Differentiation in German higher education

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Academic Institutions and Scholarly Disciplines:

For the purposes of international comparison, Burton R. Clark has recently suggested four categories which might be helpful in analyzing the differentiation of national systems of higher education. Among institutions, a division of labor may take place in two dimensions: Horizontally, alternative institutions (such as the public and private *sectors*) may serve similar purposes, or the various *sectors* may serve alternative purposes (such as universities and polytechnics). Vertically, *hierarchies* may be distinguished among the institutions, whether as rungs of the educational ladder or as prestige ranking. Within institutions, horizontal differentiation occurs "in the form of a division of labor by fields of knowledge" (*sections,* such as faculties, departments, scholarly disciplines). Vertical differentiation, on the other hand, "centers on levels of training and certification" (*tiers,* such as undergraduate and graduate study).[1]

Only two of these four distinctive cases will be considered in the present study: horizontal differentiation *among* institutions ("sectors") and horizontal differentiation *within* institutions ("sections"). Clark sums up the current state of knowledge regarding the relevant processes of differentation: "Basic research is lacking on such crucial matters as the ways in which disciplines emerge and penetrate university structures to become permanent parts of them, how prevailing disciplines split or recombine their parts to form new *sections.* ... The best ideas currently available give us some insight, largely on the development of institutional types, hence on *sector* differentiations."[2] Fortunately, it is in sector differentiation, or the division of labor among institutional types, where the major countries obviously differ. It should not be surprising that comparative education likes to take up this topic. On the other

1. Burton R. Clark, "Academic Differentiation in National Systems of Higher Education," in: *Comparative Education Review,* 22 (1978), 243, 247–8, 249–50. The extensive collecting of data for this article would not have been possible without the help of my research assistants E. Bolenz, Th. Möller, and R. Portmann.
2. Clark, 251.

hand, scholarly disciplines tend to be regarded as international commodities. Hence "the basic sectioning of the natural sciences into such fields as physics, chemistry, and biology, and well-defined subfields thereof, has wide currency," and probably a fairly common history.[3]

Within the limits of a mono-cultural study, it is inappropriate to analyze the German system of higher education as it differed from other national systems in terms of *sector* differentiation. Similarly it is impossible to examine prevailing assumptions regarding a fairly common process of differentiation by disciplines (*sections*) within institutions. Confined to developments *within* the German system of higher education, two lines of investigation will be pursued: (1) Changes in the differentiation among institutions or (2) changes in the disciplinary differentiation within institutions. Only the second of these two dimensions of differentiation deserves detailed study, especially since "basic research is lacking," as Clark has noted. Consequently, the bulk of this paper will be devoted to a rather elementary and descriptive work preparing the ground both for more specific analysis and for international comparisons.

If studied for Germany as a single country and for the time under consideration, differentiation *among* institutions is of comparatively little interest. Bearing in mind slogans such as "the rise of industrial capitalism" and "the rise of science as big business," institutional diversification of higher education in Prussia displays an extraordinary degree of continuity and stability (Table 1). Most institutions have a long history going back to earlier times when the Continental bureaucratized state of the 18th and early 19th centuries felt obliged to provide for the training of a wide range of professionals. Only one dynamic crisscrosses this seemingly well-planned functional spectrum of institutions, and that is "academization," or the endeavor to gain university-like status. An eminent case in point are the polytechnical schools which, since the 1870s, became technical universities but reached equal footing with the universities proper only in 1900. Teacher training colleges managed to emulate their technological forerunners only during the 1960s.

The traditional spectrum of institutions was enlarged merely in two instances. Business schools and academies of administration were founded from 1898 onwards, and teacher training colleges followed after 1924. In addition, the number of institutions of the traditional spectrum did not change for a long time. Exceptions are two technical universities (Breslau, Danzig) and two new universities (Frankfurt, Cologne), all founded between 1904 and 1919. The really significant changes, then, must be supposed to have taken place *within* the institutions.

A first impression of the assumed developments may be gained, if the Prussian institutions are weighted by teaching personnel and by students (Table 2). The rise of the "mass university" is too well-known to need another description. Among the non-university institutions the technical universities clearly dominate since they equal all remaining "academies" in terms of size. Because the typical "academy" is a tiny institution, we are well advised to confine the following study to universities and technical universities. Thus we are dealing with some 85 percent of the academics employed at institutions of higher learning, and with some 90 percent of the students studying at these institutions.

3. Clark, 257.

Table 1: Academic Institutions in Prussia, 1875–1930

Institutions	1875	1885	1895	1905	1913	1920	1925	1930
Universities	10	10	10	10	10	12	12	12
Technical Universities	3	3	3	4	5	4	4	4
Mining academies	2	2	2	2	2	1	1	1
Academies of agriculture	3	2	2	2	2	2	2	2
Academies of forestry	2	2	2	2	2	2	2	2
Veterinary academies	2	2	2	2	2	2	2	2
Academies of philosophy and theology	5	5	5	5	5	7	7	4
Business Schools	–	–	–	2	3	2	2	2
Academies of administration	–	–	–	–	1	1	2	2
Teacher training colleges	–	–	–	–	–	–	3	15

Source: Statistische Jahrbücher für den preußischen Staat.

Table 2: Teachers and Students at Prussian Academic Institutions, 1875-1930

Year	Teachers			Students		
	Univ.	Techn. U.	other	Univ.	Techn. U.	other
1875	866		87	7,924		601
1885	1,066	154	127	13,395	962	1,351
1895	1,267	223	220	13,598	2,824	2,422
1905	1,621	325	273	20,813	4,737	3,833
1913	1,790	431	381	27,564	4,906	4,759
1920	1,916	430	307	34,470	8,781	6,180
1925	2,303	412	470	28,282	8,472	5,647
1930	2,433	437	645	44,889	8,668	6,711

Source: Statistische Jahrbücher für den preußischen Staat.

If horizontal differentiation *within* universities and technical universities is the central topic, what are the appropriate units of investigation? Clearly it is primarily the scholarly disciplines which have to be studied. Disciplines may be defined as forms of social institutionalization which correspond, though sometimes lagging in time, to processes of cognitive differentiation within and across fields of knowledge. Typically, disciplines can be identified by the following traits: a fairly homogeneous network of communication between the scholars (scientific community); an accepted body of knowledge which can be taught in principle; a number of common problems and lines of investigation; a set of research methods and paradigmatic problem solutions; specific career structures and selection processes determining recruitment and promotion.[4] Discipline formation centers around subject-matters posing specific problems, and the autonomy of disciplines along cognitive-communicative lines can be distinguished from the organizational institutionalization of disciplines at a university. Disciplines as cognitive units may be empirically studied by relying on scholarly journals and learned societies. The present paper is rather confined to the study of disciplines as organizational or institutional units. This analysis will proceed on the basis of two main indicators: teaching subjects (disciplinary differentiation of teaching) and research institutions (institutionalization of disciplinary research).

The Disciplinary Differentiation of Teaching:

As far as the differentiation of fields of knowledge into scholarly disciplines is indicated by the denomination of chairs (or of teaching subjects), the decisive developments took place in the first half of the 19th century. A classic position is Ben-David's:

> By about 1860 the original four faculties of theology, philosophy, law and medicine, comprising just about all higher knowledge existing at the beginning of the century, had been transformed beyond all recognition. A host of new disciplines had found their place within the loose frame of the faculties, none of which—with the exception of theology—seems to have been averse to incorporating new fields. Commencing with the third quarter of the century this process of expansion and differentiation slowed down. ... The universities not only began to offer increasing resistance to the introduction of new sciences which had mushroomed outside their walls, they also placed often insurmountable obstacles on the path of disciplines which had begun to develop organically within the established disciplines.[5]

Against these sweeping judgments it must be noted that the history of disciplinary differentiation at German universities prior to 1864 simply has not yet been studied comprehensively for all teaching subjects. Therefore we have to leave aside the controversy of whether the core disciplines differentiated already around 1800 or only during the first half of the 19th century.[6] Similarly, it is not possible to evaluate the alleged slowdown after 1870 by comparing two "speeds" of disciplinary differentiation. What can be done, however, is to pinpoint the extent of disciplinary differentia-

4. Rudolf Stichweh, "Differenzierung der Wissenschaft," in: *Zeitschrift für Soziologie*, 8 (1979), 83.
5. Joseph Ben-David/Awraham Zloczower, "Universities and Academic Systems in Modern Societies," in: *European Journal of Sociology*, 3 (1962), 49.
6. Ben-David/Zloczower, 54; Stichweh, 83-4.

tion prevailing in 1864 (or, sometimes, only in 1890), and to distinguish subsequent changes presumably in the direction of additional differentiation.

The most detailed source for such an undertaking is *Minerva,* a yearbook of the learned world published since 1891.[7] *Minerva* lists all academics, employed at an individual institution by name, by professorial rank and by scholarly discipline. Covering all countries and all institutions of higher learning within each country, *Minerva* offers rich material for cross-national comparisons. But the information is difficult to handle since it has to be reorganized along disciplinary lines, at least if processes of horizontal differentiation within institutions are to be investigated. In his pioneering study of the German professoriate, Christian von Ferber fortunately has done precisely this (among other things), for the years from 1864 to 1953.[8] Confined to Germany, he relied on the annual catalogues of the individual universities and (since 1900) of non-university institutions. Coming up with a collective biography of some 23,000 academic teachers, his basic findings are presented according to faculties or fields of knowledge broken down into various subgroupings. In other words, Ferber traced his population by the current title of subjects each individual was charged to teach. Then he organized the array of denominations into clusters according to a system of disciplinary groupings. In doing so, he relies partly on traditional groupings such as faculties or departments. But since these intra-university structures do not apply to all fields of knowledge, he rightly warns against any premature inferences from nominal to real disciplinary differentiation (high or low).

On the micro-level, Ferber distinguishes 275 disciplinary units, which he distributes into 13 macro-units and their subgroupings (Table 3). Most of his tables refer to the higher levels of disciplinary aggregates, but for 45 out of the 275 individual disciplines he presents the original figures. 43 of the 45 disciplines are already present in 1864. In other words, whatever our assumptions may be regarding the institutional history of the remaining 230 disciplines, the Ferber data do not indicate much emergence of new disciplines after 1864. Rather the data show growth within a given spectrum of disciplines.[9] Do we therefore have to conclude, for the time being, that processes of differentiation date back to an earlier time and then come to a standstill?

A first answer is negative, if we broaden the concept of disciplinary differentiation to include the regional spread of disciplines. Ferber takes up this point when he compares big and small universities and discusses the respective representation of core disciplines vs. specialties at these institutions. His major findings are that, in 1864, big universities display a higher degree of specialization than small ones in the realm of core disciplines. By 1910 small universities catch up in level of specialization, whereas big universities meanwhile have established additional chairs both for the core disciplines and for some disciplinary specialties ("luxury" or research subjects).[10]

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7. *Minerva. Jahrbuch der gelehrten Welt,* vols. 1-30 (Berlin, 1892-1930).
8. Christian von Ferber, *Die Entwicklung des Lehrkörpers der deutschen Universitäten und Hochschulen 1864-1954* (Göttingen, 1956).
9. Growth processes as such are not dealt with in this paper; they are extensively documented and analyzed in Ferber's book.
10. Ferber, 54-57.

Table 3: Fields of Study and Scholarly Disciplines at German Academic Institutions after 1864

fields of study	number of disciplines			
1. Protestant theology	8			
2. Catholic theology	9			
3. Law	6			
4. Medicine	24			
5. Humanities	51			
a. European languages		11		
b. Noneuropean languages		8		
c. Comparative philology		2		
d. Philosophy, psychology, pedagogy		3		
e. History		12		
f. History of Art, fine arts		4		
g. other		11		
6. Natural sciences	50			
a. Chemistry		22		
- Basic chemistry			5	
- Applied chemistry			17	
- Technical chemistry				9
- Pharmaceutical chemistry				4
- Food chemistry				3
- Agricultural chemistry				1
b. Physics		11		
- Basic Physics			3	
- Applied Physics			8	
c. Biology		6		
d. Astronomy, geophysics, meteorology		3		
e. Geology, mineralogy		2		
f. Mathematics		3		
g. Geography		3		
7. Economics	3			
8. Social Sciences	6			
9. Veterinary medicine	10			
10. Science of agriculture	7			
11. Science of forestry	6			
12. Technical Sciences	89			
a. Surveying		3		
b. Architecture		11		
c. Civil engineering		17		
d. Machine building		23		
e. Electrical engineering		12		
f. Shipbuilding		7		
g. Aircraft construction		5		
h. Mining		4		
i. Metallurgy		7		
13. Other	5			
Total	275			

Source: Ferber, 1956, 187-94.

Similar reasoning applies to the "strength" of individual subjects as indicated by the numbers and rank level of academics representing them (Table 4). During most of the decades under consideration we find some 20 universities throughout Germany. Taking this number as a yardstick, we may ask for the points of time at which

Table 4: Full Professors (Associate Professors, Privatdozenten) per Discipline at German Universities, 1864–1931

Disciplines	1864	1873	1880	1890	1900	1910	1920	1931
Medicine								
Anatomy	23(7,11)							34(33,25)
Surgery	23(7,14)							25(119,52)
Internal medicine	20(9,10)							40(132,93)
Gynecology	16(3,18)	20(4.2)						24(63,41)
Physiology	15(3,9)		20(3,22)					27(24,23)
Pathology	7(5,4)				20(4,11)			24(21,30)
Opthalmology	3(11,8)				21(16,23)			23(36,22)
Hygienics	1(-)					23(11,28)		27(41,35)
Psychiatry	-(2,7)	1(4,12)				20(17,55)		27(65,45)
Pharmacology	7(3,3)							22(16,17)
Dentistry	-(-,1)		1(-,3)					22(31,22)
Physiological Chemistry	-	1(-,1)						9(12,10)
Natural Sciences								
Botany	17(8,10)		26(10,7)					27(25,20)
Zoology	11(5,5)			20(12,21)				30(41,30)
Pharmaceutical Chemistry	3(9,2)							15(14,7)
Physical Chemistry	-(-,1)	1(1,-)						19(12,12)
Agricultural Chemistry	1(2,-)							7(4,4)
Astronomy	12(6,2)							14(7,7)
Humanities								
Classical Philology	43(11,14)							54(14,18)
Philosophy	36(21,23)							56(51,32)
German Philogogy	14(8,9)	20(7,7)						48(22,27)
Medieval and modern history	19(4,19)			25(6,9)				24(12,19)
Ancient history	4(1,1)				20(5,11)			22(4,7)
Romance philology	3(1,3)					23(8,10)		18(11,10)
Classical archeology	9(4,6)						20(6,4)	18(9,7)
English philology	-(-,1)	2(1,1)					22(4,6)	22(10,7)
History of Art	4(2,2)							14(21,25)
Modern history	5(1,1)							18(6,11)
Indology	3(1,-)							13(6,7)
Musicology	-(3,1)				1(7,5)			8(11,18)
Pedagogy	2(1,-)							6(10,8)
Slavonic philology	1(-,1)							4(5,2)
Psychology	1(-)							5(9,10)

Source: Ferber, 1965, 204ff.
- Status of 1864
- Time when at least one full professorship is established
- Time when at least 20 full professorships are established
- Status of 1931

various disciplines are represented by 20 full professors. This bench mark of institutional maturity, which is roughly equivalent to being present at each individual university, was gradually reached or surpassed by some disciplines, or never attained by others. In some instances, disciplines below this level of general acceptance show high figures for associate professors or *Privatdozenten* (e.g., opthalmology, psychiatry); but in many other cases this plausible rule does not apply. Since almost all disciplines covered so far already existed in 1864, we may speak of differential growth rates within a given spectrum of disciplines, but not of disciplinary differentiation proper.

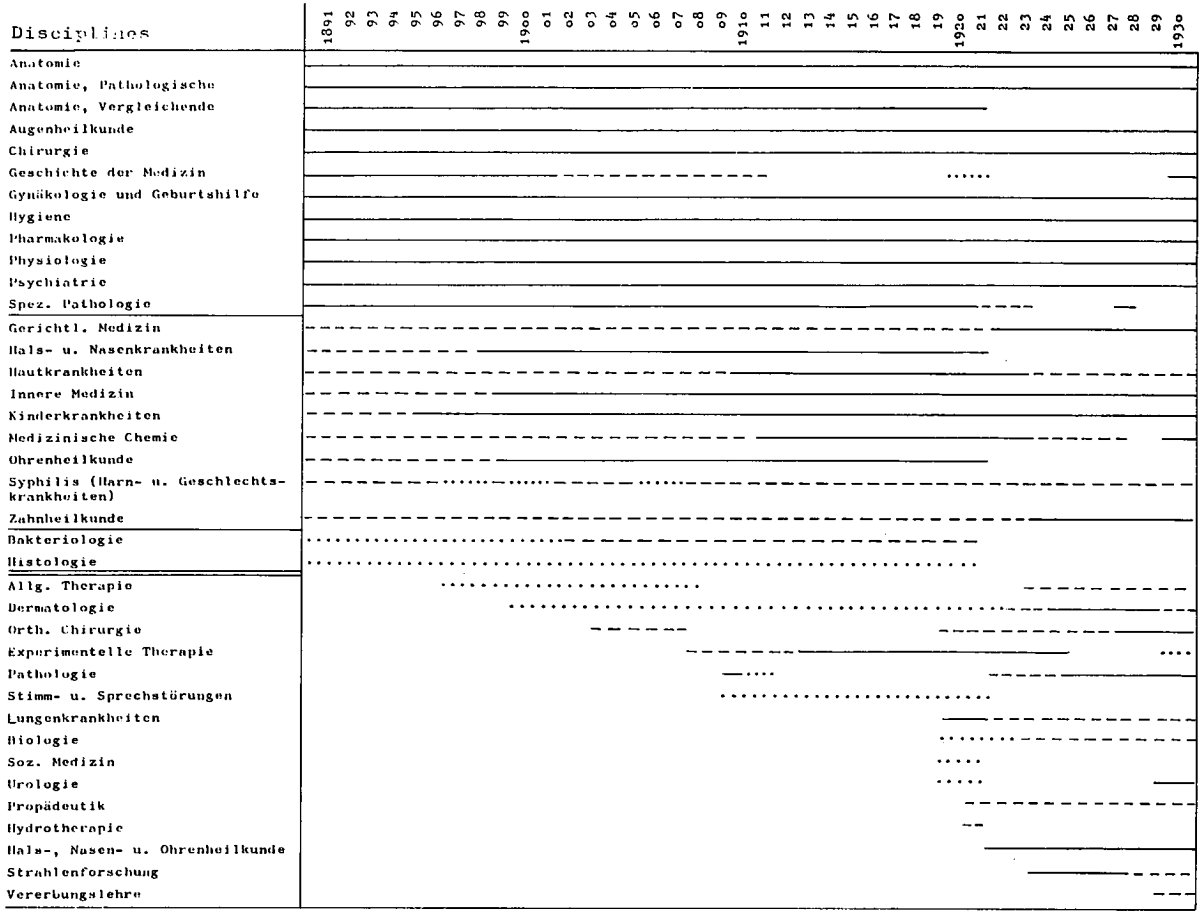
A second answer to the question of whether there was any disciplinary differentiation after 1864 is possible. If we confine the study to the period from 1890 onwards and base it on *Minerva,* the answer is positive (Tables 5–7). In order not to be overwhelmed by the massiveness of data, several limitations have deliberately been employed. First, only one out of some 20 German universities has been studied. Our example is the University of Berlin, which can safely be supposed to embrace the widest range of specialized disciplines at the time. Secondly, all questions of size and growth have been disregarded. In other words, every disciplinary unit is just counted once, and weighted only in terms of the rank level of its "highest" representatives, not in terms of their number.

Medicine is a case in point (Table 5). In 1890, some 23 different subjects (disciplinary units) are represented in the Berlin faculty of medicine. Among them some 12 had already reached the rank level of full professor, while nine and two still stood below on levels of associate professor or *Privatdozent* respectively. During the following four decades several developments took place: (1) the upgrading of established disciplines (e.g., pediatrics); (2) the downgrading of, or vacancy in, established disciplines (e.g., history of medicine); (3) the recombination of established disciplines (e.g., otorhinolaryngology in 1921); (4) the emergence of additional, specialized disciplines. New disciplines tend to start on the rank level of a *Privatdozent,* but their institutional history shows comparatively little continuity. One might think of practitioners offering specialized courses in addition to the core disciplines. On the fringes of the spectrum it seems as if we can grasp some of the differences between disciplines as cognitive or as institutional units, with the former not necessarily attaining the status of the latter permanently.

Similar observations can be made with reference to the huge faculty of philosophy which then still contained both the humanities and the natural sciences (Table 6). Disciplinary differentiation, in the sense of specialization along cognitive lines, seems especially rich within the humanities. This finding agrees with Ferber who studied differential growth rates and argues that the humanities are relatively open to including "luxury" or research specialties besides the core disciplines. Thereby the teaching professions not only received their appropriate training at the universities, but the cultural and historical interests of a wealthy bourgeoisie were also increasingly served by the flourishing liberal arts.[11] Disciplinary differentiation must also be attributed to the inherent logic or internal dynamics of scientific development. But it is only on the level of disciplinary case studies that such questions can be analyzed.

11. Ferber, 62–66.

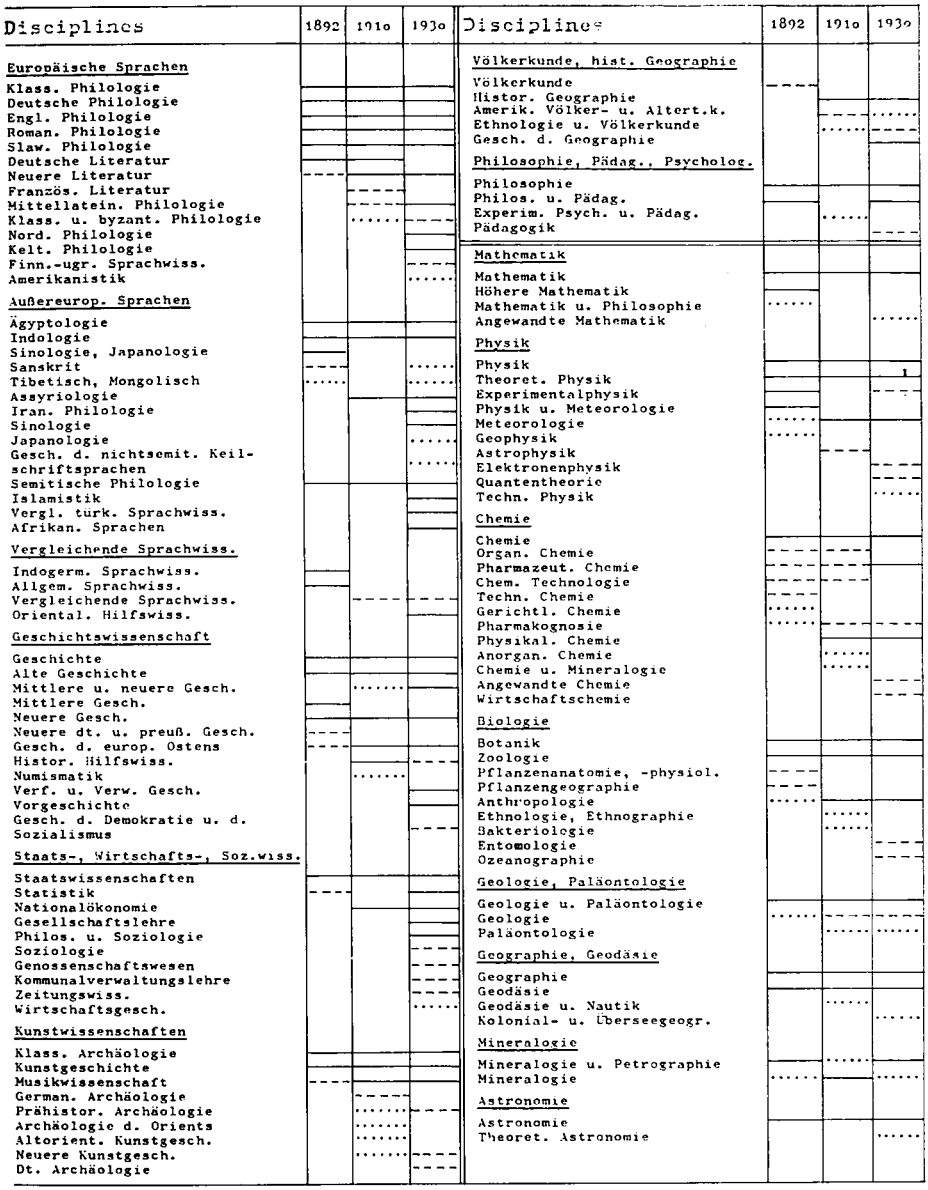
Table 5: Disciplines at the Medical Faculty of Berlin University, 1890–1930



Source: Minerva. Jahrbuch der gelehrten Welt

1st rank: professor in ordinary ——— 2nd rank: extraordinary professor ---- 3rd rank: Privatdozent .....

Table 6: Disciplines at the Philosophical Faculty of Berlin University, 1890-1930



Source: Minerva. Jahrbuch der gelehrten Welt

1st rank: full professor ———

2nd rank: extraordinary professor - - - - - -

3rd rank: Privatdozent .....

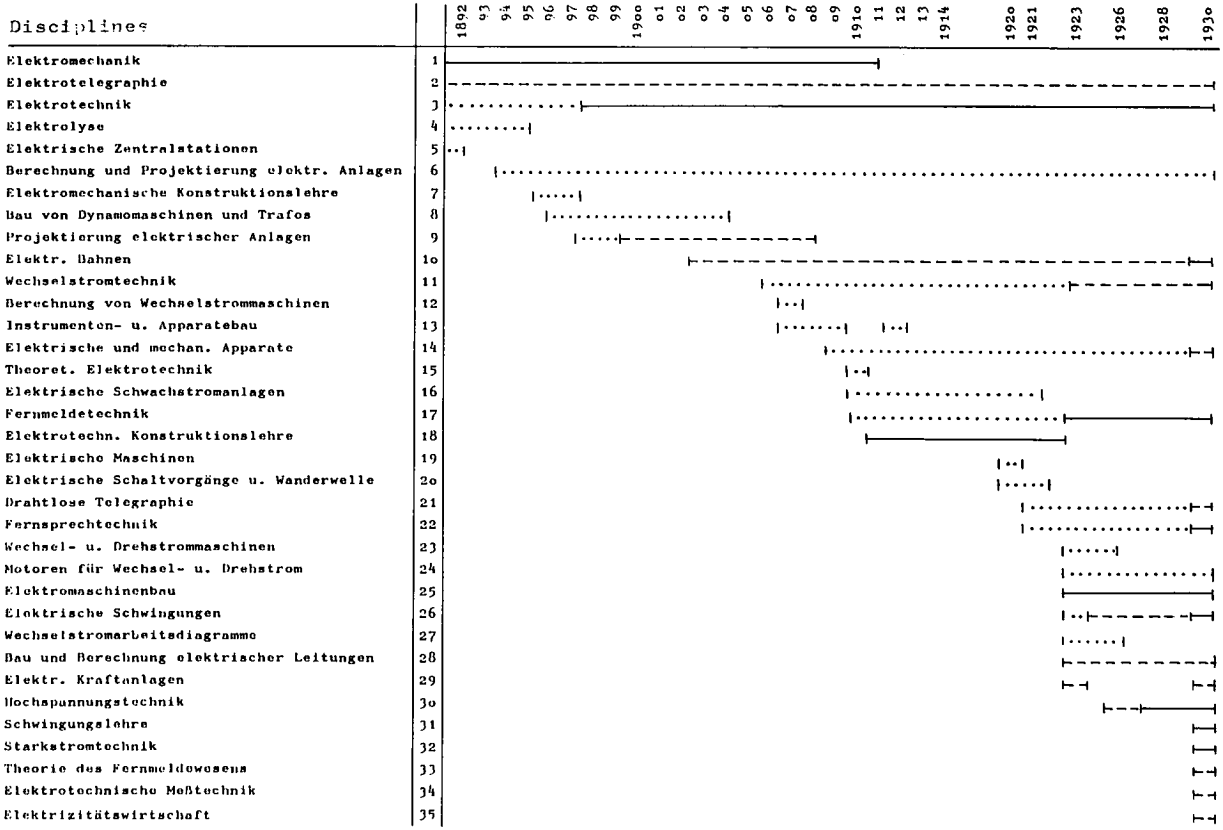
Taking into account research dynamics and generalized assumptions about usefulness and applicability, the differentiation processes within the natural sciences can be considered relatively modest (Table 6). At least at a German university, which was not the only institution to host the natural sciences, many full professors simply taught physics or chemistry, if only nominally. On the other hand, it is precisely in the natural sciences (and medicine), where the German research university found its strongest foothold. The apparent differences between the ranges of disciplines, on the rank level of full professor between medicine and the natural sciences (cf. Tables 5 and 6), probably stem from the very different labor markets for the two groups of professionals. In medicine we find an old established and very powerful profession which could use internal differentiation (or, if one prefers, "scientification" of various subject matters within medical care) for its professionalization policies. Hence there was a close relationship between an array of core disciplines and the range of medical specialists. For the natural sciences research may induce ever-growing specialization or disciplinary differentiation, but, with the exception of chemistry, there was no significant market for specialists outside the university, at least for a long time to come. Hence only a few core disciplines represent the traditional set of cognitive units which date back to the beginning of the century.

By contrast, differentiation processes are largest, at least if taken nominally, in the realm of technical sciences. Ferber deals with the technical sciences on the aggregate level only, that is by comparing, e.g., civil engineering with mechanical engineering, electrotechnology, etc. (cf. Table 3). On the basis of *Minerva,* such units can be broken down. This has been done for the technical university of Berlin, but confined to electrical engineering (Table 7). The prevailing picture is that of a few core disciplines for each kind of prospective engineering specialist and of an immense range of additional specialties, partly overlapping and often short-lived. To interpret these findings one may point to three interconnected circumstances: Professionalization policies of the engineers and special courses being taught by practitioners resemble the medical pattern. Unlike medicine, the technical sciences are institutionalized outside the university and therefore unhampered by traditional faculty boundaries. Moreover, the cognitive contents of the technical sciences are less sharply delineated and more open to nominal differentiation according to fields of practical technical work. Again we fall back on our basic distinction between disciplines as cognitive or institutional units. Any further discussion would require specifying the argumentation on a level of case studies which is clearly beyond the limits of this paper. Another dimension of disciplinary differentiation, however, can yet be added, and that is research.

The Institutionalization of Disciplinary Research:

The German university of the 19th century has often been praised as the model of the modern research university. Nevertheless, any comprehensive account of this historical development is still lacking. There is no book presenting basic data on research institutions such as Ferber's volume on teaching personnel. Under these circumstances any effort to describe disciplinary differentiation within the realm of research cannot be separated from a concomitant survey of institutionalization and growth of research at universities (and technical universities). Such an overview has been as-

Table 7: Disciplines within Electrical Engineering at Berlin Technical University, 1890–1930



Source: Minerva. Jahrbuch der gelehrten Welt

1st rank: full professor ——— 2nd rank: extraordinary professor ------ 3rd rank: Privatdozent ·····

sembled for the following tables by relying on three different types of sources: (1) The annual budget of the Prussian Ministry of Cultural Affairs.[12] It includes a listing of all institutions annexed to each Prussian university, including their budget and personnel. (2) A monograph on the history of Berlin university which offers historical accounts for each institute or seminar.[13] (3) A 1930 survey of all German research institutes in the realm of natural and technical sciences.[14].

The typical information from the Prussian annual budget can be organized on two different levels, by faculties or by disciplines. In order to present an overall impression it is necessary to begin on the aggregate level (Table 8). Comparing the four traditional faculties, research is relatively negligible in theology and law. Medicine and the natural sciences receive large shares of public expenditure and personnel employed, whereas the humanities are rich in seminars but poor in infrastructure. Even more remarkable are the differences between big and small universities, especially between Berlin and the rest. To put the data on research institutions into a developmental perspective (Fig. 1), one can speak of differential growth rates, with medical clinics and seminars in the humanities ahead of the other institutions since the turn of the century. These findings seem to support what has been said in regard to differentiation of teaching. If we relate personnel and public expenditure to the numbers of institutions, several observations can be made (Table 9): (1) Inter-university differences (Berlin vs. the mean) prevail throughout the time period under consideration. (2) In absolute terms, the number of researchers (assistants) seems fairly small, and consequently public expenditures, which include wages until 1910, are of minor size. (3) Relative growth over time appears to be modest, especially for the staffing of institutions.

The disciplinary level of analysis can only be examined for a few examples. In physics and chemistry, the typical Prussian university had just one institute for each field (Table 10). Exceptions are, for physics, Berlin with theoretical physics (1890) and Göttingen with geophysics (1905); and for chemistry, physical chemistry at Göttingen (1900), Berlin (1905) and Marburg (1931). The general impression suggests little formal differentiation, comparable to the findings regarding the denomination of chairs in these fields. Internally, however, a fair amount of differentiation may safely be supposed: First, the existence of heads of divisions points into this direction. Secondly, staffing and financing of research institutes in chemistry exceed the average for the natural sciences, both on the state level and at the University of Berlin (Table 11; cf. Table 9). Within the humanities, classical philology established the model of a seminar already in the late 18th century. Consequently, all Prussian universities have their respective seminar (Table 12). German philology, on the other hand, only achieved equal footing in terms of distribution by 1895. Typically, these seminars offered less than one assistantship per institution, except at Berlin (cf. Table 9).

Differential strength and growth within a given spectrum of research institutions has to be distinguished from disciplinary differentiation of the spectrum itself. Leav-

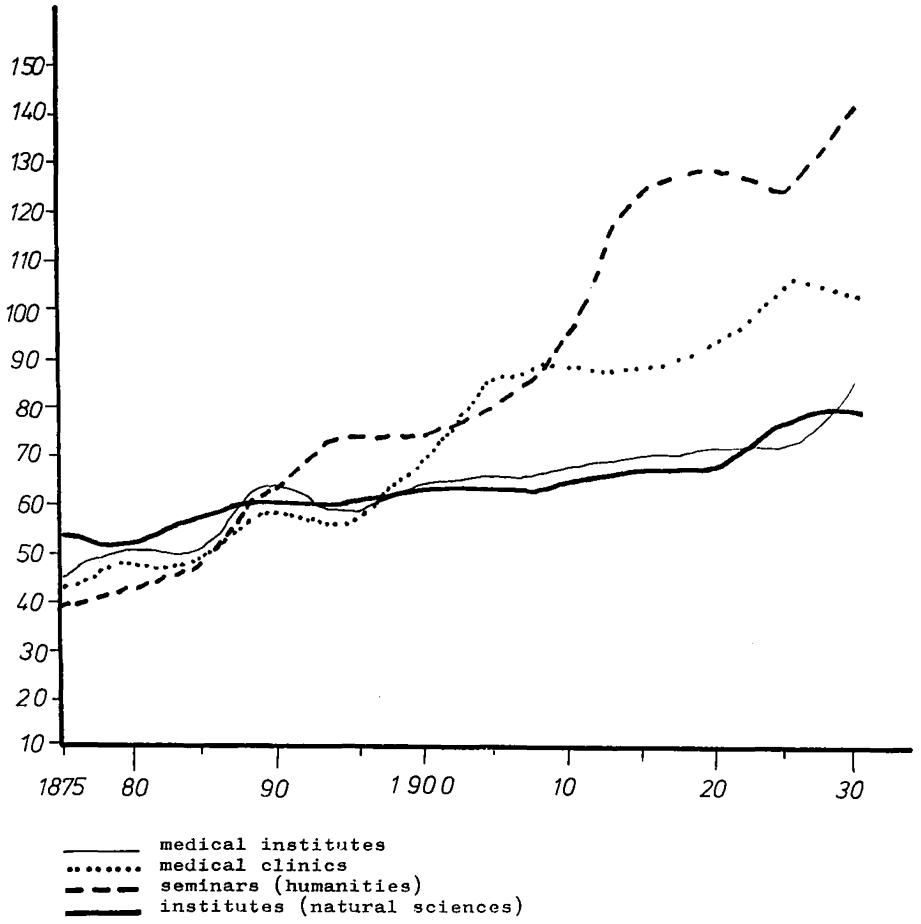
12. *Staatshaushalts-Etat für das Jahr 1870–1931* [Preussen] (Berlin 1870–1931).
13. Max Lenz, *Geschichte der Kgl. Friedrich-Wilhelms-Universität zu Berlin* (Berlin, 1910), vol. 3.
14. C. Boeck, *Die technisch-wissenschaftlichen Forschungsanstalten* (Berlin, 1931).

Table 8: Seminars, Institutes and Clinics at Prussian Universities, 1910

Universities	Theology			Law			Medicine						Philosophy					
							Institutes			Clinics			Humanities			Natural Sciences		
	Institutions	Public expenses	Academic personnel	Institutions	Public expenses	Academic personnel	Institutions	Public expenses	Academic personnel	Institutions	Public expenses	Academic personnel	Institutions	Public expenses	Academic personnel	Institutions	Public expenses	Academic personnel
Königsberg	1	580	1	2	800	-	7	65,449	18	7	282,952	27	7	15,510	5	4	50,675	11
Berlin	2	2,600	2	2	4,700	-	10	302,763	72	20	531,627	76	14	255,374	31	12	384,899	90
Greifswald	1	771	2	2	750	-	5	53,310	15	7	291,301	32	5	2,020	-	4	40,188	12
Breslau	3	2,275	-	2	1,000	-	6	100,313	27	8	387,206	55	9	17,450	5	5	66,701	17
Halle	1	-	-	2	1,200	-	5	61,247	18	8	287,861	51	8	14,110	4	4	64,491	17
Kiel	2	891	1	2	1,000	-	6	70,168	20	9	335,777	44	6	9,290	2	3	27,690	8
Göttingen	1	4,280	-	2	1,200	-	7	61,109	14	6	206,936	22	9	20,388	6	7	98,611	26
Marburg	1	900	-	2	860	-	6	92,941	26	5	201,083	23	8	15,206	4	6	101,735	24
Bonn	2	1,200	-	3	1,800	-	6	74,870	21	7	280,668	37	9	22,880	9	4	75,010	24
Münster	1	600	-	2	1,200	-	-	-	-	-	-	-	5	1,700	-	5	54,691	17
Total	15	14,097	6	21	14,510	-	58	882,143	231	77	2,805,411	367	80	373,928	66	54	964,691	246

Source: Staatshaushalts-Etat, 1910

Figure 1: Seminars, Institutes and Clinics in Medicine and Philosophy at Prussian Universities, 1875–1930



Source: Staatshaushalts-Etat, 1875–1931

ing aside the case of internal specialization under the cover of a nominally monodisciplinary institution, we probe the gradual widening of the range of such institutions. In order to extend the time span back to the beginning of the 19th century, the history of the University of Berlin (founded in 1810) serves as a useful example. Judged by the chronological sequence of their establishment, medical clinics dominate the

Table 9: Research Personnel and Expenditure in Medicine and Philosophy at Prussian Universities, 1875-1930, per Institution

(a) academic personnel

Year	Medicine				Philosophy			
	institutes		clinics		humanities		sciences	
	Prussia	Berlin	Prussia	Berlin	Prussia	Berlin	Prussia	Berlin
1875	3.6	6.3	2.9	1.3	0.5	0.0	1.7	2.0
1880	3.6	6.2	3.8	1.7	0.4	0.0	2.2	2.8
1885	3.7	5.7	4.6	4.3	0.6	0.0	2.5	4.3
1890	2.8	5.9	4.1	3.2	0.8	1.9	2.8	3.8
1895	3.4	5.8	4.7	3.1	0.8	2.3	3.0	3.9
1900	3.4	5.9	4.5	3.1	0.9	2.9	3.7	5.4
1905	3.9	6.9	4.2	2.9	0.9	2.4	4.0	6.8
1910	4.0	7.2	4.8	3.8	0.8	2.2	4.6	7.5
1915	4.2	7.8	5.3	5.1	0.6	2.1	4.8	8.5
1920	4.0	7.9	5.1	5.0	0.6	1.9	4.9	8.0
1925	4.0	8.6	5.4	6.2	0.6	1.6	3.9	4.9
1931	3.6	7.7	5.5	5.8	0.7	2.1	4.4	7.5

(b) public expenditure

Year	Medicine				Philosophy			
	institutes		clinics		humanities		sciences	
	Prussia	Berlin	Prussia	Berlin	Prussia	Berlin	Prussia	Berlin
1875	11,590	18,195	15,343	4,433	1,101	2,040	5,526	11,347
1880	12,391	28,602	15,311	4,845	1,008	1,395	7,065	14,614
1885	13,240	24,891	28,017	25,530	1,351	1,380	8,947	22,382
1890	9,089	23,541	26,526	20,032	3,102	12,057	8,669	15,406
1895	10,616	22,203	41,151	19,608	3,343	15,008	10,855	18,227
1900	11,420	22,406	30,097	19,428	3,804	17,989	12,104	22,006
1905	13,708	27,791	30,186	18,680	4,270	16,569	14,741	26,471
1910	15,209	30,276	36,433	26,581	4,674	18,241	17,865	32,079
1915	10,734	23,736	35,732	26,292	1,738	4,503	11,418	20,640
1920	10,581	24,146	32,158	26,225	1,648	4,112	12,015	20,215
1925	12,093	36,450	26,718	24,009	1,648	3,281	10,292	15,024
1931	15,797	32,939	27,028	24,712	3,608	6,277	18,204	30,100

Source: Staatshaushalts-Etat, 1875-1931

Table 10: Physics and Chemistry Institutes at Prussian Universities, 1875–1930

(a) physics

Year	Number	budget		personnel		
		public expenses	institutional revenue	head of division	assistants	auxiliary personnel
1875	12	43,521			7	11
1880	10	69,519			11	13
1885	10	76,051			15	13
1890	11	96,587	460		19	11
1895	11	102,470			19	11
1900	11	120,770			21	14
1905	12	152,580			26	15
1910	12	172,215		2	29	14
1915	12	150,101		1	35	12
1920	12	165,751	5.400	1	36	12
1925	12	149,700		1	36	14
1931	14	251,250	1.700	1	36	14

(b) chemistry

Year	Number	budget		personnel		
		public expenses	institutional revenue	head of division	assistants	auxiliary personnel
1870	11	79,529				
1875	11	120,889			27	15
1880	11	145,097	750		30	18
1885	12	160,704	4,853		34	18
1890	11	172,627	9,049		37	20
1895	11	206,307	1,521		41	22
1900	12	281,171	1,190		49	31
1905	13	324,783	4,448		54	34
1910	13	395,417	6,925	20	58	34
1915	13	281,177	12,361	22	63	35
1920	13	263,342	35,938	22	64	35
1925	13	307,650	900	22	63	31
1931	14	535,700	21,070	22	61	30

Source: Staatshaushalts-Etat, 1870-1931

early decades, and their differentiation proceeds fairly gradually (Table 13). By 1890, there are even specialized institutions for fields which are not yet represented by a full professor (e.g., dentistry, orthopedic surgery, pulmonary diseases, venereal diseases) (cf. Table 5). Medical therapeutics is sometimes ahead of medical teaching in terms of specialization. This applies even more to medical research such as radiology and neurobiology.

Table 11: Personnel and Expenditure for Physics and Chemistry Institutes at Prussian Universities, 1875–1930

Year	physics				chemistry			
	academic personnel		public expenditure		academic personnel		public expenditure	
	Prussia	Berlin	Prussia	Berlin	Prussia	Berlin	Prussia	Berlin
1875	1.7	2.0	3,627	11,415	2.5	4.0	10,989	20,367
1880	1.1	3.0	6,952	27,854	2.7	4.0	13,190	20,572
1885	1.5	3.0	7,605	27,860	2.8	3.5	13,392	19,550
1890	1.7	2.5	8,781	15,445	3.4	3.5	15,693	20,067
1895	1.7	2.5	9,315	15,824	3.7	4.0	18,755	22,415
1900	1.9	2.5	10,979	17,409	4.1	5.5	23,431	48,617
1905	2.2	2.5	12,715	16,709	4.2	5.5	24,983	49,832
1910	2.6	3.0	14,351	20,184	6.0	7.5	30,417	54,625
1915	3.0	3.5	12,508	15,487	6.5	7.5	21,629	39,775
1920	3.1	3.5	13,813	15,487	6.6	7.5	20,257	32,058
1925	3.1	3.5	12,475	15,525	6.5	7.5	23,665	41,625
1931	2.6	3.0	17,946	20,900	5.9	7.5	41,207	70,200

Source: Staatshaushalts-Etat, 1875-1931

Table 12: Seminars for Classical and German Philology at Prussian Universities, 1875-1930

(a) classical philology

Year	Number	budget		personnel		
		public expenses	institutional revenue	director	assistants	auxiliary personnel
187o	1o	11,22o	-	8	-	-
1875	1o	13,89o	-	8	-	-
188o	1o	14,34o	-	8	-	-
1885	1o	15,24o	-	9	-	-
189o	1o	9,17o	-	8	-	-
1895	1o	7,35o	-	7	-	-
19oo	1o	1o,o35	-	3	3	-
19o5	9	1o,56o	-	3	4	-
191o	9	13,12o	-	-	5	-
1915	9	6,18o	83o	-	5	-
192o	9	6,18o	887	-	5	-
1925	8	6,15o	-	-	7	-
1931	5	9,6oo	1,3oo	-	4	-

(b) German philology

Year	Number	budget		personnel		
		public expenses	institutional revenue	director	assistants	auxiliary personnel
187o	-					
1875	2	6oo	-	-	-	-
188o	5	1,5oo	-	-	-	-
1885	5	1,5oo	-	-	-	-
189o	8	2,38o	-	-	-	-
1895	1o	3,18o	-	-	-	-
19oo	1o	3,18o	-	-	-	-
19o5	1o	3,78o	-	-	-	-
191o	1o	3,78o	-	-	-	-
1915	1o	3,78o	2,435	-	-	-
192o	1o	3,98o	4,589	-	-	-
1925	1o	4,2oo	-	-	1	-
1931	1o	27,5oo	5,69o	-	2	-

Source: Staatshaushalts-Etat, 1870-1931

Table 13: Medical Clinics and Institutes at the University of Berlin, 1810–1909

(a) clinics

Institution	1810/19	1820/29	1830/39	1840/49	1850/59	1860/69	1870/79	1880/89	1890/99	1900/09
Univ.:										
Klin.Institut f. Chirugie	—	—	—	—	—	—	—	—	—	—
Klin. f. Frauenkrankheiten und Geburtshilfe	—	—	—	—	—	—	—	—	—	—
Poliklin.Institut f. innere Medizin	—	—	—	—	—	—	—	—	—	—
Augenklinik						—	—	—	—	—
Klinik f. Ohrenkrankheiten							—	—	—	—
Klinik f. Hals- u.Nasenkranke								—	—	—
Zahnärztl. Institut								—	—	—
Poliklinik f. orthopäd.Chirugie									—	—
Poliklinik f. Lungenleiden									—	—
Hydrotherapeut. Anstalt										—
Ambulatorium f.Sprachstörungen										—
Mechanotherapeut. Anstalt										—
Charité:										
Chirurg. Klinik u. Poliklinik	—	—	—	—	—	—	—	—	—	—
Erste medizin. Klinik	—	—	—	—	—	—	—	—	—	—
Psychiatr. u. Nervenklinik	—	—	—	—	—	—	—	—	—	—
Klinik f. Haut-u.Geschlechtsk.		—	—	—	—	—	—	—	—	—
Klinik f. Kinderkrankheiten			—	—	—	—	—	—	—	—
Frauenklinik					—	—	—	—	—	—
Zweite medizin. Klinik					—	—	—	—	—	—
Klinik f. Augenheilkunde									—	—
Klinik f. Hals-u. Nasenkranke									—	—
Klinik f. Ohrenkrankheiten									—	—
Inst. f. Krebsforschung										—
Total	6	7	8	8	10	11	12	14	19	23

(b) institutes

Institution	1810/19	1820/29	1830/39	1840/49	1850/59	1860/69	1870/79	1880/89	1890/99	1900/09
Anatomisches Institut	—	—	—	—	—	—	—	—	—	—
Pharmakologisches Institut				—	—	—	—	—	—	—
Physiologisches Institut					—	—	—	—	—	—
Pathologisches Institut					—	—	—	—	—	—
Anatom.-biolog. Institut								—	—	—
Hygienisches Institut								—	—	—
Inst. f. Unters. mit Röntgenstrahlen									—	—
Neuro-biolog. Laboratorium										—
Total	1	1	1	2	4	4	4	6	7	8

Source: Lenz, 1910

Within the faculty of philosophy, the natural sciences witness a steep rise in disciplinary research units only after 1860. They are followed two decades later by the humanities which display a similar pattern of differentiation (Table 14). By the end of the 19th century, the respective range of teaching subjects on the rank level of full professor coincides rather closely with research institutes (cf. Table 6). Sometimes, teaching is more differentiated than are the seminars which obviously host clusters of related disciplines. This practice seems to be appropriate for the humanities, but one might have expected a greater degree of disciplinary differentiation within the natural sciences. Of course, intra-institutional specialization and division of labor needs to be taken into account. Moreover, there may be more differentiation in the 20th century. Finally, however, traditional faculty boundaries may have blocked further external differentiation. The last two points can be checked, if research institutes for the natural and technical sciences at all German universities and technical universities are compared.

The following survey is based on Boeck who in 1931 published a handbook listing all then existing research institutes in basic and applied sciences (excluding biology). He included institutions whether they were part of universities and other academic institutions, or run by public authorities, by private industry, by associations or by foundations. Those annexed to universities or technical universities have been sampled and ordered according to the sequence of their foundation as well as according to disciplinary boundaries (by various degrees of specification). An overview, put into very broad categories, suggests two basic facts (Fig. 2): (1) Research institutes for the natural sciences are nearly as strongly represented at the German technical universities as at the universities proper, although the latter outnumber the former by 2:1. (2) Research institutes for the technical sciences follow closely their sisters in the natural sciences at the technical universities until about 1900, when an immense growth, probably accompanied by differentiation, carries them far ahead.

Broken down by disciplines, two different developments can be discerned with respect to research institutes for the natural sciences (Table 15): (1) Much of the growth is attributable to inter-university differentiation. In other words, minimal standards in terms of established institutes rise and generalize. This holds true both for universities and for technical universities. (2) Additional growth goes back to disciplinary differentiation (e.g., technical physics, mechanics) for both sets of institutions. Most interesting is the case of chemistry. The traditional bifurcation between inorganic and organic chemistry was followed by an external institutional separation almost exclusively at the technical universities. These findings support our assumption that non-university institutions, lacking traditional faculty organization, were more open to institutional change or disciplinary differentiation on a nominal, i.e., institutional scale.

Turning to the technical sciences one might expect an even higher degree of institutional differentiation along disciplinary lines, in accordance with the pattern prevailing in teaching (cf. Table 7). Indeed this was the case, and probably continues to be (Tables 16–17). As has been noted earlier, growth rates explode after the turn of the century, and we find many specialties which are equipped with research institutes after this time (e.g., automobile and aircraft-construction, shipbuilding). In other instances, established research fields spread to the various technical universities (e.g., metallurgy, material testing, geodetics). Generally, some sort of "scientification"

Table 14: Philosophical Institutes and Seminars at the University of Berlin, 1810–1909

(a) sciences

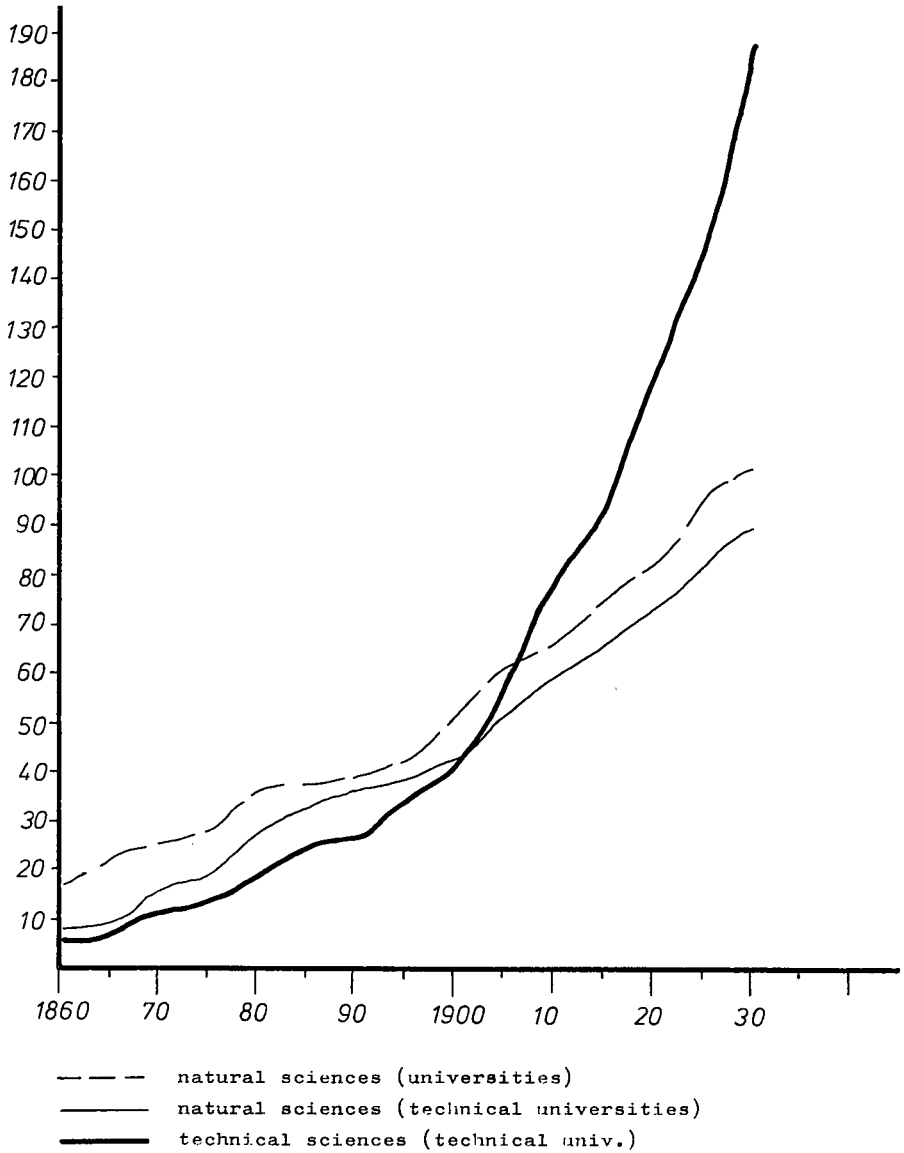
Institution	1810/19	1820/29	1830/39	1840/49	1850/59	1860/69	1870/79	1880/89	1890/99	1900/09
Sternwarte										
Zoologisches Museum										
Universitätsgarten, Bot. Garten										
Physikalisches Institut										
Chemisches Institut										
Mathemat. Seminar										
Seminar z. Ausbildung im wiss. Rechnen										
Botanisches Institut										
Pflanzenphysiolog. Inst.										
Astronom.Rechen-Institut										
Institut f. theoret.Physik										
Geograph. Institut										
Mineralog.-petrograph.Inst.										
Geolog.-paläontolog.Inst.										
Zoologisches Institut										
Technologisches Institut										
Meteorologisches Institut										
Botanisches Museum										
Physikal.-chem. Institut										
Inst. f. Meereskunde										
Pharmazeut. Institut										
Total	2	3	4	4	4	6	10	17	18	21

(b) humanities

Institution	1810/19	1820/29	1830/39	1840/49	1850/59	1860/69	1870/79	1880/89	1890/99	1900/09
Philologisches Seminar	—	—	—	—	—	—	—	—	—	—
Archäologischer Apparat					—	—	—	—	—	—
Apparat f. neuere Kunstgeschichte							—	—	—	—
Institut f. Altertumskunde								—	—	—
Germanisches Seminar								—	—	—
Seminar f. oriental. Sprachen								—	—	—
Historisches Seminar								—	—	—
Staatswiss.-statist. Sem.								—	—	—
Seminar f. roman. Philologie									—	—
Seminar f. engl. Philologie									—	—
Seminar f. histor. Geographie									—	—
Psychologisches Institut									—	—
Philosophisches Seminar										—
Indogerm. Seminar										—
Seminar f. osteurop. Geschichte										—
Musikhistor. Seminar										—
Total	1	1	1	1	2	2	3	8	12	16

Source: Lenz, 1910

Figure 2: Natural Science and Technical Institutes at German Universities and Technical Universities, 1860–1930



Source: Boeck, 1931

Table 15: Natural Science Institutes at German Universities and Technical Universities, 1860–1930

(a) natural sciences

Year	Chemistry (total)		Physics		Technical physics		Mechanics		Geology, mineralogy		Agricultural biology		Agricultural technology		Food-stuffs	
	Uni	TH	Uni	TH	Uni	TH	Uni	TH	Uni	TH	Uni	TH	Uni	TH	Uni	TH
1860	4	4	6	2					6	1				1	1	
1865	6	4	8	2					7	1		1		1	1	
1870	7	8	8	3					7	2	1	1	1	1	1	1
1875	9	9	8	3					7	3	2	2	1	1	1	1
1880	13	14	10	4					9	4	2	3	1	1	1	2
1885	13	16	10	5					10	4	2	3	1	2	1	3
1890	14	18	11	5					10	4	2	3	1	3	1	3
1895	15	20	12	5					11	5	3	3	1	3	1	3
1900	19	22	15	5					13	6	4	3	1	3	1	3
1905	21	26	17	6	1	1	1		14	7	4	3	1	4	2	4
1910	22	32	17	7	1	1	1		18	8	4	3	1	4	2	4
1915	25	34	18	7	2	1	1	2	22	8	4	5	1	5	2	4
1920	28	36	18	8	2	2	1	2	24	8	5	5	2	6	2	5
1925	30	39	21	10	4	2	1	3	26	8	6	5	3	8	5	6
1930	32	39	23	13	5	4	1	5	26	10	6	5	3	8	5	6

(b) chemistry

Year	Chemistry											
	total		inorganic and organic		inorganic		organic		physical, electro		technical	
	Uni	TH	Uni	TH	Uni	TH	Uni	TH	Uni	TH	Uni	TH
1860	4	4	4	1		2						1
1865	6	4	6	1		2						1
1870	7	8	7	1		4		1				2
1875	9	9	8	1		4		1	1			3
1880	13	14	9	1	1	5		3	3	1		4
1885	13	16	9	2	1	5		4	3	1		4
1890	14	18	10	2	1	5		4	3	2		5
1895	15	20	10	2	1	6		5	4	2		5
1900	19	22	10	3	1	6		5	6	3	2	5
1905	21	26	10	3	2	6		6	6	5	3	6
1910	22	32	11	3	2	7		7	6	7	3	8
1915	25	34	12	3	2	7		8	8	8	3	8
1920	28	36	12	3	2	7		9	10	9	4	8
1925	30	39	12	3	2	7		9	11	9	5	11
1930	32	39	12	3	2	7		9	13	9	5	11

Source: Boeck, 1931

Table 16: Technical Institutes at German Technical Universities, 1860–1930

I

Mining, Metallurgy, Materials, Processing Technologies

Year	Mining, Metallurgy, Metal processing					
	total	mining	metallurgy	metallography	mechanical technology	material testing
1860	2	1		1		
1865	2	1		1		
1870	3	1		1		1
1875	4	1	1	1		1
1880	7	2	2	1		2
1885	9	3	2	1		3
1890	9	3	2	1		3
1895	11	4	2	1		4
1900	12	4	2	2		4
1905	14	4	2	3		5
1910	24	6	3	7	1	7
1915	27	7	4	8	1	7
1920	35	12	4	9	1	9
1925	40	15	4	9	2	10
1930	44	17	5	9	3	10

Year	Materials and processing technologies								
	total	fuels	building materials	textile technol.	paper technol.	photo technol.	glass technology	painting technology	welding technology
1860									
1865									
1870									
1875									
1880	2			1		1			
1885	3			1		1		1	
1890	3			1		1		1	
1895	5			2	1	1		1	
1900	5			2	1	1		1	
1905	8			2	3	2		1	
1910	9			2	3	3		1	
1915	13			3	4	4	1	1	
1920	20	3	2	4	4	5	1	1	
1925	25	4	2	4	4	6	2	1	2
1930	30	6	2	4	4	7	3	1	3

Source: Boeck, 1931

within many fields of technical practice seems to gain speed. For example, the various materials and their processing technologies get specific research institutions (Table 16). Similarly machine building is specialized very early for steam engines, later for automobiles, aircraft and shipbuilding (Table 17).

If one goes beyond the disciplinary categories used by Boeck, an even greater degree of differentiation is evident. A listing like that of the research institutions in electrical engineering (Table 18) displays both inter-university differences and disciplinary specialization over time. On the other hand, seven research institutes for electrical engineering at the technical university of Berlin constrast sharply with the unstable range of specialties prevailing in teaching (cf. Table 7). It might not be too

Table 17: Technical Institutes at German Technical Universities, 1860-1930
II
Engineering, Construction, Surveying

Year	civil engineering, machine building, construction							
	total	civil engineering	machine building	steam engine	shipbuilding	aircraft construction	automobile construction	transportation
1860	1		1					
1865	1		1					
1970	1		1					
1875	2		1	1				
1880	3		2	1				
1885	3		2	1				
1890	4		3	1				
1895	5		4	1				
1900	10	1	8	1				
1905	19	6	10	1			1	1
1910	26	7	16	1			1	1
1915	30	9	18	1			1	1
1920	38	10	21	2		2	2	1
1925	44	10	25	2		2	2	3
1930	64	20	29	2	1	3	4	5

Year		energy technology; surveying				
	total	electrical engineering	light technology	heat and refrigerating technology	geodesy	techniques of measurement
1860					3	
1865					4	
1870					7	
1875					7	
1880					7	
1885	3	3			7	
1890	4	4			7	
1895	7	7			7	
1900	8	8			7	
1905	9	9			7	
1910	13	13			8	
1915	15	15			8	
1920	19	18	1		8	
1925	27	24	2	1	8	1
1930	38	34	2	2	8	1

Source: Boeck, 1931

Table 18: Electrical Engineering Institutes at German Universities and Technical Universities, 1882–1931

Academic institutions	Institutes for electrical engineering	
	Foundation	Name (of 1930)
TH Aachen	1883	Elektrotechn. Institut
	1910	Elektrotechn. Versuchsfeld
TH Berlin		Elektrotechn. Laboratorium
	1906	Elektrotechn. Versuchsfeld
	1911	Lab. für Fernmeldetechnik, Werk- u. Gerätebau
	1926	Hochspannungs-Institut
	1926	Inst. f. Elektr. Schwingungslehre u. Hochfrequenztechnik
	1927	H. Hertz-Institut f. Schwingungsforschung
	1927	Forschungsinstitut f. Schaltungen u. Getriebe
Univ. Bonn	1922	Röntgen-Forschungs-Institut
TH Braunschweig	1890	Inst. f. elektr. Meßkunde u. Hochspannungstechnik
	1920	Institut für elektr. Maschinen
	1921	Institut für techn. Elektronik
	1927	Inst. f. Fernmelde- u. Hochfrequenztechnik
TH Breslau	1910	Elektrotechn. Institut
TH Darmstadt	1882	Elektrotechn. Institut
	1906	Institut für Fernmeldetechnik
	1907	Hochspannungs-Laboratorium
	1911	Institut für Schwachstromtechnik
	1928	Röntgen-Institut
TH Dresden	1885	Elektrotechn. Institut Inst. f. Telegraphie u. Eisenbahnsignalwesen
	1920	Institut f. Starkstrom- u. Hochspannungstechnik
	1924	Lab. f. angewandte Röntgenographie
BA Freiberg	1885	Elektrotechn. Institut
Univ. Göttingen	1895	Institut für angewandte Elektrizität
TH Hannover	1884	Elektrotechn. Institut I Grundlagen der Elektrotechnik und Hochspannungstechnik II Elektrische Maschinen III Elektr. Anlagen u. Bahnen, Elektrowärmetechnik IV Elektr. Meßtechnik u. Fernmeldetechnik
	1923	Institut für Hochfrequenzphysik
	1924	Lab. f. elektr. Meß- u. Fernmeldetechnik
	1928	Forschungsinstitut für Elektrowärmetechnik
TH Karlsruhe	1896	Elektrotechn. Institut
	1928	Hochspannungsinstitut
TH München	1895	Elektrotechn. Institut
	1923	Hochspannungs-Lab.
	1924	Elektrophysikalisches Lab.
TH Stuttgart	1895	Elektrotechn. Institut
	1919	Röntgen-Lab.

Source: Boeck, 1931

far off to conclude that at least in the realm of technical sciences it is sometimes the research institutes which combine cognitive substance and social organization of disciplines, whereas teaching follows somewhat different paths of specialization. Whether findings and suggestions of this sort hold true must be left to future research along two lines: Cross-national comparisons on the macro-level; and case studies for disciplinary clusters. It is mainly on these levels that we can also hope to find answers to some other questions only occasionally addressed, which center around the *causes* of scientific differentiation. At this point the following causes can tentatively be linked to some major findings for the sake of a brief summary:

(1) A high degree of differentiation within teaching of the humanities seems attributable to the cultural and historical predilections of a wealthy bourgeosie interested in the liberal arts as a token of sophisticated consumption, available even to female students at a relatively early date.

(2) The natural sciences displayed less differentiation than expected, both in teaching and in research, compared to medicine and to the technical sciences. Two possible causative factors have been suggested in explanation. Differences in the labor market for academics may lead to a "scientification" of subject-matter handled by academic practitioners (physicians, engineers), whether determined by the "need" for more scientific knowledge or by social strategies of professionalization. Differences in the rigidity or flexibility of institutional boundaries may facilitate differentiation in the case of the technical sciences.

(3) Attention has frequently been paid to the differences between cognitive and institutional criteria of differentiation. It could well be that disciplinary differentiation is only poorly mirrored by intra-university indicators such as teaching and research. However, our findings seem to corroborate the existence of major differences between science, medicine and technology which have also been suggested by indicators appropriate for the cognitive-communicative entity of disciplines.[15] According to citation analyses, sciences are said to be prone to publishing, which leads towards a cumulative, close-knit structure by "research-front citation." On the other hand, technology does not grow cumulatively by paying attention to research-fronts enshrined in literature. Rather, technological research-fronts center around a "state of the art" familiar to a school of practitioners. Medicine, it is noted, goes both ways in that it is partly scientific, partly technological (or practical, i.e., clinical). It is tempting to visualize a decreasing order of powerful theoretical paradigms (or theories, or research programs) which might determine the increasing degree of cognitive differentiation within the sciences, medicine, and technology, and which might contribute to the respective degrees of differentiation within institutions of higher learning.

15. Derek I. de Solla Price, "Is Technology Historically Independent of Science? A Study in Statistical Historiography," in: *Technology and Culture*, 6 (1965), 553–568.