

# The Laboratory

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The laboratory is an exemplary site of modernity. In it, human and machine, organisms and mechanisms, body and technology combine and contrast with one another in order to produce new scientific facts. However, the beginnings of the laboratory are to be found in the early modern period. In particular, the workshops of alchemists and apothecaries were referred to as laboratories from the 17th century onwards. In the context of the university reforms of the 19th century, laboratories for chemistry, physics and biology increasingly became genuine sites of research. In the process, the distinct laboratory cultures in the various countries enriched each other, but also competed with one another, as the example of Franco-German relations shows. The laboratory and its iconography continue to define our understanding of scientific practice up to the present. At the same time, the laboratory is undergoing a process of dissolution and dispersal, as demonstrated by international macro-projects such as the Human Genome Initiative or the gigantic particle accelerators of current physics research. The laboratory has created history largely as an enclosed space. However, its future appears to be open.

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## Introduction

It is impossible to imagine science without laboratories. Our concept and image of science is fundamentally defined by those special buildings in which experts utilize vast technical resources to investigate natural phenomena and processes. A whole iconography exists, depicting the laboratory scientist in the midst of extremely complex and precise instruments examining an object in his hand or a model next to him, or looking at a brightly illuminated screen. However, the concept of the laboratory on which this iconography is based is being called into question by current developments in scientific practice. In particular, the large research centres for particle physics, such as Fermilab near Chicago or CERN in the canton of Geneva, and the large scientific projects of current biological research, such as the Human Genome Project, have contributed to the expansion of the laboratory into a network, which bears little resemblance to the traditional image of table-top experiments in an enclosed space. Nonetheless, there is no doubt that the architecturally delimited laboratory – like the factory, the railway station or the department store – is an exemplary site of modernity.<sup>1</sup>

▲ 1

During the last third of the 19th century in particular, buildings specially designed and equipped for the purpose became central institutions of scientific endeavour. Being involved in this endeavour no longer involved striving for the formation of individual character and personality, as was the case in the Romantic period. On the contrary, work in modern laboratories was increasingly carried out by demystified professionals who applied professional methods for creating innovations. As the workplace of the chemist, the physicist and the biologist – and subsequently also of other specialists, such as the psychologist, the archaeologist and the linguist, for example – the laboratory was transformed in this period to a space of knowledge which was primarily used for establishing new scientific facts. In turn, this special form of knowledge production was subject to an economic regime which was guided by the principles of specialization, mechanization and standardization (→ Media Link #ab). In the laboratory, the activities of the scientist assumed some of the characteristics of work at the conveyor belt. According to the frequently repeated expectation – and in some case the

fears of the historical protagonists of the late-19th century – novel facts could be produced by the dozen in the laboratory.<sup>2</sup>

▲2

It is not surprising, therefore, that the laboratory reflected the often contradictory tendencies of an increasingly industrialized society. Like a metropolis in miniature, the laboratory was a site where combinations and confrontations of human and machine, body and technology, organism and mechanism occurred, the effects of which were registered, measured and calculated. The multifarious materials of the laboratory environment and its products were a counterpoint to the idealism of scientific categories and values, and the increasingly divided nature of the research process contrasted with the ascription of discoveries and achievements to individuals – on the level of individual people, but also on the level of nations. Additionally, the routinization of work processes continuously conflicted with the principle of being open to the unexpected, a principle which is particularly characteristic of the activity of the modern scientist. The activity of the scientist became work in the sense of labour. At the same time, however, the scientist had to be prepared at all times to break with his routine in order to allow time and space for new and surprising developments. Thus, in the context of a society which regarded itself as progressive, the laboratory can be viewed as one of the sites where that society is "condensed". This applies to the production of that which is new, but also with regard to the problem of its representation. It is not sufficient to discover a new scientific fact; that fact must also be communicated to the public in a suitable manner.<sup>3</sup>

▲3

It is therefore surprising that a comprehensive history of the laboratory has not yet been produced. As a consequence, a comparative history (→ Media Link #ac) dealing with different national and cultural traditions of laboratory research or local aspects of the "laboratory revolution" in different disciplines is nowhere in sight. Not even overviews regarding the history of the laboratory such as exist for other spaces of knowledge – like the clinic or the observatory – have been produced.<sup>4</sup> The interest in researching day-to-day life in laboratories from an ethnological perspective, which has primarily been awakened by current trends in the sociology of scientific knowledge, has in recent years prompted a number of science historians to focus on individual laboratories. For example, detailed studies of the history of the physiological laboratories in Leipzig, Berlin and St. Petersburg exist. Relevant information about the founding and expansion of laboratories in individual national contexts has also been collected for other disciplines, such as, for example, physics in the German-speaking territories and also – though less comprehensively – ecology, ethology and evolutionary biology in the USA.<sup>5</sup> Thus far, however, no overall picture emerges from these contributions. And while these studies are quite varied, they almost always attempt to draw analogies between the laboratory and the factory, between scientification and industrialization, without expressly allowing room for the emergence of differences. As a result, the aspect of production is emphasized above the aspect of representation in a way which does not seem justified by historical events. Viewed from a perspective of historical proximity, the laboratory has never just been a space of knowledge production; it has also always been a place of illustrating, recording and documenting.<sup>6</sup> As we shall see, even the history of the knowledge of laboratories has been heavily dependent on drawings and other forms of graphical representation.

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## Laboratories in the Early Modern Period

The Latin term *laboratorium* (from the Latin term *labor*, meaning exertion, effort or work) was already in use in the medieval period. However, it was only in the late-16th century that the term assumed the meaning which it retains – in modified form – in modern languages today. In the 14th century, the term *laboratorium* meant simply a task or work. Around 1450, the first usages of the term relating to workshops can be detected in the context of monasteries. The term was apparently used parallel to terms such as *scriptorium* (copying room for scribes in medieval monasteries) and *dormitorium* (dormitory). In the 16th century, *laboratorium* primarily denoted workshops of alchemists, apothecaries and metallurgists, and subsequently came to refer to all accommodation in which natural phenomena and processes were explored by means of tools and instruments.<sup>7</sup>

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The modern generalization of the term "laboratory", with its focus on science, only occurred around the turn of the 20th century. As defined in the German encyclopedia *Brockhaus*, for example, in present-day German the term describes a "workspace for scientific and technical experiments, measurements, evaluation tasks, controls, etc., with the furnishings

and equipment required for these tasks". In a similarly general fashion, the current *Oxford English Dictionary* defines "laboratory" as a "building set apart for conducting practical investigations in natural science".<sup>8</sup>

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Due to the focus on gaining knowledge by practical material means, the history of the laboratory should be regarded as closely connected to the history of the anatomical theatre, of the cabinet of curiosities, of botanical gardens, of the observatory and of other knowledge spaces. In fact, one of the first laboratories for which detailed information exists was housed in Uraniborg, the research centre which was built and equipped in the late-16th century for the Danish astronomer Tycho Brahe (1546–1601) (→ Media Link #ad). Brahe's castle-like building on the island of Ven in the Öresund was divided into three parts: The upper floor contained astronomical equipment and was used for observing the sky; underneath this was the mathematical laboratory with tables for maps and calculations; and the cellar contained the laboratory of the alchemist. (→ Media Link #ae) This division and arrangement reflected Brahe's basic assumption that the microcosm and the macrocosm correspond to one another: "By looking up, I see downwards; by looking down, I see upwards." Astronomy corresponded with alchemy and vice versa, though the particular type of alchemistic activity involved was not specified.<sup>9</sup>

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There are no explicit references to astronomy in the engravings and woodcuts from the 16th century depicting laboratories. In the case of Hans Weiditz (ca. 1500–1536) (→ Media Link #af), for example, or Pieter Brueghel the Elder (1525/1530–1569) (→ Media Link #ag), the laboratory appears as a jumbled workspace around which numerous vessels and instruments are strewn. In the midst of like-minded others, the alchemist goes to work at a fireplace with his bellows, test tube and similar devices in a manner which remains vague.<sup>10</sup> (→ Media Link #ah) In contrast, the depiction of Brahe, and also of the chemists' house of Andreas Libavius (1555–1616) (→ Media Link #ai), show spacious accommodations in which the instruments are placed in an orderly fashion, as though waiting to be used in a precisely controlled manner.<sup>11</sup>

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An image from the same period depicts the basic components of the alchemistic laboratory which Count Wolfgang II of Hohenlohe (1546–1610) (→ Media Link #aj) had constructed at Weickersheim Castle. Similar to Weiditz and Brueghel, Paul van der Doort (around 1600) (→ Media Link #ak) depicts a fireplace with a vent in this copper engraving, but he arranges the test tubes and other vessels neatly on ledges, shelves and window-sills. Also, the alchemist is not at work handling equipment in this depiction. Instead, he is facing the books in a respectful pose.<sup>12</sup> (→ Media Link #al) Similarly static – though not as bright or as neat – are the paintings of David Teniers the Younger (ca. 1610–1690) (→ Media Link #am), who painted the motif of the "Alchemist in the Laboratory" in multiple variations during the 17th century. However, the depictions in these paintings are highly conventionalized and owe more to the genre paintings and still lifes on which they were based than to the reality of contemporary laboratories.<sup>13</sup>

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Around the end of the 17th century, the laboratory of the alchemist became the first anchor point for a new type of science. The aim of this science was to discover useful facts about nature by concrete actions and, in doing so, to contribute to a renewal of the world. Francis Bacon (1561–1626) (→ Media Link #an) and Robert Boyle (1627–1691) (→ Media Link #ao) promoted the view that human craft should "challenge" nature, in order to "subjugate" it for the sake of truth and usefulness. Boyle in particular, who conducted experiments in chemistry and physics in his own laboratory, established a practice in which experiments were performed before a learned audience and were then published in a manner designed to be easily understandable so that others could repeat them. This new, active method of "philosophizing" was also the aim of the first scientific academies: the Academia dei Lincei in Rome (1603), the Academia Naturae Curiosorum (later Leopoldina) in Schweinfurt (1652), and the Royal Society in London (1660).<sup>14</sup>

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There was a good reason why the early iconography of the laboratory frequently displayed books along with instruments. In this way, a new synthesis of manual and textual knowledge was represented visually, defining the laboratory not only as a place of manual work, but also as a space of reading and writing.

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Perhaps this constitutes the defining change in the modern history of the laboratory. Workshops as such had existed for a long time. However, the intention to use such spaces to discover scientific knowledge by means of physical activity, as well as to record this knowledge on paper, was new.

▲ 12

This interaction between scholarly and artisanal cultures during the Renaissance is the most important source for the transformation of values that led to the legitimization of bodily labour in a specially designed space as a means of producing scientific knowledge.<sup>15</sup>

Indeed, one could say that it was only through this interdependency of science, handicraft and writing that the term "laboratory" received its ultimate meaning: the production site of scientific knowledge.

▲ 13

However, even in the late-18th century this concept of laboratory had still not gained dominance. In spite of developments in chemical science – driven in particular by Antoine Lavoisier (1743–1794) (→ Media Link #ap) – the laboratory remained primarily a workshop, a place of material production. Even in the 1770s, the perception of the laboratory focused on the aspect of an increasingly rationalized activity in the developing area of chemical production. Thus, the laboratory is described in the *Encyclopaedia Britannica* (1771) as "the chemist's work-house", as the place where pharmacists and pyrotechnicians do their work.<sup>16</sup> The *Encyclopédie* (1765) of Denis Diderot (1713–1784) (→ Media Link #aq) and Jean-Baptiste le Rond d'Alembert (1717–1783) (→ Media Link #ar) defines the term in a similar way as a "lieu clos & couvert, salle, piece de maison, boutique qui renferme tous les ustensiles chimiques qui sont compris sous les noms de *fourneaux*, de *vaisseaux*, & d'*instruments* & dans lequel s'exécutent commodément les opérations chimiques".<sup>17</sup>

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However, the accompanying illustration (→ Media Link #as) enriched the iconography of the laboratory by adding a new aspect: the organized division of labour. As in previous depictions, the room is dominated by a fireplace and a vent hood. The bellows for the smiths is also reminiscent of considerably older pictures of alchemists by Weiditz and Brueghel, and the ledge of the chimney contains a carefully arranged row of vessels, some of which had already been used for alchemy. However, the room is populated by a collective which appears strikingly modern. Its members perform different tasks at different positions in the room: a chemist sitting at the table discusses the production of solutions with a physicist; on the left, a laboratory assistant brings coal from the cellar; and on the right, another laboratory assistant washes vessels. This is the first depiction of a laboratory which includes a principle of organisation that would subsequently become a fundamental aspect of scientific laboratories in the modern period.

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## The Laboratory Revolution of the 19th Century

In the early-19th century, there were two factors driving the development of the laboratory. Firstly, the reform of existing universities and the founding of new universities was an important stimulus. After 1800, universities were no longer only places for the collection and ordering of knowledge; they increasingly became places of scientific and technical research. Of fundamental importance in this context was the foundation of the Friedrich Wilhelm University in Berlin (1810), which quickly attained international renown. Secondly – and more importantly – the success of individual private teaching and research laboratories contributed to a dynamically expanding and widely distributed system of laboratories. Initially set up and directed by highly motivated university teachers on their own initiative, some of these private laboratories quickly developed a strong pulling power and were then integrated into the reformed universities.

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A typical example of this is again a chemical laboratory: namely the one which was set up by Justus Liebig (1803–1873) (→ Media Link #at) in the 1820s at his home university in Giessen after returning from a research trip to Paris. Liebig's laboratory was a prime example of the endeavour to establish comprehensive teaching based on experiments, in which there was no longer a contradiction between science and handicraft. Indeed both were now complementary aspects of a single activity whose primary goal was the gaining and transmission of knowledge. A famous

drawing by Wilhelm Trautschold (1815–1877) (→ Media Link #au) and Hugo von Ritgen (1811–1889) (→ Media Link #av) shows Liebig's laboratory as it was at the beginning of the 1840s. (→ Media Link #aw) With their *Innere Ansicht des Analytischen Laboratoriums in Gießen* (*Interior View of the Analytical Laboratory in Giessen*), Trautschold and von Ritgen show for the first time the laboratory as a vibrant place of teaching. They break with the static orderliness of the *Encyclopédie* and show a space where students and teachers from various countries work as a collective.<sup>18</sup>

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Significantly, instead of Liebig himself, the laboratory assistant, who – among other things – was responsible for supplying the basic chemicals and the glass and porcelain vessels, is at the centre of the drawing. The principle of the division of labour is also reaffirmed and highlighted. The laboratory does not only appear as a workshop, as a manufactory, but also as a kind of exchange or transit point of discourses, concepts and recipes, where ideas and physical materials could be confronted with each other and combined in increasingly new ways. Additionally, one of Liebig's interior architectural innovations is shown in the drawing. In older laboratories, the experimentation tables were usually placed against the wall, with one free-standing table placed in the centre. Liebig's contribution to the rearrangement of the laboratory was to distribute the experimentation tables throughout the entire room. This arrangement meant that more students could be accommodated and more experiments could be performed simultaneously, while the laboratory director still had a good overview and could easily move from one table to the next.<sup>19</sup>

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Building on Liebig's groundwork, the establishment of modern chemistry in the German-speaking territories is regarded as one of the great success stories of science in the 19th century. Around 1850, another teaching and research laboratory for chemistry was established in Heidelberg under the direction of Robert Bunsen (1811–1899) (→ Media Link #ax). It led development internationally, not least because teaching there was enriched by impressive demonstrations of experiments. In addition to the rooms for work and practise, the weighing room, the stores and the library, the lecture theatre together with its preparation chamber at the back thus became an important component of laboratory buildings. In the 1860s, completely new institutes for chemistry came into existence in Bonn, Berlin and elsewhere. These were quickly recognized throughout Europe as being exemplary with regard to their exterior and interior architecture, as well as their technical equipment.<sup>20</sup>

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The "laboratory revolution" occurred somewhat later in other disciplines. The first physics laboratory in the modern sense of the word was opened in 1833 by Wilhelm Weber (1804–1891) (→ Media Link #ay) at Göttingen University. Previously, only physics "cabinets" had existed, that is, individual rooms in which collections of instruments were kept. In 1843, Heinrich Gustav Magnus (1802–1870) (→ Media Link #az) set up a physics laboratory in Berlin. Franz Neumann (1798–1895) (→ Media Link #b0) followed suit in Königsberg in 1847. However, both were "private laboratories which were located in the living accommodation of the founders and were thus only accessible to others with the special permission of the founders".<sup>21</sup> Only in 1846 was a (teaching) laboratory opened at Heidelberg University. In 1874, a newly built laboratory was completed in Leipzig. In subsequent years, similar teaching and research laboratories followed in Berlin (1878), Würzburg (1879) and Strasbourg (1882). The *Technisch Physikalische Reichsanstalt* (Imperial Physico-Technical Institution)<sup>22</sup> opened in Berlin in 1887 and remained the biggest laboratory complex for engineering and physical fundamental research in the world up to the First World War.

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The laboratory revolution took a similar path in another important area of science in the 19th century: the area of experimental physiology. The first physiological laboratory in the German-speaking territories was the institute in Breslau, which Jan Purkinje (1787–1869) (→ Media Link #b1) officially directed from 1839. Inspired by the sensualistic pedagogy of Johann Heinrich Pestalozzi (1746–1827) (→ Media Link #b2), Purkinje practiced a form of experimentation teaching based on *Anschaung* ("visual perception"). However, until the 1870s, this ideal was only rarely put into practice due to a lack of appropriately equipped physiological teaching and research laboratories, as well as the cost of the appropriate instruments. Thus, the institute of Johannes Müller (1801–1858) (→ Media Link #b3), which produced many important physiologists of the 19th century, prescribed participation in practical experiments in physiology, but could not provide the instruments required for this purpose. Instead, the students themselves had to make or buy them, and bring them to class. Additionally, around 1840 it was not at all uncommon for physiologists such as Theodor Schwann (1810–1882) (→ Media Link #b4) or Emil Du Bois-Reymond (1818–1896) (→ Media Link #b5) to experiment at home or in a hotel room. Modern laboratories for physiology only came into being later: in 1869 in Leipzig,<sup>23</sup> in 1872 in Utrecht,<sup>24</sup>

in 1877 in Budapest<sup>25</sup> and Berlin,<sup>26</sup> in 1885 in Strasbourg,<sup>27</sup> and so on. The importance of demonstration lectures for the teaching of experimental knowledge is demonstrated by the fact that Johann N. Czermak (1828–1873) (→ Media Link #b6), a former student of Purkinje, had a *spectatorium* erected at his own expense for the teaching of physiology in the early 1870s in Leipzig.<sup>28</sup> This *spectatorium* subsequently served as an example for the building of similar viewing theatres at university institutes.<sup>29</sup>

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It is only in the context of these developments, i.e. the emergence – particularly in the German-speaking territories – of specific laboratory cultures in chemistry, physics and physiology, i.e. biology, that the term "laboratory" acquired the breadth of meaning which we are familiar with today. In the dictionaries and encyclopaedias of the 19th century, "laboratory" is almost universally equated with "chemical laboratory". This prevailing definition was only revised in 1898 when the expression was described as "generally" applying to a room "in which chemical, pharmaceutical, physical or technical work is performed".<sup>30</sup>

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The iconography of the laboratory had also changed noticeably by that time. On the one hand, the laboratory appears as the background in paintings depicting eminent scientists, such as Louis Pasteur (1822–1895) (→ Media Link #b7), as geniuses working largely alone, thereby harking back to earlier depictions of alchemists. On the other hand, laboratories appear as anonymous architectural plans and photographs of interior rooms which are usually empty of people.

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From the 1870s, detailed descriptions of laboratories also appeared in scientific journals. Generally, such descriptions were produced by the directors of the institutions in question. Besides floor plans, such descriptions often presented various views, cross-sections and drawings of individual details such as experimentation tables, cupboards or darkening facilities in the lecture theatre. From the end of the 1880s, similar depictions can also be found in construction journals and architecture handbooks.

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## Laboratory Interactions Around 1870

In this period, knowledge of laboratories was increasingly disseminated by such books and articles. However, publications did not represent the only source of such knowledge: in particular, travel – study trips and research trips – served to spread it. In fact, besides articles and books, it was primarily visits and sojourns abroad, and increasingly – from the 1910s and 1920s – international collaborations and exchange programmes which led to communication between laboratory workers in various countries within Europe and to interactions between different laboratory cultures. Liebig had travelled to Paris in the first third of the 19th century to witness the experimentation teaching of Joseph Louis Gay-Lussac (1778–1850) (→ Media Link #b8), Louis Jacques Thénard (1777–1857) (→ Media Link #b9) and other chemists. In the early 1840s, however, chemistry students from France and other countries attended experimentation lessons in Liebig's laboratory in Giessen. Among those students were Victor Regnault (1810–1878) (→ Media Link #ba), Jules Pelouze (1807–1867) (→ Media Link #bb) and Adolphe Wurtz (1817–1884) (→ Media Link #bc).<sup>31</sup>

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Wurtz subsequently became the director of his own laboratory for organic chemistry at the medical faculty in Paris. Having been promoted to Dean, he campaigned in the 1860s for the setting-up of appropriate teaching and research facilities for students of medicine. To this end, in the late 1860s he visited a number of laboratories at German-speaking universities which were considered as leaders in this respect. This journey was undertaken in an official capacity. The education minister Victor Duruy (1811–1894) (→ Media Link #bd) had entrusted Wurtz on June 5th, 1868 with the task of "viewing and studying" scientific facilities at German-speaking universities, in particular, those in Göttingen, Greifswald, Berlin, Leipzig, Prague, Vienna, Munich, Würzburg and Heidelberg. According to Duruy's instructions, Wurtz was to pay particular attention to laboratories, scientific collections, clinics and institutes for physiology and pathology. The motive was not only scientific, but also explicitly political. Duruy requested that Wurtz collect all the information about the scientific institutions in the neighbouring country which could be used for the benefit of "national education" in France.<sup>32</sup>

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The report of the trip, which Wurtz published in 1870, concentrated on descriptions of laboratories. The first part contained descriptions of chemical laboratories; the second part dealt with laboratories of physiology; while the third and last part was dedicated to the institutes for anatomy and pathological anatomy. Particular importance was given to drawings. In 17 illustrations, Wurtz reproduced detailed floor plans of the laboratories he had visited. Additional illustrations in the text gave views and cross-sections of the respective laboratory buildings. In Wurtz's opinion, combining these illustrations with the descriptive texts (that elucidated the principles governing laboratory operation as well as the financial situation of the teaching and research institutions Wurtz had visited) was the best way of fulfilling the task entrusted to him. According to Wurtz, the report presented his impressions and memories in a balanced fashion: It avoided any uncalled for enthusiasm, which might have caused him to overstate the "glorious endeavours" of a foreign nation, as much as it avoided a weakness which would have caused him not to recognize these endeavours and to remain silent about them.<sup>33</sup>

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As the physiologist Claude Bernard (1813–1878) (→ Media Link #be) began his lectures on general physiology in the summer term of 1870, he made reference to Wurtz's report. Bernard began with a brief overview of the history of his subject while emphasizing that not only "new discoveries and ideas" had been decisive in the development of physiology. According to Bernard, the "materials of work" and the "culture" of the discipline were also decisive factors.<sup>34</sup> What Bernard was referring to was the institutional context and technical equipment of physiological research. Given that three years earlier he himself had compiled an officially-commissioned report on the progress of general physiology in France, he was particularly familiar with these considerations.

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Speaking only a few weeks before the outbreak of war with Prussia, Bernard contrasted in his lectures the poor state of physiology in France with the "installations splendides" available to physiologists in the neighbouring country. To demonstrate the contrast, he described the building and equipment of a top-class laboratory to his audience. The laboratory in question was Carl Ludwig's (1816–1895) (→ Media Link #bf) "Physiological Institute", which opened in 1869 in Leipzig and was the first institution of its kind to be fitted with a steam-engine as a central power source. But Bernard did not limit himself to a verbal description. He used visual aids to portray Ludwig's laboratory:

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Je mets sous vos yeux le plan d'un de ces laboratoires, c'est celui de Leipzig dirigé par Ludwig ... Je veux que vous voyiez par cet exemple la richesse de ces installations scientifiques dont nous n'avons pas même l'idée en France.<sup>35</sup>

The floor plan mentioned is the one included in the report by Wurtz. (→ Media Link #bg) The horseshoe shape of the Leipzig laboratory building is immediately evident in the drawing. Contained within the horseshoe-shaped building were the workspaces for performing experiments in vivisection, biophysics and biochemistry, as well as rooms for spectroscopy, microscopy and work with mercury, in addition to a library. In the centre was the lecture theatre with space for an audience of around 150. The institute also contained living accommodation for the director and a mechanic, while the animals required for experimentation were kept in the garden. Rabbits, birds and frogs were kept in stalls, cages and aquariums which were erected opposite the opening of the horseshoe.

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Bernard emphasized in particular this differentiation in Ludwig's laboratory. He found the division between different types of workspaces particularly important: "Il est très important pour une bonne économie expérimentale", he declared, "d'avoir des pièces séparées pour les expériences qui réclament une instrumentation spéciale. On évite ainsi toutes les pertes de temps qu'exigerait une nouvelle installation et la réunion de matériaux quelquefois très difficiles à rassembler. Cette disposition, qui n'est au fond qu'une bonne administration du temps, pourrait d'ailleurs s'étendre à tous les travaux scientifiques."<sup>36</sup>

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Here the laboratory not only appears as an exemplary space of knowledge. Simultaneously, this space becomes the embodiment of a particular time regime which is also a regime of scientific work. "Time is space" is the paradoxical phrase coined by Bernard regarding activity in the modern laboratory while holding the report of Wurtz in his hand.

However, the Wurtz report of 1870 did not result in the direct transfer of the foreign model to France. The considerable array of institutions in the German-speaking territories described above, which increased even further after the foundation of the *Kaiser-Wilhelm-Gesellschaft zur Förderung der Wissenschaften* (Kaiser Wilhelm Society for the Advancement of Science) in 1911, greatly outnumbered the corresponding institutions in France, which only included the laboratories of Wurtz at the *Ecole de médecine* and of Bernard at the *Collège de France* until Étienne-Jules Marey's (1830–1904) (→ Media Link #bh) *Station physiologique* and the Pasteur Institute were added in the 1880s. Visits by German physiologists to laboratories in France were accordingly rare in this period.

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One of the few examples of such visits was the "scientific journey" to Paris, Lyon und Bordeaux undertaken by the physiologist Maximilian von Frey (1852–1932) (→ Media Link #bi), who worked in Leipzig at that time. In his short report, von Frey only mentions the laboratories of Marey and Pasteur in Paris and otherwise limits his descriptions to technical details of physiological instruments, such as the respiration apparatuses of Auguste Chauveau (1827–1917) (→ Media Link #bj) and Félix Jolyet (1841–1922) and the calorimeter of Arsène d'Arsonval (1851–1940) (→ Media Link #bk).<sup>37</sup>

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This further demonstrates the fact – mentioned above with regard to physiological laboratories<sup>38</sup> – that the spread of modern laboratory cultures within Europe was not a uniform and one-dimensional process which can be adequately described using terms such as "rationalization", "mechanization" or "industrialization". On the contrary, it was a multi-faceted process of transportation and transfer, of adaptations to local contexts and traditions, but which also contained individual examples of counter-transfers. Even in cases where an explicit attempt was made to follow the example of German-speaking institutions, translations occurred on the most varied of levels – the level of texts, of instruments and of experimentation procedures – and the information transferred was changed in the process.<sup>39</sup>

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A further result of these processes of transportation and translation can be seen in the emergence of "industrial laboratories" at the turn of the 20th century. In the European context, this development was linked to the rapid growth of the dye industry, which in turn must be viewed in the context of the history of modern chemistry. Heinrich Caro (1834–1910) (→ Media Link #bl), who in 1868 assumed a leading position at the recently founded Badische Anilin- und Sodafabrik (BASF), and Eugen Lucius (1834–1903) (→ Media Link #bm), a co-founder of the company which was subsequently known as Hoechst, had both trained as chemists. Lucius had even been a student of Bunsen. In the 1870s and 1880s, companies such as Hoechst, Agfa and Bayer began to employ chemists in large numbers, in some cases in laboratories specially built by the companies. Similar developments occurred in the USA at the same time, albeit in other branches of industry. In 1875, the Pennsylvania Railroad Company set up its own research laboratory, followed by East Man Kodak in 1886 and General Electric in 1900. As in Europe, the goal of these laboratories was to produce useful knowledge which could be employed in the struggle for commercial advantages. Instead of publishing articles in scientific journals, the researchers in these laboratories were interested in getting patents recognized so as to have commercial control of the processes and products involved in their research. To a degree, they resembled the alchemists in their laboratories: They produced results in a very deliberate fashion, and the means by which these results were obtained was only shared with other insiders.<sup>40</sup>

▲ 36

Another result of the processes of transportation and translation which the laboratory experienced at the turn of the 20th century was the emergence of large-scale laboratories, usually in military complexes. Typical of this development was the restructuring of the Kaiser Wilhelm Institute for Physical Chemistry and Electrochemistry in Berlin by Fritz Haber (1868–1934) (→ Media Link #bn) during the First World War. At the end of 1918, this institute had 1,450 employees. Most of them were engaged in the development of gas weapons and means of protecting against gas weapons. The research institutions which emerged during the Second World War were even larger. One of the most famous was the Los Alamos National Laboratory founded by the government of the USA in 1943, in which the atomic weapons programme of the United States was initiated as part of the Manhattan Project. Employing at one time more than 120,000 people, this project marked the irreversible entry into the era of "Big Science", in which the growth of science is no



longer exclusively measured by the number of publications or patents, growth in the numbers of scientific personnel, or the level of state funding devoted to research, but also by the exponential increase in the energy usage of particle accelerators.<sup>41</sup> The 20th century saw the intensification of the founding of industrial laboratories and the emergence of large-scale laboratories, which increased the worldwide competition affecting private and public laboratories of all types and sizes. Simultaneously, the "dispersal of the laboratory" which is characteristic of the present time began.

▲ 37

## Conclusion

Laboratories are exemplary sites of modernity. However, they do not only function as passive reflectors of an increasingly globalized culture and society, but also as active examples, as forces for change whose influence is by no means limited to science. Besides new knowledge and technologies, laboratories produce personalities. They train scientists and researchers, who learn to strive with all their being for high ideals and, as part of a collective, to enter into a performance-related competition which is supposed to be governed by transparent rules and fair behaviour. In this and other regards, it is not possible to draw direct analogies between the laboratory and the factory. As a site of education and practice, comparisons between the laboratory and, for example, the gymnastics hall or the sports field are just as valid. In fact, this parallel is drawn particularly in US universities in order to demonstrate to a fast-growing number of students the guiding principles of academic institutions which subscribe to the principle of the unity of research and teaching according to the European example. Not only the university becomes "a laboratory where everyone is busy, and where enthusiasm in study is the predominant characteristic",<sup>42</sup> as the founder of the Johns Hopkins University put it in 1883. In the programmatic view of Daniel C. Gilman (1831–1908) (→ Media Link #bp), the whole world is "a great laboratory, in which human society is busy experimenting".<sup>43</sup> This view of an "experimentation society" is another aspect of the opening and subdivision of the laboratory which has fundamentally changed our concept of what science means.

▲ 38

Henning Schmidgen, Berlin

## Appendix

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- <sup>3</sup> Knorr-Cetina, *Das naturwissenschaftliche Labor* 1988; also Latour, *Give Me a Laboratory* 1983.
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- <sup>12</sup> See Smith, *Laboratories* 2006, pp. 290–293.
- <sup>13</sup> Hill, *The Iconography of the Laboratory* 1975; on Teniers, see also Shapin, *The House of Experiment* 1988, p.

14. ^ On Boyle, see Shapin / Schaffer, *Leviathan and the Air Pump* 1995.
15. ^ Smith, *Laboratories* 2006, p. 296.
16. ^ *Encyclopaedia Britannica* 1771, p. 857.
17. ^ *Encyclopédie* 1765, p. 145 ("enclosed and covered place, room, part of a house or shop which contains all chemical utensils included under the terms ovens, vessels and instruments, and in which chemical activities can be readily performed." Transl. by N.W.).
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34. ^ Bernard, *Leçons* 1885, p. 15.
35. ^ *Ibid.*, p. 15 ("I place before you the floor plan of one of these [exemplary] laboratories, the one in Leipzig which is directed by Ludwig. ... By this example, I want you to see the riches of these scientific installations, of which we in France have no idea." Transl. by N.W.).
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42. ^ Owens, *Pure and Sound Government* 1985, p. 184.
43. ^ *Ibid.*

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## Citation

Schmidgen, Henning: The Laboratory, in: European History Online (EGO), published by the Institute of European History (IEG), Mainz 2011-08-08. URL: <http://www.ieg-ego.eu/schmidgenh-2011-en> URN: urn:nbn:de:0159-2011080805 [YYYY-MM-DD].

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
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

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



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



#### Link #b3

- Johannes Müller (1801–1858) VIAF   (<http://viaf.org/viaf/100203900>) DNB  (<http://d-nb.info/gnd/118585053>) ADB/NDB  (<http://www.deutsche-biographie.de/pnd118585053.html>)





#### Link #b4

- Theodor Schwann (1810–1882) VIAF   (<http://viaf.org/viaf/8183370>) DNB  (<http://d-nb.info/gnd/118762834>) ADB/NDB  (<http://www.deutsche-biographie.de/pnd118762834.html>)

#### Link #b5

- Emil Du Bois-Reymond (1818–1896) VIAF   (<http://viaf.org/viaf/8178869>) DNB  (<http://d-nb.info/gnd/118527665>) ADB/NDB  (<http://www.deutsche-biographie.de/pnd118527665.html>)





#### Link #b6

- Johann N. Czermak (1828–1873) VIAF   (<http://viaf.org/viaf/54908970>) DNB  (<http://d-nb.info/gnd/116776951>) ADB/NDB  (<http://www.deutsche-biographie.de/pnd116776951.html>)

#### Link #b7

- Louis Pasteur (1822–1895) VIAF   (<http://viaf.org/viaf/54152415>) DNB  (<http://d-nb.info/gnd/118591959>)


#### Link #b8

- Joseph Louis Gay-Lussac (1778–1850) VIAF   (<http://viaf.org/viaf/41893883>) DNB  (<http://d-nb.info/gnd/118716581>) ADB/NDB  (<http://www.deutsche-biographie.de/pnd118716581.html>)

#### Link #b9

- Louis Jacques Thénard (1777–1857) VIAF   (<http://viaf.org/viaf/56695277>) DNB  (<http://d-nb.info/gnd/117302023>)

#### Link #ba

- Victor Regnault (1810–1878) VIAF   (<http://viaf.org/viaf/2584163>) DNB  (<http://d-nb.info/gnd/118788132>) ADB/NDB  (<http://www.deutsche-biographie.de/pnd118788132.html>)

#### Link #bb

- Jules Pelouze (1807–1867) VIAF   (<http://viaf.org/viaf/39487493>) DNB  (<http://d-nb.info/gnd/119390256>)

#### Link #bc

- Adolphe Wurtz (1817–1884) VIAF   (<http://viaf.org/viaf/54924315>) DNB  (<http://d-nb.info/gnd/11737587X>)





#### Link #bd

- Victor Duruy (1811–1894) VIAF   (<http://viaf.org/viaf/66562025>) DNB  (<http://d-nb.info/gnd/116256893>)

#### Link #be


- Claude Bernard (1813–1878) VIAF   (<http://viaf.org/viaf/73849966>) DNB  (<http://d-nb.info/gnd/118656244>)

#### Link #bf




- Carl Ludwig (1816–1895) VIAF   (<http://viaf.org/viaf/62343814>) DNB  (<http://d-nb.info/gnd/118729470>) ADB/NDB  (<http://www.deutsche-biographie.de/pnd118729470.html>)

#### Link #bg







-  (<http://www.ieg-ego.eu/en/mediainfo/plan-of-the-ground-floor-in-the-leipzig-laboratory-for-physiology-1870?mediainfo=1&width=900&height=500>)  
Leipzig Laboratory for Physiology (1870)

#### Link #bh

- Étienne-Jules Marey (1830-1904) VIAF   (<http://viaf.org/viaf/54170694>) DNB  (<http://d-nb.info/gnd/11906278X>)

#### Link #bi

- Maximilian von Frey (1852–1932) VIAF   (<http://viaf.org/viaf/15569376>) DNB  (<http://d-nb.info/gnd/118955144>) ADB/NDB  (<http://www.deutsche-biographie.de/pnd118955144.html>)





#### Link #bj

- Auguste Chauveau (1827–1917) VIAF   (<http://viaf.org/viaf/9706535>) DNB  (<http://d-nb.info/gnd/117655708>)





#### Link #bk

- Arsène d'Arsonval (1851–1940) VIAF   (<http://viaf.org/viaf/76409478>) DNB  (<http://d-nb.info/gnd/132415992>)





#### Link #bl

- Heinrich Caro (1834–1910) VIAF   (<http://viaf.org/viaf/15563415>) DNB  (<http://d-nb.info/gnd/118668471>) ADB/NDB  (<http://www.deutsche-biographie.de/pnd118668471.html>)

#### Link #bm

- Eugen Lucius (1834–1903) VIAF   (<http://viaf.org/viaf/81323537>) DNB  (<http://d-nb.info/gnd/137083955>) ADB/NDB  (<http://www.deutsche-biographie.de/pnd137083955.html>)

#### Link #bn

- Fritz Haber (1868–1934) VIAF   (<http://viaf.org/viaf/37018070>) DNB  (<http://d-nb.info/gnd/118699814>) ADB/NDB  (<http://www.deutsche-biographie.de/pnd118699814.html>)

#### Link #bp

- Daniel C. Gilman (1831–1908) VIAF   (<http://viaf.org/viaf/30292566>) DNB  (<http://d-nb.info/gnd/116626216>)





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<http://www.ieg-ego.eu> ISSN 2192-7405