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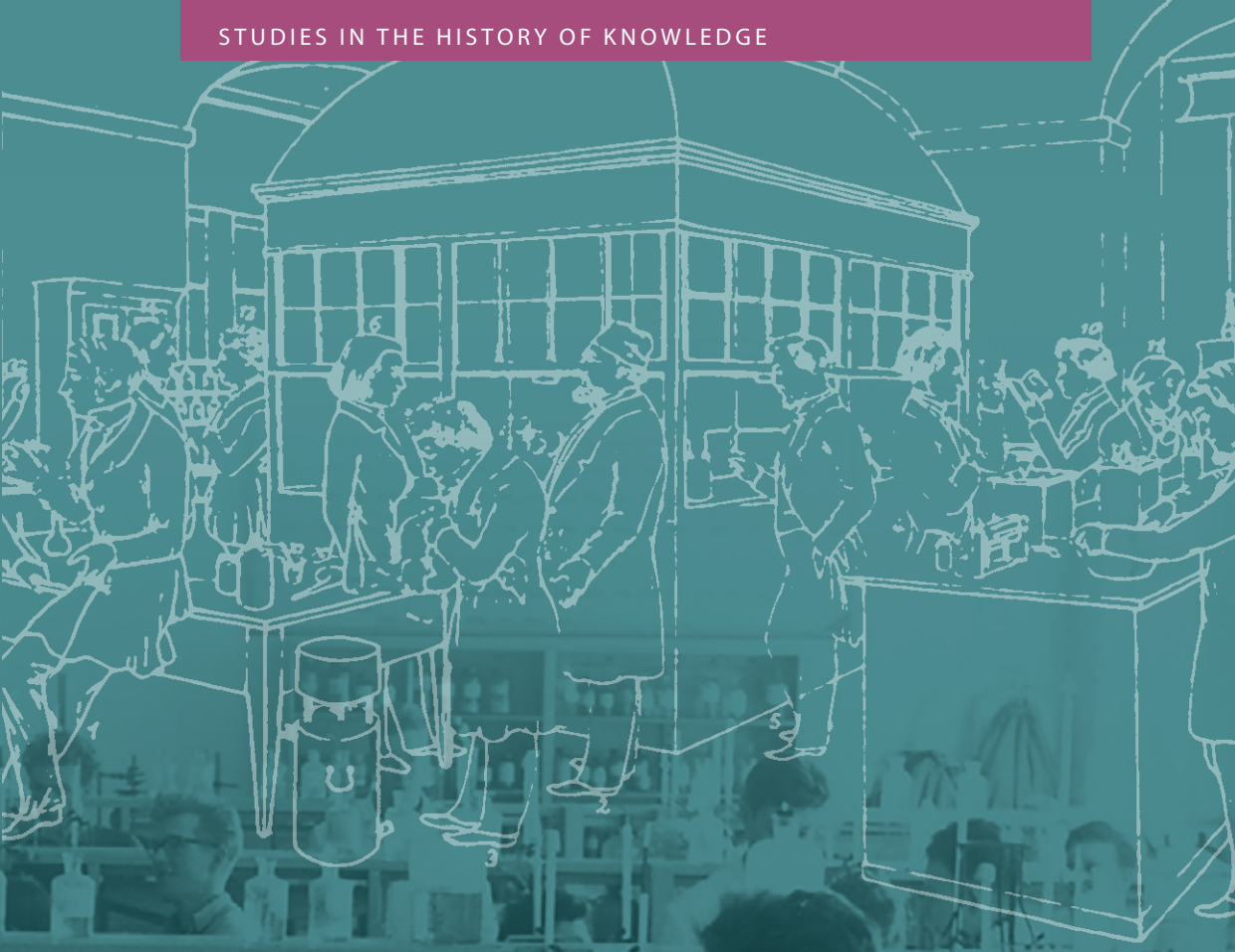

Edited by Klaas van Berkel and Ernst Homburg

The Laboratory Revolution and the Creation of the Modern University, 1830-1940

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Preface

In this volume we have brought together more than a dozen new studies about the rapid, even revolutionary, development of the laboratory in the nineteenth and early twentieth centuries, especially in the context of the expanding universities. The importance of the research laboratory for the development of science in the second half of the nineteenth century is uncontested, as is the revival of the universities as centres of innovative science and scholarship in the same period. The connections between these two revolutionary developments are seldom studied in detail though. This is partly due to a current lack of interest in laboratory studies as well as in institutional history, but a main reason is also that histories of universities are commonly written by authors with a background in the humanities. This collection of essays tries to bridge the gap and bring representatives from the sciences and the humanities together in a concerted effort to integrate laboratory studies and the history of universities. We have cast a wide net ranging from detailed studies of particular universities and laboratories to general accounts of the laboratory ethos emerging in the nineteenth century, as well as of the rise of the laboratory as a publishing house. Of course, the treatment of this theme is not exhaustive, and we therefore hope that this volume will stimulate others to continue the study of the co-creation of the modern research laboratory and the modern research university.

Klaas van Berkel and Ernst Homburg
November 2022

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Part I

The Laboratory Revolution: Origins and Impact

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1 The Joint Emergence of the Teaching-Research Laboratory and the Modern University: An Introduction

Klaas van Berkel and Ernst Homburg

Abstract
The tremendous impact of the Laboratory Revolution on the universities as centres of science and learning has thus far received too little attention. Yet the rise of the modern teaching and research laboratory within the university dramatically changed the outlook, the social structure, and the very idea of the university. This introduction offers a brief survey of the long road to the Laboratory Revolution, a review of recent historiography, and an outline of each of the contributions to this volume.

Keywords: Laboratory Revolution, university science, historiography, Justus Liebig, scientific ethos

Introduction

In the public imagination a scientist today is someone in a laboratory. A man or a woman in a white coat, with safety glasses and a tube in his or her hand. Over the course of the nineteenth century, the laboratory became the ultimate place where new knowledge is created. By the end of that century, the former workplace of chemists, situated on the fringes of the learned world, had turned into a central and indispensable element in the infrastructure of science and science education. A true 'laboratory revolution' had taken place, changing both the sciences and the universities.

Over the past decades, the rise of the laboratory, its growth in numbers, its architectural presentation, and its internal organization have been studied by many historians. Another subject of detailed research has been

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the tremendous changes laboratory research brought about in the kind of knowledge we strive for.[1] One important but understudied aspect of the Laboratory Revolution, however, is the impact it had on the university as a centre of science and learning. Of course, not all laboratories were university laboratories. Private laboratories remained important for a long time, and today industrial and testing laboratories employ more researchers than university laboratories. But the rise of university laboratories deserves special treatment because it is there that new generations of researchers are trained and educated. In the nineteenth century simple lecture halls gave way to purpose-built laboratories, which would dominate the cityscape. Even academic disciplines that ostensibly needed no laboratory space to develop, such as astronomy and linguistics, each acquired their own laboratories. Other branches of the humanities, like history, employed the idea of a laboratory metaphorically by saying that their libraries, archives, and seminars were their workplaces, their laboratories. Finally, the nature of the academic community changed tremendously as a result of the rise of the laboratory, with each laboratory becoming a small or not-so-small self-contained community of professors, technical assistants, students, and administrative personnel. The rise of the laboratory was a major factor in the creation of the modern research university between 1850 and the first half of the twentieth century.

The Long Road to the Laboratory Revolution

The laboratory has a long history. Originally it was the workshop of an (al) chemist or an apothecary, where medicines were prepared or other chemical substances were made. In the seventeenth century several universities in Germany, Italy, the Netherlands, and some other Western European countries established chemical laboratories within their faculties of medicine that complemented anatomical theatres and botanical gardens as teaching facilities for students of medicine. In several instances the lectures on chemistry took place in the private laboratory of the professors. During the seventeenth and eighteenth centuries, the term 'laboratory' was used almost exclusively for a place where chemical operations such as distillation were performed.[2] Until the early nineteenth century, laboratories within

1 Robert E. Kohler, 'Lab History: Reflections', *Isis*, 99 (2008), 761-68.

2 The only exception we are aware of is Leiden University, where the *Theatrum physicum* was also called *Laboratorium physicum* in several eighteenth-century sources. See: Cornelis de

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the universities were in many respects similar to artisanal laboratories. Both were dominated by fireplaces, furnaces, distillation apparatus, and related chemical equipment.[3]

Here we will focus on the situation in the universities. In many of the private and public teaching laboratories of the seventeenth and eighteenth centuries, chemistry professors allowed some of their students to get experience through the practice of chemistry. This was the case, for instance, in Marburg, Utrecht, Leiden, and Glasgow. These lessons in practical chemistry were then not part of a regular curriculum, but a favour granted—often against payment—by the professor.[4]

During the last three decades of the eighteenth century, a few laboratories started to offer practical training in chemistry to far larger groups of the students. Starting in 1779, several private pharmaceutical institutes that offered practical courses were erected in Germany by pharmacists and chemists such as Johann Christian Wiegleb, Johann Bartholomäus Trommsdorff, Sigismund Friedrich Hermbstädt, and, later, Justus Liebig. During the early decades of the nineteenth century, several of these institutes became integrated into the local university.[5]

Pater, 'Experimental physics', in Th.H. Lunsingh Scheurleer and G.H.M. Posthumus Meyjes, eds., *Leiden University in the Seventeenth Century: An Exchange of Learning* (Leiden: Universitaire Pers Leiden/ E.J. Brill, 1975), pp. 308–27, esp. pp. 315, 318-19, 321-22.

3 Frederic L. Holmes, *Eighteenth-Century Chemistry as an Investigative Enterprise* (Berkeley, CA: Office for History of Science and Technology, 1989); Ernst Homburg, 'The Rise of Analytical Chemistry and its Consequences for the Development of the German Chemical Profession (1780–1860)', *Ambix*, 46 (1999), 1–32; Ursula Klein, 'Die technowissenschaftlichen Laboratorien der Frühen Neuzeit', *NTM*, 16 (2008), 5–38; Ursula Klein, 'The Laboratory Challenge: Some Revisions of the Standard View of Early Modern Experimentation', *Isis*, 99, 769–82; Ursula Klein, 'Chemical and Pharmaceutical Laboratories before the Professionalization of Chemistry', in Marta C. Lourenço and Ana Carneiro, eds., *Spaces and Collections in the History of Science. The Laboratorio Chimico Overture* (Lisbon: Museum of Science of the University of Lisbon, 2009), pp. 3–12.

4 Owen Hannaway, 'Johann Conrad Barchusen (1666–1723) – Contemporary and Rival of Boerhaave', *Ambix*, 14 (1967), 96–111; Frederic Lawrence Holmes, 'Laboratory, Chemical', in J.L. Heilbron et al., eds., *The Oxford Companion to the History of Modern Science* (Oxford: Oxford University Press, 2003), pp. 441–2; Robert G.W. Anderson, 'The Creation of the Chemistry Teaching Laboratory', in Lourenço and Carneiro, eds., *Spaces and Collections in the History of Science*, pp. 13–23, esp. p. 14; Marieke M.A. Hendriksen and Ruben E. Verwaal, 'Boerhaave's Furnace. Exploring Early Modern Chemistry through Working Models', *Berichte zur Wissenschaftsgeschichte*, 43 (2020), 385–411 (pp. 392–93).

5 Dieter Pohl, 'Zur Geschichte der pharmazeutischen Privatinstitute in Deutschland von 1779 bis 1873' (PhD diss., Marburg, 1972); A. Wankmüller, 'Pharmazeutische Privatinstitute und Universitäten zu Beginn des 19. Jahrhunderts', *Deutsche Apotheker-Zeitung*, 113 (1973), 636-39, 673-76; H.R. Abe, 'Zur Geschichte der ersten pharmazeutischen Lehranstalten Deutschlands', *Medicamentum* (Berlin), 17 (1976), 93-95.

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At about the same time some universities and mining academies set up chemistry courses for future mining officials and supervisors of mines. From 1767 to 1768 a large new laboratory was erected at the University of Uppsala for the professor of chemistry Torbern Bergman, in which excellent facilities for experimental research and for the teaching of chemistry were combined. According to Marco Beretta, 'Bergman's laboratory was attended by hundreds of students, many from foreign countries, and it soon became a model followed outside Sweden'. It inspired chemistry teachers in Paris and strongly influenced the 1785 renovation of the laboratory of the important mining academy in Schemnitz in the Habsburg Empire. Other large laboratories erected in those years were the *Laboratorio Chimico* of the University of Coimbra (1772) and the chemical laboratory of the University of Göttingen (1784), directed by Johann Friedrich Gmelin. Under Gmelin's successor Friedrich Stromeyer the laboratory was enlarged several times. Stromeyer organized practical chemistry courses for growing numbers of students, especially during the 1820s. In those years practical chemistry could also be studied at several other German universities, and in Scotland and England as well. Only in France would it take several decades for universities to take over the role played by private teaching laboratories.[6]

Parallel to the rise of these teaching laboratories, the practice of chemistry itself changed quite drastically. The investigation of gases (pneumatic chemistry) accelerated the introduction of physical instruments into chemistry. Along with this, new, rather small-scale analytical chemical methods were developed, such as the blowpipe and gravimetric and volumetric techniques. Torbern Bergman and especially Antoine Lavoisier were the leaders of this new approach, which brought chemistry and physics into closer mutual contact.[7] This is illustrated by the growing number of sales catalogues

6 Marco Beretta, 'Laboratories and Technology', in: Matthew Daniel Eddy and Ursula Klein, eds., *A Cultural History of Chemistry in the Eighteenth Century* (London: Bloomsbury Academic, 2022), pp. 71–91, esp. pp. 84–87; Peter Konečný, 'Sites of Chemistry in the Schemnitz Mining Academy and the Eighteenth-Century Habsburg Mining Administration', *Ambix*, 60 (2013), 160–78 (pp. 169–72); Pedro Enrech Casaleiro, 'The Restoration of the *Laboratorio Chimico* at the University of Coimbra', in Lorenço and Carneiro, eds., *Spaces and Collections in the History of Science*, pp. 235–44; Lena Hoppe, *Historische Stätten der Chemie: Das Göttinger Alte Chemische Laboratorium, Göttingen, 17. Oktober 2019* (Frankfurt a.M.: Gesellschaft Deutscher Chemiker, 2019); Homburg, 'The Rise of Analytical Chemistry', pp. 9–18; Alan J. Rocke, 'Academic Chemical Laboratories in Paris, 1823–1894', in Lourenço and Carneiro, eds., *Spaces and Collections in the History of Science*, pp. 25–31.

7 Holmes, 'Laboratory, Chemical'; Peter J.T. Morris, *The Matter Factory. A History of the Chemistry Laboratory* (London: Reaktion Books, 2015), pp. 43–46, 58–59; Beretta, 'Laboratories and Technology', pp. 82–85.

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for chemical instruments that appeared during the early decades of the nineteenth century. There was even a new periodical created for disseminating the innovations in laboratory instrumentation and architecture: *Das Laboratorium. Eine Sammlung von Abbildungen und Beschreibungen der besten und neuesten Apparate zum Behuf der practischen und physicalischen Chemie*, which was published from 1825 to 1840.[8] During the early nineteenth century this and other innovations, such as the introduction of gaslight, would also finally revolutionize the architecture of chemical laboratories. Whereas the laboratory between about 1600 and 1820 had remained relatively unchanged, dominated by furnaces, a new type of laboratory emerged after a transition period from 1820 to 1850; this space was dominated by benches and tables, Bunsen burners, glassware, and fume hoods. This so-called 'classical laboratory' (Peter Morris) would dominate chemical university practice until the 1960s.[9]

The lessons taught in practical chemistry at some universities from about 1770 onwards, as mentioned above, focused primarily on training skills in making chemical substances and analysing their composition. One essential ingredient of later academic chemistry was missing: research. As Alan Rocke has argued, Justus Liebig took the crucial step in that direction. He not only engaged selected students in his research programme but also created small teams of students who collectively worked on important research questions. Liebig's creation of a research laboratory within the University of Giessen is often seen as the starting point of the Laboratory Revolution. (See also the section on historiography below.[10]

Turning a teaching laboratory into a teaching-research lab was definitely a revolution in science. It was not just a matter of doing the same kind of research but with more hands than before; it also implied a new conception of what chemical knowledge was about and what was required for breeding up-to-date academic chemists. This new trend in science and academic

8 Brian Gee, 'Amusement Chests and Portable Laboratories: Practical Alternatives to the Regular Laboratory', in Frank A.J.L. James, ed., *The Development of the Laboratory: Essays on the Place of Experiment in Industrial Civilization* (Basingstoke/London: The Macmillan Press, 1989), pp. 37–59; *Das Laboratorium. Eine Sammlung von Abbildungen und Beschreibungen der besten und neuesten Apparate zum Behuf der practischen und physicalischen Chemie*, 44 Hefte (Weimar: Grossherzogl. Sächs. priv. Landes-Industrie-Comptoirs, 1825–40).

9 Holmes, *Eighteenth-Century Chemistry*; Homburg, 'The Rise of Analytical Chemistry'; Holmes, 'Laboratory, Chemical'; Klein, 'The Laboratory Challenge'; Peter J.T. Morris, 'The History of Chemical Laboratories: A Thematic Approach', *ChemTexts: The Textbook Journal of Chemistry*, 7(3) (2021), p. 7.

10 Alan J. Rocke, 'Origins and Spread of the "Giessen model" in University Science', *Ambix*, 50 (2003), 90–115, reprinted as Chapter 2 in this volume; Holmes, 'Laboratory, Chemical', p. 442.

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training therefore met with fierce resistance from more traditional chemists. The Viennese professor of chemistry Paul Meissner criticized Liebig for turning chemistry into a search for new substances. Liebig did this, so Meissner argued, only to become a celebrity. He called it 'a French disease' to strive for novelty instead of deep understanding. In his view the aim of science ought to be to develop a 'system', to order known facts in a logical way. Liebig had attacked Meissner for his failure to produce any new chemical 'fact', but the Austrian professor did not care much about discovering new facts. He saw himself as a scholar, not as an experimentalist.[11]

Resistance was also quite common when laboratory research later entered the field of medicine.[12] Hospital physicians were sceptical of the usefulness and the relevance of laboratory studies in medicine. According to them, clinical experience was much more important than expertise in experimental research in a laboratory. But proponents of the laboratory revolution in medicine, like Claude Bernard, claimed that their experimental research on the causes of disease not only delivered important clinical benefits but also resulted in unmediated, and therefore much more reliable, knowledge of 'Nature' than the observation of sick patients in a hospital. The new techniques and instruments in the laboratory eliminated the human, subjective element and made it possible to get an objective idea of the workings of nature. According to Bernard and his followers, nature was most herself in the laboratory, where she spoke clearly in her own voice. Just like in chemistry, the cognitive claims of the advocates of laboratory science went against the established views of science. The rise of the laboratory was therefore not the result of a gradual evolution of techniques and ideas, but of a revolutionary break with existing ideas and conceptions of what science should be.

Despite the resistance from some established scientists and practitioners, the 'model' of the teaching-research laboratory developed by Liebig was introduced in most universities in Europe and North America between about 1840 and 1880, not only in chemistry but also in other disciplines. Alan Rocke and others have demonstrated that shortly after Liebig introduced his new laboratory practices during the 1830s, other professors in chemistry in Germany, Austria, Switzerland, and Great Britain followed in his footsteps:

11 Ernst Homburg, *Van beroep 'Chemiker': De opkomst van de industriële chemicus en het polytechnische onderwijs in Duitsland (1790-1850)* (Delft: Delftse Universitaire Pers, 1993), pp. 314–16, 323–25, 328–34.

12 See especially: Andrew Cunningham and Perry Williams, eds., *The Laboratory Revolution in Medicine* (Cambridge: Cambridge University Press, 1992), esp. pp. 10–11.

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Göttingen (1838), Prague (1840), Marburg (1841), Leipzig (1842), Royal College of Chemistry, London (1845), University College, London (1845), Vienna (1845), and Halle (c.1846). By the 1870s almost all university chemistry departments in Europe and the United States had followed these examples.[13]

Compared to this rather rapid dissemination of the 'Giessen model' among university chemistry departments, the diffusion to other disciplines was more gradual. In these disciplines there were 'cabinets', 'theatres', 'botanical gardens', and 'dissection rooms', but no 'laboratories'. During the nineteenth century a kind of two-step process becomes evident: first, the introduction of 'laboratories' or the renaming of cabinets etc. into 'laboratories', and second, the development of these laboratories into full-fledged teaching-research laboratories.

Physics was among the earliest non-chemical disciplines in which the term 'laboratory' was introduced. As Frans van Lunteren notes in his chapter in this book, many of the leading 'experimental physicists' of the first half of the nineteenth century also had a background in chemistry. An example is Gustav Magnus, who started a physics laboratory in Berlin during the 1840s. He was joined by a few 'mathematical physicists', such as Wilhelm Weber in Göttingen and Franz Neumann in Königsberg, who established physics laboratories at about the same time.[14] Most of these early physics laboratories were quite small though. The same applies to the student numbers, resulting from the then very limited career prospects for physicists as compared to chemists. Only after 1860 would larger teaching-research laboratories be created in, for instance, Göttingen, Berlin, and Oxford.[15]

A similar pattern was followed in medicine, particularly in physiology. The first laboratories in this field were also founded in the 1830s and 1840s, for instance by Johannes Müller in Berlin, Jan Purkyně in Breslau, and Jacob

13 Rocke, 'Origins and Spread' (Ch. 2); W.V. Farrar, 'Science and the German University System, 1790–1850', in Maurice Crosland, ed., *The Emergence of Science in Western Europe* (London/Basingstoke: The Macmillan Press, 1975), pp. 179–92, esp. p. 187; Homburg, *Van beroep 'Chemiker'*, pp. 328–34; Anderson, 'The Creation of the Chemistry Teaching Laboratory', p. 20; Morris, *The Matter Factory*, pp. 109–14; Holmes, 'Laboratory, Chemical', p. 442.

14 Frans van Lunteren, 'The Laboratory Ethos, 1850–1900', see Chapter 3 in this volume; Farrar, 'Science and the German University System', pp. 187–88; Henning Schmidgen, 'The Laboratory', *European History Online* (EGO), published by the Institute of European History (IEG) (2011), p. 5, <http://ieg-ego.eu/en/threads/crossroads/knowledge-spaces/henning-schmidgen-laboratory> (accessed 8 November 2022).

15 Farrar, 'Science and the German University System', pp. 187–89; Graeme Gooday, 'Precision Measurement and the Genesis of Physics Teaching Laboratories in Victorian Britain', *British Journal for the History of Science*, 23 (1990), 25–51; Graeme Gooday, 'Placing or Replacing the Laboratory in the History of Science?', *Isis*, 99 (2008), 783–95; Rocke, 'Origins and Spread' (Ch. 2).

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Henle in Heidelberg. It also took until the 1860s and 1870s before large teaching-research laboratories in medicine were erected in Leipzig, Paris, Groningen, Berlin, and Utrecht.[16]

Between 1870 and 1900 most other disciplines followed. Teaching-research laboratories were, for instance, erected by universities in bacteriology,[17] biology,[18] and engineering,[19] to mention some examples documented in the literature.

Historiography

Writing the history of the laboratory was part of the Laboratory Revolution. Whenever a laboratory celebrated its 25th or 50th anniversary, an opportunity presented itself to write the history of the laboratory and, in doing so, re-write the history of the discipline in question. In this way, the rise of the research laboratory was presented as the inevitable result of the progressive development of science, while the once highly contested claims of the advocates of the laboratory took on the character of self-evident and naturally compelling statements. In the 1980s the social history of science

16 Farrar, 'Science and the German University System', pp. 187–89; Timothy Lenoir, 'Laboratories, Medicine and Public Life in Germany, 1830–1849: Ideological Roots of the Institutional Revolution', in Cunningham and Williams, eds., *The Laboratory Revolution in Medicine*, pp. 14–71; Richard L. Kremer, 'Building Institutes for Physiology in Prussia, 1836–1846: Contexts, Interests and Rhetoric', in Cunningham and Williams, eds., *The Laboratory Revolution in Medicine*, pp. 72–109; Schmidgen, 'The Laboratory', p. 6; Sven Dierig, 'Engines for Experiment: Laboratory Revolution and Industrial Labor in the Nineteenth-Century City', *Osiris*, 18 (2003), 116–34; Rocke, 'Origins and Spread' (Ch. 2); Van Lunteren, 'The Laboratory Ethos' (Ch. 3).

17 Farrar, 'Science and the German University System', pp. 188–89; Cunningham and Williams, eds., *The Laboratory Revolution in Medicine*, pp. 3–4.

18 Farrar, 'Science and the German University System', pp. 188–89; Robert E. Kohler, *Landscapes and Labscapes: Exploring the Lab-Field Border in Biology* (Chicago/London: University of Chicago Press, 2002); Helge Kragh, 'From Ørsted to Bohr: The Sciences and the Danish University System, 1800–1920', in Ana Simões, Maria Paula Diogo, and Kostas Gavroglu, eds., *Sciences in the Universities of Europe, Nineteenth and Twentieth Centuries. Academic Landscapes* (Dordrecht: Springer, 2015), pp. 31–47, esp. p. 38; Schmidgen, 'The Laboratory', p. 11; Van Lunteren, 'The Laboratory Ethos' (Ch. 3); Bas Nugteren, 'Of Growing Significance. The Support Staff in the Laboratories and Institutes of Utrecht University during the Interwar Period', Chapter 10 of this volume.

19 Graeme Gooday, 'Teaching Telegraphy and Electrotechnics in the Physics Laboratory: William Ayrton and the Creation of an Academic Space for Electrical Engineering, 1873–84', *History of Technology*, 13 (1991), 73–114; Graeme Gooday, 'Placing or Replacing the Laboratory', p. 792; Wilhelm Borchers, 'Über die Mitarbeit der Hochschulen an der Förderung des Metallhüttenwesens seit Erteilung des Promotionsrechtes', *Chemiker Zeitung*, 36 (1912), p. 465; Gisela Buchheim and Rolf Sonnemann, eds., *Geschichte der Technikwissenschaften* (Basel, Boston, Berlin: Birkhäuser, 1990).

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effectively discredited these claims and several studies raised an awareness that laboratories were not to be considered as neutral fora for the study of nature. Bruno Latour and Steve Woolgar's *Laboratory Life: The Construction of Scientific Facts* (1979) and Simon Schaffer and Steven Shapin's *Leviathan and the Air-Pump* (1985) were just two of the studies that opened our eyes to the constructive role of laboratory space in the development of science.[20] The volume edited by Frank A.J.L. James, *The Development of the Laboratory: Essays on the Place of Experiment in Industrial Civilisation* (1989), although restricted in scope, signalled that 'laboratory studies' had developed into a new subdiscipline of the history of science.[21] The advent of this new specialty was also announced in a widely read contribution by Karin Knorr Cetina, 'Laboratory Studies: The Cultural Approach to the Study of Science' (1995).[22]

Thirteen years later Robert E. Kohler, in a Focus section of the journal *Isis* (2008), concluded, though, that laboratory studies still had not been established as a duly recognized specialty in the history of science: 'the lab is a neglected subject.'[23] Notwithstanding quite a few excellent laboratory studies, he looked in vain for a book-length overview of the subject or for helpful entries on the laboratory in the major handbooks and encyclopaedias of the history of science. The main reason for this odd development was, in Kohler's eyes, the decline of institutional history as such. He also attributed the lack of general accounts of the development of the laboratory to the emerging realization that so many different institutions and practices are taken together under the umbrella of 'the laboratory'—the grand university laboratories of the late nineteenth century as well as the country-house labs, the monasteries as well as the eighteenth-century amusement chests and portable laboratories. This discouraged historians from even believing in the possibility of a single unified history of the laboratory. Add to this that the laboratory took on so many different shapes in all the branches of science—medicine, physics, biology, engineering, etc.—and it becomes clear why Kohler had trouble finding general accounts.[24] Kohler could only

20 Bruno Latour and Steve Woolgar, *Laboratory Life. The Social Construction of Scientific Facts* (Beverly Hills, CA: Sage, 1979), republished as *Laboratory Life. The Construction of Scientific Facts* (Princeton, NJ: Princeton University Press, 1986); Simon Schaffer and Steven Shapin, *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life* (Princeton, NJ: Princeton University, 1985).

21 James, ed., *The Development of the Laboratory*.

22 Karin Knorr Cetina, 'Laboratory Studies: The Cultural Approach to the Study of Science', in Sheila Jasanoff et al., eds., *Handbook of Science and Technology Studies* (Beverly Hills, CA: Sage, 1995), pp. 140–66.

23 Kohler, 'Lab History', p. 761.

24 Morris, *The Matter Factory* is a laudable exception, but, as the title announces, the book only deals with the chemistry laboratory. The book has a very helpful bibliography. Recently the

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hope that a renewed attention to the congruence between the values of the laboratory and the dominant values in society would reinvigorate the struggling subspecialty of laboratory studies. Historians should again be curious about 'how the conventions of laboratory life embody those of other important social institutions (court, state, market, media) and how they in turn shape public meanings of knowledge in general'.[25]

Whether by coincidence or not, the basis of Kohler's complaints soon evaporated following a flood of historical studies of laboratories in the following decade. As a result of the 'spatial turn' in the history of science, 'spaces' and 'sites' suddenly became hot topics. In 2009 the collection *Spaces and Collections in the History of Science. The Laboratorio Chimico Overture* was published, edited by Marta C. Lourenço and Ana Carneiro. In November 2010 John Perkins and Antonio García Belmar organized a meeting in London where they initiated a series of international workshops on 'Sites of Chemistry, 1600–2000', leading to special issues of the journal *Ambix* on sites of chemistry in the eighteenth, nineteenth, and twentieth centuries. The wealth of new case studies published in these and other publications was synthesized and brought to a higher level by Catherine Jackson in overviews in handbooks and in Peter Morris's book *The Matter Factory*.[26]

Another way to overcome the restrictions to laboratory studies that Kohler identified might be to put the concept of the Laboratory Revolution, with capitals, at centre stage in the history of the laboratory. The history of science as a whole was stimulated enormously in the post-World War II period when 'the' Scientific Revolution (of the seventeenth century) was

laboratory metaphor has gained popularity among general historians to indicate geographical and social spaces that lend themselves to the study of particular developments. See for instance: Georgiy Kasianov and Philipp Ter, eds., *A Laboratory of Transnational History: Ukraine and Ukrainian Historiography* (Budapest and New York: Central European University Press, 2009) and Klaas van Berkel, 'The Dutch Republic as a Laboratory of the Scientific Revolution', *Low Countries Historical Review*, 25 (2010), 81–105.

25 Kohler, 'Lab History', p. 764.

26 Lourenço and Carneiro, eds., *Spaces and Collections in the History of Science*; John Perkins, ed., 'Sites of Chemistry in the Eighteenth Century', special issue of *Ambix*, 60 (2013), 95–178; Antonio García-Belmar and John Perkins, eds., 'Sites of Chemistry in the Nineteenth Century', special issue of *Ambix*, 61 (2014), 109–86; Antonio García-Belmar and John Perkins, eds., 'Sites of Chemistry in the Twentieth Century', special issue of *Ambix*, 62 (2015), 109–88; Catherine M. Jackson, 'The Laboratory', in Bernard Lightman, ed., *A Companion to the History of Science* (Chichester: Wiley, 2016), pp. 296–309; Catherine M. Jackson, 'Laboratorium', in Marianne Sommer, Staffan Müller-Wille, and Carsten Reinhardt, eds., *Handbuch Wissenschaftsgeschichte* (Stuttgart: J.B. Metzler, 2017), pp. 244–55; Morris, *The Matter Factory*, esp. p. 16. See also: Lissa L. Roberts and Simon Werrett, eds., *Compound Histories: Materials, Governance and Production, 1760–1840* (Leiden/Boston: Brill, 2018).

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propagated as the central category in the historical development of science; on a lesser scale, the concept of the Laboratory Revolution might do the same.[27] This volume aims to do just that.

The Laboratory Revolution and the Universities

The university was one of the institutions that helped in creating the modern laboratory and was in turn transformed by the rise of the laboratory. Liebig's engagement of students in his laboratory research was, after all, crucial to the further diffusion of the research laboratory across Europe. At Utrecht University the professor of chemistry Gerrit Jan Mulder also put his students to work in his laboratory. These pioneers inspired others to do the same, and during the nineteenth century one university after another supplied research-minded professors with laboratories and equipment. Whereas Liebig and his contemporaries usually worked in existing buildings that sometimes also housed other departments,[28] the view became widely shared by the middle of the century that only new, purpose-built laboratories could accommodate up-to-date scientific research. In chemistry, which was then still a relatively cheap science (the work was mainly done with relatively inexpensive glass-work), this trend was not a major problem for the authorities, but the costs rose substantially as one science after another followed the example set by chemistry and the numbers of students being educated in the lab grew. Still, the authorities went along with it and paid for the salaries, buildings, and equipment. By the end of the nineteenth century, the new stately laboratories had changed the look of universities in both Europe and the United States.[29]

The rise of the university also had a fundamental impact on the kind of education the students received. Until the nineteenth century lectures in which students listened passively to the professor formed the core of a university education, and dissertations seldom presented new knowledge. During the nineteenth century laboratory work began to replace these lectures as the core element in education. This development started in the science departments, but historians, as one example of scholars who had no need for furnaces or Erlenmeyer flasks, developed a system of 'seminars' (working groups led by the professor) that in a sense imitated the collective

27 See: Floris H. Cohen, *The Scientific Revolution. A Historiographical Inquiry* (Chicago: University of Chicago Press, 1994).

28 A few exceptions (Uppsala, Göttingen) have been mentioned above.

29 For these 'palaces', see: Morris, *The Matter Factory*, pp. 146–69.

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work done in the chemical laboratory.[30] At the end of the nineteenth century the new dogma was that the best education is found in the laboratory, where students learn by practising science instead of just listening to the professor.

In the field of the history of universities, this co-creation of the modern research laboratory and the modern research university has seldom attracted much attention.[31] Historians of science interested in the laboratory often take the university for granted as a background for developments in the laboratory,[32] while university historians rarely spend much time discussing what happened inside the laboratory. There is an abundance of literature on the architecture of science, but these studies are usually more concerned with the outer appearance of the buildings than with their constructive details.[33] The laying of foundations and the construction of sewage systems receive scant attention, certainly compared to the attention given to ornaments and murals. Nonetheless, historians of the university seem hardly aware that the laboratory is much more than just one of the facilities needed for teaching and research. In the third volume of the well-known *History of the University in Europe* on the universities in the nineteenth and twentieth centuries, Matti Klinge indeed recognizes the expansion of the university laboratories:

> Being at first separate and often somewhat obscure and dirty annexes to the university itself, the laboratories and institutes of natural sciences became, in the latter half of the century, more respected and, in the new buildings of the turn-of-the-century, achieved an almost sacral status.[34]

30 When the Institute of Historical Research in London was opened in 1921, a pamphlet issued by the institute declared that its aim was to become 'an index to historical knowledge, a focus of historical research, a clearing-house of historical ideas, and a historical laboratory open to students of all universities and all nations'. Quoted in: Debra J. Birch and Joyce M. Horn, eds., *The History Laboratory. The Institute of Historical Research 1921–96*, (London: University of London, Institute of Historical Research, 1996), p.15.

31 A recent and notable exception is: Ku-Ming (Kevin) Chang and Alan Rocke, eds., *A Global History of Research Education: Disciplines, Institutions, and Nations, 1840–1950* (= *History of Universities*, 34/1) (Oxford: Oxford University Press, 2021).

32 But see: Christoph Meinel, 'Artibus Academicis Inserenda: Chemistry's Place in Eighteenth- and Early Nineteenth-Century Universities', *History of Universities*, 7 (1988), 89–115.

33 Sophie Forgan and Graeme Gooday, '"A Fungoid Assemblage of Buildings": Diversity and Adversity in the Development of College Architecture and Scientific Education in Nineteenth-Century South Kensington', *History of Universities*, 13 (1994), 153–92. Peter Galison and Emily Thompson, eds., *The Architecture of Science* (Cambridge, MA: MIT Press, 1999) does indeed pay attention to the more technical details of modern laboratories, but this volume does not deal with university laboratories or with the university context of the laboratory.

34 Walter Rüegg, ed., *A History of the University in Europe. Volume III. Universities in the Nineteenth and Twentieth Centuries (1800–1945)*, 4 vols. (Cambridge: Cambridge University Press, 2004), p. 144.

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But what this sacral status entailed and how it changed the university is not discussed in that volume. There is no paragraph or chapter devoted to the laboratory as a driving force behind the creation of the modern research university.[35] This volume is trying to remedy this neglect of how the new laboratories shaped the modern university.

The Book in Brief

This volume brings together what until now have essentially been two separate fields of inquiry: the study of the rise of the laboratory as the ultimate source of reliable knowledge and the history of the university as a teaching-research institution. The stage is set by a key essay by Alan Rocke first published in 2003, which opens the first part of this volume: 'The Laboratory Revolution: Origins and Impact'.[36]

Since the early 1970s authors writing on the Laboratory Revolution—sometimes under a different banner—were in large agreement that the 'Giessen model', or 'German model', had played a crucial role in it.[37] There was less agreement, though, about when this model emerged and what its precise nature was. In terms of the 'founding fathers' of the model: did it start with Wilhelm von Humboldt, or with Friedrich Stromeyer, or with Justus Liebig?[38] Rocke brings this discussion to a higher level by investigating in detail what made the laboratory-based education developed by Liebig in Giessen after 1835 distinct from earlier practices in several ways. He also demonstrates the impact of that specific (Giessen) model not only on the development of chemistry laboratories in Germany and abroad but also on the nature of laboratories in other disciplines, such as physics and physiology. The experimental courses organized by Liebig were more intense and were given to more students than ever before. Moreover, they were financially supported by the university and—importantly—offered the opportunity

35 For a recent improvement of the historiography on this point, see: Chang and Rocke, eds., *A Global History of Research Education*.

36 Originally published as Rocke, 'Origins and Spread'. We thank the author as well as others mentioned in the acknowledgement in Chapter 2.

37 Among the earliest contributions are: R. Steven Turner, 'The Growth of Professorial Research in Prussia, 1818–1848 – Causes and Context', *Historical Studies in the Physical Sciences*, 3 (1971), 137–82; J.B. Morrell, 'The Chemist Breeders: The Research Schools of Liebig and Thomas Thomson', *Ambix*, 19 (1972), 1–46; Farrar, 'Science and the German University System'.

38 See for instance: Geert Vanpaemel, 'The German Model of Laboratory Science and the European Periphery (1860–1914)', in Simões, Diogo, and Gavroglu, eds., *Sciences in the Universities of Europe* (Dordrecht: Springer, 2015), pp. 211–25.

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for the more advanced students to work in teams on research questions. Rocke argues that these novel elements not only resulted from general institutional, socio-political, and economic factors (state funding, industrial demand), but also from a few very specific material and theoretical aspects of the emerging discipline of organic chemistry, which came together during the 1830s: the discovery of isomers, the practice of using 'paper tools', and the new *Kaliapparat*, invented by Liebig, used in organic analysis. Taken together, a network of quite heterogeneous factors and circumstances in Giessen created the practices that were eventually associated with all modern research universities, and Liebig's extraordinary charisma and communicative skills greatly helped in disseminating his 'model'.

The impact of the Laboratory Revolution that Liebig initiated implied much more than the national and international dissemination of materially well-equipped, spacious new buildings; it also changed the codes and norms that regulated academic life in general. How the rise of the laboratory led to the introduction of a new scientific ethos in several disciplines is analysed in detail by Frans van Lunteren. He explores the shift in the values and self-image of the scientist by looking at character traits prized most highly in a laboratory setting, such as discipline, self-restraint, precision, perseverance, modesty, and (in the case of the physiologists) emotional control. These epistemic virtues moulded a new scientific identity that took different shapes in different disciplines (the author discusses chemistry, physiology, and physics) but that also showed remarkable resemblances. Contrary to recent literature on the emergence of these virtues, the author shows that the rise of the laboratory specifically was instrumental in forging these new scientific virtues. These new virtues only fully took shape after the introduction of the university teaching and research laboratory in the 1830s and not in the late eighteenth century. On the other hand, he points out that the rise of the modern bureaucratic state, which more or less exemplifies the same virtues, also influenced the development of the new scientific ethos.

In the next two parts of the book, these spatial and normative dimensions of the Laboratory Revolution are explored in greater detail, starting the analysis of *Laboratory Networks* (in part two), which include scientists, suppliers, and administrators. One of the earliest university laboratories outside Germany where the teaching-research model was introduced—even without a direct connection to Liebig—was in Zürich. Peter Ramberg shows that the emergence of academic chemistry in Zürich resembled the path followed in Germany, but it also differed from it because of a complex interplay between the policies of the Swiss Federation and the local needs and finances of the Canton of Zürich. Due to limited financial means at

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the different political levels and a still limited industrial demand for skilled chemists during the 1840s and 1850s, a situation emerged in which most professors had dual appointments at the Cantonal University and at the new Federal Polytechnic. The laboratories of both schools were closely connected but followed different models: the University was explicitly founded on the German model, with its faculties and academic freedom. The Polytechnic was modelled after the Polytechnic at Karlsruhe, with its divisional structure and more restricted freedom for staff and students. Despite these German influences, the final result differed. Ramberg demonstrates that the physical proximity of the University and Polytechnic in the same city, with dual appointments and a shared chemical laboratory until 1861, resulted in arrangements that were largely absent in the German system. The development of organic chemistry also played a crucial role in Zürich. After 1860 the synthetic dye industry in Switzerland, and elsewhere, required growing numbers of (organic) chemists, and at the same time chemistry professor Johannes Wislicenus and his successors set up a very successful research school in organic chemistry, which attracted many students. Wislicenus also untangled the complex relationship in the field of chemistry between the University, the Polytechnic, and other schools in Zürich. By the late nineteenth century Zürich had become the most productive site for chemistry in Switzerland and one of the most successful in the world, largely due to the close spatial and personal network that included the University and the Polytechnic.

While a close collaboration between different laboratories emerged (albeit in the same discipline) in Zürich, Klaas van Berkel demonstrates in his chapter that laboratories erected during the Laboratory Revolution in Groningen—as well as in other cities—undermined the unity of the local universities. The decades around 1900 were a time of great expansion for the Dutch university system, particularly in experimental science, medicine, and some other fields such as psychology. In the state-funded universities in Utrecht, Leiden, and Groningen, new laboratory buildings were erected to accommodate the new science of the times. The distribution of these laboratories over the city had both intended and unintended consequences. There were often unrecognized effects on ideas and perceptions of science, its practitioners, and these practitioners' place within the university. Discussing the example of Groningen in greater detail, Van Berkel shows that the spatial 'diaspora' of laboratories that started in the late-nineteenth century undermined the contact between professors of different disciplines, and the same was true for the students. It was a disruptive force that contributed to a disintegration of the university as a unified social and intellectual

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community. Although several measures were taken to counteract the consequences of these spatial changes, basically all of them failed. Only after World War II did the establishment of campuses constitute a more serious attempt to re-unify the university, but even that step was only partially successful.

In the chapters discussed so far, the spatial (Ramberg, Van Berkel) and socio-political (Rocke, Ramberg) networks influencing laboratory science come to the fore, and to a lesser extent material aspects as well, such as the role played by the *Kaliapparat*. Pierre Laszlo puts the mutual relations between material and spatial concerns centre stage in his study of the suppliers of laboratory chemicals and instruments in Paris. Historical studies of laboratories often discuss the 'outputs' of laboratories, such as the number of chemists or other professionals who were 'bred' (Morrell), or the number of discoveries made. But the 'inputs' are often overlooked. Laszlo sheds an unexpected light on the Laboratory Revolution by investigating the role of the commercial laboratory suppliers. He identifies and locates the main Parisian laboratories and discusses in detail the interplay between the Parisian scientists and the ten to twenty local suppliers from 1880 to 1910. Interestingly, most suppliers to laboratories had their shops predominantly in the Latin Quarter, in close proximity to the laboratories. Many suppliers had a background in pharmacy. They occupied the 'trading zone' (Galison) between laboratory chemists, wholesalers, and industrialists, and between chemists and physicians. To some extent, they can be called 'activists', because they were not merely merchants but also proponents of the contemporary ideology of progress through science, reinforced by their participation in the 1889 and 1900 World Fairs. Over time, they not only supplied the Parisian laboratories but increasingly also laboratories and hospitals in the French colonies worldwide. The chapter therefore illustrates the large-scale consequences of the Laboratory Revolution in an unexpected way.

It should be no surprise that spatial factors would play a large role in a geographically 'long' country such as Norway. The traditional university of the country was positioned in a rather eccentric way in the capital Kristiana (Oslo) in the south. When an Institute of Technology was established in 1910, the town of Trondheim was chosen, positioned more or less in the middle of the country to better serve the industry of different regions. Discussing the competition between the University in Kristiania and the Institute in Trondheim with respect to the erection of new, large, and modern laboratories, Annette Lykknes shows that more was at stake than geography. It was also a socio-political and ideological battle. The University of Kristiana had

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the advantage of being close to the national centre of power. Trondheim, in turn, could profit from its network with industry. Even more important was the debate on the type of chemists that industry needed. Professors from the University argued that a solid background in pure science was also a good preparation for industrial positions. The professors from the Institute, by contrast, claimed that knowledge of industrial chemistry and chemical engineering was what industry needed. The visions of those two opposing parties did of course have consequences for laboratory design. The competition became worse in the hard financial times after World War I. On top of differences in training and qualities of education, the geographical differences in Norway added to this polarization, with questions related to centre and periphery sharpening the dispute. Lykknes argues that in those years, the laboratory even became a symbol of the nation for the chemistry professors in Trondheim. Without a proper chemical laboratory, the industry and the whole country would suffer. The examples show that although Kristiania would get priority in the construction of a new laboratory, the Laboratory Revolution was part of a whole network of interests and ideas on the future of the nation.

Socio-political and ideological issues are also centre stage in Ab Flipse's contribution on the laboratory of the Vrije Universiteit (Free University) in Amsterdam, founded by Dutch Calvinists in 1880. Although the laboratory was generally seen as a symbol of scientific progress, in religious circles it also carried a negative image as a symbol of 'materialism' and disbelief. It therefore took almost four decades before the leaders of the Vrije Universiteit decided that Calvinist physicians were also important for the constituency of their university and that a medical faculty with a laboratory was a crucial next step in developing their university. Founded in 1918, the physiological laboratory started rather smoothly. The scientists connected to the laboratory succeeded in performing a careful balancing act by arguing that it would be possible to create a radically different research strategy on the basis of Calvinist principles. The foundation of this first laboratory was in a sense revolutionary because it initiated the Vrije Universiteit's own 'laboratory revolution'. For the first time, the university came into contact with an academic discipline in the sciences. As a result, more than before, the university adapted to what was already customary elsewhere. The physiological laboratory paved the way for the future science faculty in 1930 and for further growth into a university that comprised all faculties later in the century.

The third part of this volume, *Laboratory Values*, is less concerned with the laboratory itself than with the ethos that has become prevalent in a

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laboratory setting, especially in the case of academic and semi-academic laboratories. Laboratories changed the face of the university, not only by claiming so many spacious new buildings but also by changing the codes and norms that regulated academic life in general. The new scientific virtues—discussed by Frans van Lunteren in his chapter mentioned above—were propagated mainly by the professors, but these were not the only people who inhabited laboratories. Peter Morris and Bas Nugteren both attend to the academic and technical staff below the rank of full professor. Morris compares German and English laboratories, more precisely the academic laboratories in Heidelberg and London (Imperial College). He shows that the intricate social organization of the laboratories in these countries, different though they were, did not hinder them from becoming productive and dynamic social communities. The technicians and assistants were crucial for the success of a laboratory. Therefore, laboratory studies in which the historian or sociologist only pays attention to the professor paint an unrealistic picture of how science proceeds. The emergence of new epistemic virtues in the late nineteenth century not only depended on the professor's powers of persuasion; virtues like precision, disinterestedness, and the strict following of fixed procedures were also moulded by the practices of a modern laboratory. The new laboratory was a factory-like organization not only because of the use of machines and instruments, but also because of its social structure.

Bas Nugteren focuses on the laboratories at one particular institution: Utrecht University in the first half of the twentieth century. He details the finer social structure in the laboratories while also documenting the gradual but growing appreciation for the contributions of the support staff. Public statements by university authorities, the awarding of royal distinctions for long-term service to the university, and newspaper articles all point to a growing awareness that the support staff was essential to the smooth operation of the laboratory and should be honoured for that. At the same time non-academic staff members also started to manifest themselves strongly in labour unions, who were then recognized by the university administration. However, as Nugteren also shows, the staff was not included in the concept of the *civitas academica*, the imaginary academic community consisting solely of professors, lecturers, and students.

Ida H. Stamhuis adds another perspective to the study of laboratory life by considering the issue of gender. The rise of the laboratory was not without consequences for the gender relations within the university and in science in general. The growing importance of laboratories can, as Margaret W. Rossiter in 2003 claimed, 'be seen as a new level of exclusion, creating new

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male retreats or preserves to which women gained entry only by special permission'.[39] She spoke specifically about the physical sciences, but her statement is roughly true for laboratories in other disciplines as well. Yet, as Stamhuis demonstrates, the situation is ambivalent. In the case of the emerging field of genetics, the newly created laboratories at the fringes of the university were indeed led by male scientists, but—because relationships were not yet fixed in these emerging fields—they at the same time offered new opportunities for female scientists to make important contributions to science. As so often happens, change started at the periphery rather than the centre of the university.

Quite a few of the laboratories founded during the Laboratory Revolution began publishing their own journal. One of the first laboratory journals was Gerrit Jan Mulder's *Scheikundige onderzoekingen, gedaan in het Laboratorium der Utrechtsche Hoogeschool* ('Chemical investigations undertaken at the laboratory of Utrecht University'), founded in 1842. The rise of this new type of science publication thus more or less coincided with the Laboratory Revolution. In her chapter Dorien Daling discusses a sample of these 'in-house' publications and analyses their functions. She concludes that these journals, which almost ceased to exist after the mid-twentieth century, did not aim to circulate new knowledge as such. These journals often comprised articles that had already been published elsewhere. Instead, the laboratory journals served to legitimize the existence of the laboratories, to further the internal social cohesion of the laboratory, and to offer assistants and PhD students training in writing scientific articles. By setting up exchange subscriptions, these journals also forged closer ties between laboratories in the same discipline all over the world.

In the final chapter, Geert Vanpaemel discusses how the laboratory was (or was not) represented in popular science magazines during the Laboratory Revolution. He focuses on the engravings and photographs in the French magazine *La Nature*, published since 1872. The author concludes that pictorial representations of science in the late nineteenth century retained quite a few elements of an older iconography, especially the images of the alchemical laboratories and workshops of the early modern period. Furthermore, he observes that although there is a growing recognition in *La Nature* of the laboratory as the most important expression of a stable

39 Margaret W. Rossiter, 'A Twisted Tale. Women in the Physical Sciences in the Nineteenth and Twentieth Centuries', in Mary Jo Nye, ed., *The Physical and Mathematical Sciences. The Cambridge History of Science, vol. 5*, 8 vols. (Cambridge: Cambridge University Press, 2003), pp. 54–71, quote on p. 55.

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scientific research environment and as an institution of cultural authority, the editors of the journal seemed to be even more interested in technological innovation and industrial machinery. Apparently, the magazine did not perceive the laboratory as the major driving force of science; instead, the modern laboratory was seen as an adaptation of science to the modernization of industry and society.

This last and tentative conclusion harks back to Van Lunteren's remarks in his chapter on the agreement between the new values of laboratory life and the values of the modern bureaucratic state, such as the 'specialization and division of labour, hierarchical layers of authority, selection on the basis of technical skills acquired through training and experience, and, above all, a strong emphasis on impersonal rules and procedures'. This would imply that the new value system introduced by the laboratory, which in turn to a large extent created the modern university, basically reflected the values of a modern industrial and bureaucratic society.

About the Authors

Klaas van Berkel recently retired as Rudolf Agricola Professor of History at the University of Groningen. In his research he focuses on cultural history and the history of science, especially the history of scientific institutions (academies, universities). In 2021 he published, with Guus Termeer, *The University of Groningen in the World. A Concise History* (Amsterdam: Pallas Publications).

Ernst Homburg is professor of history of science and technology emeritus at Maastricht University. His research is mainly on the interaction between science and technology in industry and academia from the nineteenth to the twenty-first century. His most recent book publications are: *Hazardous Chemicals: Agents of Risk and Change, 1800–2000* (New York, Oxford: Berghahn, 2019), edited with Elisabeth Vaupel, and *Een eeuw chemische technologie in Nederland* (Delft: Stichting Hoogewerff-Fonds, 2021), with Ton van Helvoort.

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