift zur 125-Jahrfeier der Technischen Hochschule Hannover. 1831-1956* (Hannover 1956), 9-60; G. Grüner, *Die Entwicklung der höheren technischen Fachschulen im deutschen Sprachgebiet. Ein Beitrag zur historischen und zur angewandten Berufspädagogik* (Braunschweig 1967), esp. 13, 15-23, 25, 29-31, 36, 96-98, 112, 123, 196; Helmuth Albrecht, *Technische Bildung zwischen Wissenschaft und Praxis. Die Technische Hochschule Braunschweig 1862-1914* (Hildesheim 1987), esp. 48-56, 66-70, 85, 104-106, 238-239, 283.

9 Schödler, *Die höheren technischen Schulen*, 119-120; A. Lipsmeier, 'Die Auseinandersetzungen über 'gymnasiale' und 'reale' oder 'technische' Bildung. Aufgezeigt an der Vorgeschichte und Ausformung der Darmstädter Real- oder technische Schule (1826) zur Höheren Gewerbeschule (1836) und zur Technischen Hochschule (1872/73)', *Die deutsche Berufs- und Fachschule* 62 (1966), 918-932, esp. 921-922; Ulrich Troitzsch, 'Zur Entwicklung der (poly-)technischen Zeitschriften in Deutschland zwischen 1820 und

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1850' in: Karl-Heinz Manegold (ed.), *Wissenschaft. Wirtschaft und Technik* (München 1969). 331-339. esp. 333; Karl-Heinz Manegold. 'Technik. Staat und Wirtschaft. Zur Vorgeschichte und Geschichte der Technischen Hochschule Hannover im 19. Jahrhundert'. in: R. Seidel et. al. (ed.), *Festschrift zum 150jährigen Bestehen der Universität Hannover. Teil 1: Universität Hannover 1831-1981* (Stuttgart 1981). 35-73. esp. 40-41.

10 Homburg, *Van beroep 'Chemiker'*, 198.

11 Often, for instance by Manegold, this freedom of choice has been misinterpreted as the result of Humboldtian ideas on *Lernfreiheit*, but the actual reasons were the percentage of adults at the schools, and, especially, the eighteenth century pedagogical idea that the student should only follow those courses which had a direct relevance suited to his future occupation. Compare Manegold, *Universität, Technische Hochschule und Industrie*, 39; with Schubring, *Entstehung des Mathematiklehrerberufs*, 86; Christian Hantschk, *Johann Joseph Prechtl und das Wiener Polytechnische Institut*, Perspektiven der Wissenschaftsgeschichte, Bd. 3 (Vienna 1988), 110-111, 113-114, 122-123; and Voigt, 'Lehre', 32, 41, 54-55, 126.

12 Homburg, *Van beroep 'Chemiker'*, 211.

13 Karl A. Naumann, *Lehrbuch der Chemie mit besonderer Hinsich auf Technologie. Zum Selbstbelehrung gebildete Gewerbtreibende*, vol. 1 (Leipzig/ Prague 1810); Johann Joseph Prechtl, *Grundlehren der Chemie in technischer Beziehung. Für Kammeralisten, Oekonomen, Techniker und Fabrikanten*, 2 vols. (Vienna 1813-1815); Benjamin Scholz, *Lehrbuch der Chemie*, 2 vols. (Vienna 1824-1825); Otto Linné Erdmann, *Populäre Darstellung der neueren Chemie mit Berücksichtigung ihrer technischen Anwendungen* (Leipzig 1828); Ernst Ludwig Schubarth, *Handbuch der technischen Chemie. Zum Gebrauch beim Unterricht im Königl. Gewerbinstitut und den Provinzial-Gewerbschulen des preuss. Staats*, 2 vols. in 3 parts (Berlin 1830-1831); Jean-Baptiste Dumas, *Handbuch der angewandten Chemie. Für technische Chemiker, Künstler, Fabrikanten und Gewerbetreibende überhaupt*, 8 vols. (Nuremberg 1830-1847).

14 On the pedagogical ideas of the philanthropists, see W. Schöler, *Geschichte des naturwissenschaftlichen Unterrichts im 17. bis 19. Jahrhundert. Erziehungstheoretische Grundlegung und schulgeschichtliche Entwicklung* (Berlin 1970); James Bowen, *A History of Western Education. Volume Three: The Modern West. Europe and the New World* (London 1981), 197-201, 218-232.

15 H. Gollob, 'Zur Frühgeschichte der Technische Hochschule in Wien' in: H. Sequenz (ed.), *150 Jahre Technische Hochschule in Wien, 1815-1965*, vol. I (Vienna 1965), 159-200, esp. 183; Paul Traugott Meissner, *Justus Liebig, Dr. der Medizin und Philosophie, ... analysiert* (Frankfurt a/M 1844), 29-34.

16 On Fourcroy's didactic ideas, see J. Langins, 'The decline of chemistry at the Ecole Polytechnique (1794-1805)', *Ambix* 28 (1981), 1-19.

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17 Quoted from W.D. Miles, 'With James Curtis Booth in Europe, 1834', *Chymia* 11 (1966), 139-149 (quotation on page 141).

18 Justus Liebig, 'Der Zustand der Chemie in Preussen', *Annalen der Chemie und Pharmacie* 34 (1840), 97-136, esp. 128-129.

19 For Prechtl's pedagogical ideas, see Hantschk, *Johann Joseph Prechtl*, 46-61, 101-115, 152-193. For his ideas on chemistry teaching, see Prechtl, *Grundlehren der Chemie*, vol. I and II, Hantschk, *op. cit.*, 62-65, 70-71, 107-109, 276-277, 291-295; and Homburg, *Van beroep 'Chemiker'*, 171-175. Hantschk's interpretation is sometimes misleading, however, probably because of insufficient knowledge of the textbooks of Prechtl's contemporaries Chaptal and Hermbstaedt, which influenced his ideas.

20 On this conflict, see Hantschk, *Johann Joseph Prechtl*, 293, 320-343; Homburg, *Van beroep 'Chemiker'*, 175-182. See also: Paul Traugott Meissner, *Anfangsgründe des chemischen Theiles der Naturwissenschaft. Zum Selbstunterricht und zur Grundlage seiner ordentlichen und ausserordentlichen Vorlesungen* (= *Handbuch der allgemeinen und technischen Chemie*), 8 vols. (Vienna 1819-1833), esp. vol. I, 'Vorbericht'. To my view Hantschk's account of this conflict is too biased, in favour of Prechtl, and too uncertain in chemical matters.

21 J.J. Pohl, 'Beitrag zur Statistik des Studiums der Chemie am k.k. polytechnischen Institute zu Wien', *Sitzungsberichte der Oesterreichischen Akademie der Wissenschaften (mathematisch-naturwissenschaftliche Classe)*, 6 (1851), 361-370; Hantschk, *Johann Joseph Prechtl*, 476. With respect to the attendance of the lectures in 'special technical chemistry', Hantschk (p. 332) gives higher numbers for 1819 and 1823 (34 and 40 resp.) than the ones in the table, which I took from Pohl.

22 Cf. Schöler, *Geschichte des naturwissenschaftlichen Unterrichts*; Schubring, *Entstehung des Mathematiklehrerberufs*; Peter Lundgreen, *Sozialgeschichte der deutschen Schule im Überblick. Teil I: 1770-1918* (Göttingen 1980); Hubert Buchinger, *Die Geschichte der bayerischen Realschule. Erster Teil: Die Entwicklung der bayerischen Realschule von ihren Anfängen bis zur Errichtung der Oberrealschule im Jahre 1907* (Passau 1983), esp. 108-132.

23 Homburg, *Van beroep 'Chemiker'*, 223-251.

24 Friedrich B.W. Hermann, *Über Polytechnische Institute* (Nürnberg 1826); Carl Friedrich Nebenius, *Über technische Lehranstalten in ihrem Zusammenhange mit dem gesamten Unterrichtswesen und mit besonderer Rücksicht auf die Polytechnische Schule in Karlsruhe* (Karlsruhe 1833); August Uhde, *Die höhere technische Lehr-Anstalt oder die technische Abtheilung des herzoglichen Collegii Carolini zu Braunschweig nach Zweck, Plan und Einrichtung* (Braunscheig 1836), quoted by Wolfgang Schneider, 'Aus 200 Jahre Braunschweiger Hochschulgeschichte', in: W. Schneider (ed.), *Die Technische Hochschule in Braunschweig* (Berlin/ Basel 1963), 7-61, on pp. 22-23; W. Riedner, 'Technische Hochschule München' in: *deutschen technischen Hochschulen*, 223-242; Gert Schubring, 'Mathematics and teacher training: Plans for a polytechnic in

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Berlin', *Historical Studies in the Physical Sciences* 12 (1981), 161-194.

25 Liebig pupil Friedrich Schödler, for example, gave in his *Die höheren technischen Schule* of 1847 an extensive social legitimation of the new hierarchical structure of technical education (on pp. 1-8). Instead of the usual early-nineteenth century distinction between state technicians and private-business technicians, he strongly emphasized the differences between scholars (*Gelehrte*) and technicians (*Techniker*), and between 'higher technicians' (*höhere Techniker*) and artisans (*Handwerker*). For the French developments, see J.H. Weiss, *The Making of Practical Man: The Social Origins of French Engineering Education* (Cambridge (Mass.) 1982), esp. 52, 89-96; and Schubring, 'Mathematics and teacher training', 173-176 for the role of Von Humboldt.

26 There are only one or two studies specially devoted to the chemistry teaching at the polytechnic schools before 1850: J. Goubeau, 'Die Anfänge der Chemie', in: Voigt (ed.), *Festschrift ... Universität Stuttgart*, 223-240; see also W. Ruske, 'Zur Geschichte der technischen Chemie in Berlin', in: R. Rürup (ed.), *Wissenschaft und Gesellschaft. Beiträge zur Geschichte der Technischen Universität Berlin 1879-1979*, vol. II (Berlin 1979), 153-176. I used a great many general histories of the polytechnic schools for my analysis. See Homburg, *Van beroep 'Chemiker'*, 292-302, 328-339.

27 Homburg, *Van beroep 'Chemiker'*, 263-273. I benefitted greatly from the numerous publications by Arnim Wankmüller on the education of German pharmacists, published in the *Deutsche Apotheker-Zeitung* between 1961 and 1982, and in the *Beiträge zur württembergischen Apothekergeschichte*.

28 Based on a prosopographical study of the chemistry professors at the polytechnic schools. See Homburg, *Van beroep 'Chemiker'*, 276, 424-431.

29 The German expression is '*technische Chemiker*'. I use the expressions industrial chemist and technical chemist as synonyms.

30 For instance, in Giessen between 1839 and 1842, in Munich in 1840, in Göttingen between 1840 and 1842, and in Leipzig between 1842 and 1844. Homburg, *Van beroep 'Chemiker'*, 291.

31 For a full discussion, see Homburg, *Van beroep 'Chemiker', 302-339.*

32 Voigt, 'Lehre', 58, 62-63; Goubeau, 'Anfänge der Chemie', 226-240; Schödler, *Die höheren technischen Schulen*, 85, 88, 94, 107; Pohl, 'Beitrag zur Statistik'; Gollob, 'Frühgeschichte', 195-198; Peter Borscheid, *Naturwissenschaft, Staat und Industrie in Baden (1848-1914)*, Industrielle Welt, Bd. 17 (Stuttgart 1976), 51-53.

33 Pohl, 'Beitrag zur Statistik'; Homburg, *Van beroep 'Chemiker'*, 328-334.

34 Homburg, *Van beroep 'Chemiker'*, 337.

35 Homburg, *Van beroep 'Chemiker'*, 302-313.

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36 Cf. Homburg, *Van beroep 'Chemiker'*, 362.

37 Cf. Homburg, *Van beroep 'Chemiker'*, 367-368; Robert F. Bud and Gerryllyn K. Roberts, *Science versus Practice. Chemistry in Victorian Britain* (Manchester 1984), esp. 33-34; François Leprieur, 'La formation des chimistes français au XIXe siècle', *La Recherche* 10 (1979), 732-740.

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