

THE OXFORD HANDBOOK OF

THE HISTORY
OF QUANTUM
INTERPRETATIONS

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OXFORD
UNIVERSITY PRESS

OXFORD
UNIVERSITY PRESS

Great Clarendon Street, Oxford, OX2 6DP,
United Kingdom

Oxford University Press is a department of the University of Oxford.
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First Edition published in 2022

Impression: 1

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Published in the United States of America by Oxford University Press
198 Madison Avenue, New York, NY 10016, United States of America

British Library Cataloguing in Publication Data
Data available

Library of Congress Control Number: 2022900685

ISBN 978-0-19-884449-5

Printed and bound by
CPI Group (UK) Ltd, Croydon, CRO 4YY

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INTRODUCTION

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THIS Handbook is dedicated to the memory of Silvan Samuel Schweber (1928–2017), who was the first to note that we needed such a volume, but who unfortunately was unable to see the work to its completion and sign this introduction with us. Sam Schweber was an accomplished physicist in the domain of quantum field theories until he moved to history of sciences where he wrote influential works such as a history of quantum electrodynamics and a biography of Hans Bethe (Schweber 1994, 2012; see also, on Schweber's works, Gavroglu and Renn, 2007). More importantly, he was an exceptional human being and a source of inspiration and encouragement for all of us.

Quantum mechanics, created in 1925–1927, is approaching its centenary with an impressive record. It became the backbone of most research in physics, led to applications such as the transistor and laser, and prompted an upheaval in the philosophy of science. Its scope and its precision have been constantly growing, and it is now promising more powerful computers, safer cryptography, and more sophisticated sensing devices. This century of conquests has also been a time of ongoing debates about the foundations and interpretation of the theory, which has been referred to as the quantum controversy. The Oxford Handbook of the History of Quantum Interpretations is dedicated to these debates. Although quantum physics is not the first scientific theory to spark fierce debates about its foundations, the resulting controversy has been unusually long and remains open. Half a century ago, the historian of physics Max Jammer aptly called it 'a story without an ending' (Jammer, 1974, p. 521). There still is no ending or closure in sight.

In fact, the debates on the foundations and interpretation of this physical theory began when its first elements appeared with the works of Max Planck, Albert Einstein, and Niels Bohr at the beginning of the 20th century. They coalesced between 1925 and 1927 when the very quantum theory was still *in statu nascendi*. These early debates

CHAPTER 28

FORM AND MEANING

Textbooks, Pedagogy, and the Canonical Genres of Quantum Mechanics

JOSEP SIMON

'One can find a "correct" meaning in textbooks, or in some philosophical writings on the quantum theory—in short, in the graveyards of science. On the research frontier nothing is immune to reappraisal...'

(Beller, 1999, p. 6)

A decade ago, the editors of a *Compendium of Quantum Mechanics* stressed the need for such a work, and its ability to highlight connections between physics, philosophy, and history for the benefit of the study of the atom (Greenberger *et al.*, 2009, p. v). It was arranged as a series of alphabetically ordered entries, just like the *Oxford Companion to the History of Modern Science*. Years later, the *Oxford Handbook of the History of Physics* introduced a compendium of longer essays and a thematic arrangement, but recognized yet again the same goals: presenting the complexity of a grown-up and rich discipline in a compact form (Heilbron, 2003; Buchwald and Fox, 2013, p. 1).

Compendia, handbooks, and companions are types of academic publication per se, which share many features with another genre: the *textbook*. A major common feature is that of being introductory reference works; another is their fundamental aim of synthesizing a whole field of knowledge in a single volume. All four can be used both in teaching and research, although the term 'textbook' has evolved more clearly than others to mean a work explicitly conceived and used for teaching purposes. All of them are challenging forms of knowledge production whether created by single or collective authorship (Simon, 2013 and 2016).

To follow a rigorous and well-established method of scholarship, when planning a chapter on the history of quantum physics textbooks, it would be wise to read the major human output on this topic, in the genre of companions, encyclopedias, articles, handbooks, treatises and monographs, research reports, laboratory notebooks, conference

proceedings, grant proposals, correspondence collections, source inventories, manuscript and printed lectures, textbooks, and compendia. But, where to start? Experience advises us to check first the last reference work in the relevant field (Heilbron, 2016). Since the history of quantum physics textbooks is as much the history of quantum physics (textbooks) as the history of (quantum) physics textbooks, this is arguably the *Oxford Handbook of the History of Physics* (2013). In that loyal companion to the historian of physics, one can find a chapter on physics textbooks that focuses a great deal on the 19th-century rise of the physics textbook genre and proposes a historiographical agenda, but deals only in passing with quantum physics (Simon, 2013). There is also another chapter that provides an overview and periodization of the making of quantum mechanics in the early 20th century, and gives some mention to textbooks (Seth, 2013).

Seth's big picture of quantum mechanics is supported by primary sources such as research papers, lecture series arranged into books, correspondence, collected works, and society and academy proceedings. He also introduces three textbooks that are crucial for his account: Arnold Sommerfeld's *Atombau und Spektrallinien* (Friedrich Vieweg & Sohn, 1919, 1st ed.), as a reference for the early quantum theory; P. A. M. Dirac's *The Principles of Quantum Mechanics* (Oxford University Press, 1930) and Werner Heisenberg's *The Physical Principles of the Quantum Theory* (University of Chicago Press, 1930), as the works marking the consolidation of quantum mechanics within physics. The latter came to substitute Sommerfeld's *Atombau* as canonical works and represented two different strands within the new quantum mechanics, one more mathematical, the other more philosophical. Later on, Seth clarifies that Heisenberg's book was based on lectures given in Chicago the year before its publication, and that Dirac's book arose from lectures at Cambridge from 1927 on. Seth implies but never expresses quite explicitly that books such as those were of special interest to college students and professors, and that these lectures took place in universities. This absence of reflection on the relevance of form and audience applies not only to textbooks, but to most sources used by Seth in his chapter.

Seth's proceeding is not an exception but a general pattern in most of the literature. The history of quantum physics is one of the pioneering fields within the history of science in the use of sources such as lectures, correspondence, oral interviews, and teaching and research notebooks. Its impulse has been to follow in minute detail the evolving thoughts of physicists in a field in formation, to establish priorities on the throne of modern physics, and to clarify the concepts of contemporary physics through research on its foundations. Paradoxically, methodological reflection on the use of such sources is scarce, and the meaning of quantum mechanics has been elucidated independently (and in certain aspects, in spite) of the form of its historical sources.¹

¹ There are of course exceptions to this trend, such as the innovative focus of Beller (1999) on dialogue as a tool of knowledge creation in analysing correspondence. This is noted by recent historiographical reviews such as Badino (2016). In spite of this, the field could benefit from more reflexive and broad-minded pictures, especially on the historiographical and methodological side. Reflection on

In delineating the rationale of the Sources for History of Quantum Physics (SHQP) project, John Heilbron emphasized that: '[letters and manuscripts] often permit the historian to follow the development of ideas, techniques and research projects from week to week, sometimes even from day to day. [...] When supplemented by the interviews, they give a lively impression of the nature and practice of physics two and three generations ago'. In the same guise, he characterized the interest in successive editions of textbooks such as *Atombau* (4 editions, 1919–1924): 'The individual volumes are still shots, so to speak, of a given moment in quantum physics; when compared they afford an animated picture of its development' (Heilbron, 1968, pp. 91, 100). The impressive historical potential of such sources, and their contemporary significance, led Heilbron to encourage historians of science to devote their research to this field. As he predicted, the field has grown considerably in the last half century and has made good use of the richness of sources he contributed to gather.

Seth's *Crafting the Quantum* (which follows some of Heilbron's recommendations) provides a detailed picture of the scholarly life of Sommerfeld and his research school, and emphasizes the interaction and intersection of research and pedagogy in the making of quantum mechanics. In passing, it also mentions that the first edition of Sommerfeld's *Atombau* emerged from a lecture given between 1916 and 1917 to university chemists and medical doctors and that its author defined it sometime as 'a popular book about atomic models'. With this readership in mind, through successive editions the complexity of mathematical language was kept out as much as possible, and deferred to a closing appendix (Seth, 2010 and 2008).

What strikes the historian and philosopher alike is how such contextual knowledge of the craft, form, and status of a source is not brought to the fore for a more thorough discussion, since the conclusions derived from the analysis of such a source would—for obvious methodological reasons—depend on this too. What were Sommerfeld's motivations to write such a textbook, how did he write it, what decisions did he take both about its contents and form, how did the printed form of his physics thought-style relate to his lecturing practice, what was his intended vs actual readership, what did the diversity of its readers think about the book and what were the various uses they gave to it, how was it used in teaching and in research, how did readers' reactions contribute to reshape successive editions of the book? Too many questions. They apply in fact to any quantum physics textbook. They bring together the tension between form and meaning inherent to the craft of making physics into the history of physics.

In this chapter, I call attention to the methodological importance of problematizing sources when writing the history of science, to the place of textbooks and pedagogy in the historiography of quantum physics, and to the promiscuous relationships between different genres of scientific literature shaping the interaction of research, teaching, and

sources, historical goals, and engagement with other areas of the history of physics and of science could be particularly helpful. For further evidence, compare Badino (2016) (diachronically) with Heilbron (1968) and (synchronically) with Chang (2016) or Bensaude-Vincent and Simon (2008).

popularization. I end up by discussing what allows us to qualify certain quantum physics textbooks as classic or canonical works, and suggesting future avenues for research.

28.1 HISTORICAL STRATA OF OUR RECENT TEXTBOOK PAST

When in 1961 Thomas Kuhn and his collaborators launched the SHQP project, their preparatory research included a survey of general and quantum physics textbooks (by authors such as Chwolson, Reiche, Van Vleck, and Sommerfeld), and handbooks such as the one edited by Geiger. The project had a major focus on interviews, but also as the one edited by Geiger. The project had a major focus on interviews, but also retrieved personal and institutional papers, correspondence, memoirs, photographs, and, last but not least, lecture notes by Bohr, Born, Hilbert, Debye, Langevin, Rutherford, Hevesy and J. J. Thomson, Fowler, and Larmor. In parallel, Kuhn produced his canonical work *The Structure of Scientific Revolutions*, which promoted the salience in history and philosophy of science of research concepts such as *structure*, *pedagogy*, and *textbooks* (Kuhn *et al.*, 1967; Kuhn, 1962; Simon, 2013).

In the previous section, we saw that Heilbron held a rather appreciative (and Kuhnian) view on textbooks, as sources for historical research. It clearly contrasts with Beller's, presented at the head of this chapter. Beller is known for her innovative approach to some of the now traditional sources for quantum physics history. While her major aim was to show how the orthodox interpretation of quantum mechanics emerged in the late 1920s, she brought a new hermeneutic to correspondence, by positing *dialogue* as a driving process in the making of quantum mechanics (Beller, 1999, pp. 1–14; Badino, 2016, p. 332). She did not apply analogous interpretative sophistication to textbooks. For her, if research-frontier science is the matter of life (thus changing constantly), textbooks are dead (for their immobility and immutability). Beller did not count—as opposed to Heilbron—on the ontology of multi-edition textbooks, nor considered that geological metaphors seeing textbooks as historical strata can be as pertinent as biological metaphors depicting scientific research as a living organism.²

A good methodological contrast that helps us to value the historical sophistication of the SHQP project arises when comparing it to some contemporary efforts. For instance, the source compilation coordinated by mathematician and historian of science Bartel Leendert van der Waerden (a colleague of Heisenberg in 1930s Leipzig), with advice from several quantum physicists (and an original idea by Max Born). This was a compilation of quantum mechanics historical papers (preceded by short summaries), which was a useful tool (in the 1960s), but providing just one type of source, a

² In fact, Beller's perspective is quite common among physicists and some historians of physics. See e.g., Schwinger (1973), p. 414, and Kragh (1999), p. 10.

rough taxonomy, and a parsimonious justification of its selection. The same applies to Dirk ter Haar's compilation of papers in *The Old Quantum Theory*, and the personal account of Friedrich Hund (assistant to Born in the 1920s). All were volumes published in 1967 (van der Waerden, 1967; ter Haar, 1967; Hund, 1967; Weizsäcker *et al.*, 1963). Heilbron qualified them as 'a sequence of often misleading epitomes of the important papers [...] and intended for advanced students of physics'. Kuhn, however, found van der Waerden's publication 'an invaluable anthology'. In that period, historians and philosophers of science (like Kuhn himself) developed history of quantum mechanics graduate courses (in which they confronted students with original papers), for which these compilations were surely handy (Heilbron, 1968, n. 15, p. 106; Kuhn, 1967, p. 415; WengersHerron, 2011).

In a review of the SHQP project, Tetu Hirosige reminded us that 'The historian of science starts his research with facts as all other scientists do. But the historian draws his "facts" from various forms of written source materials which, in general, have existed long before he begins his research, whereas a scientist produces his scientific facts by intentionally designed experiments. This is certainly one of the notable differences in the mode of research between the history of science and science itself'. He also characterized as candid and detailed the way that Kuhn *et al.* described in the first chapter of their report 'a basic process in studying the history of science—the gathering of historical facts from various sources'.

Hirosige was not fully aware of the innovative drive of such project, not that different from those scientific experiments he imagined, since building an archive like this meant not only a passive gathering of existing materials, but an active conceptual endeavour of creating a new source platform for historians of contemporary physics. Its plan of action contained a sophisticated evaluation of the field, based on a methodical survey of available knowledge in reference works and contemporary sources. Its rationale gave priority to the recovery of different types of documents considered pertinent to write the history of quantum physics from a historian's perspective, including for instance not only research but also pedagogical questions. Moreover, since Kuhn foresaw at the time that 'at least for the last few decades, there may be special problems about manuscript sources, for scientists have in recent years increasingly substituted the telephone and personal contact for the letter as a means of informal communication', the project did not limit itself to manuscript sources. It was particularly innovative in its endeavour to create an archive of oral history sources—something unusual for the history of science up until then. This effort included a methodological explanation of procedures, which might have been candid—as noted by Hirosige—since the project members were embarked for the first time on an enterprise of this nature, and they did not appear to have many previous examples to refer to. But they displayed a major quality of the historian's craft: methodological and historiographical transparency that leads to historical accuracy (Hirosige, 1968; Cook, 1971; Kuhn, 1967, pp. 418–419).

In the same period, Max Jammer worked on a comprehensive account of the conceptual foundations of quantum mechanics. His investigation proceeded implicitly through not only classic journal papers but also an international set of influential

textbooks, as main sources to elucidate the conceptual, logical, epistemological and mathematical structure of quantum theory. Although often buried in footnotes, it also showed the importance of textbook writing for contemporary physicists to clarify or solve complex scientific and philosophical implications in the making of quantum mechanics as an evolving research field. In the process of writing his book, Jammer discussed parts of it with physicists involved in the facts he dealt with (e.g. de Broglie, Born, Heisenberg, Dirac, Hund, Heitler, van der Waerden, Fierz, Jost, Andrade, Slater, Fues, and Tank) and with philosophers of science (Holton, Feyerabend, and Kuhn). In its preface, he indicated that his book was 'neither a textbook nor a collection of biographical notes nor even a study of priority questions', but in fact, it has become a classic textbook for any student of quantum physics history.

Heilbron considered that 'this important book is not quite history', and classified it in the 'historico-critical' genre. Its focus was on 'what now seem the central conceptual innovations in quantum physics, and not necessarily upon what were historically the most important steps in its development'. Analogously, Kuhn considered that it was an impressive contribution dealing with a vast literature. But, in questions of analytical depth Jammer had often acted more as a physicist than as a historian. He had fallen prey to historical presentism by attributing 'to particular experiments or theories the significance they are given in the contemporary curriculum rather than the one they had in their own time', and neglecting 'lines of development displaced by subsequent events but of vast importance in their own time'. Beller puts it another way: Jammer and other authors representing the orthodox way in the history of science are historically inaccurate because they rarely question the narrative of the winners. The impact of Jammer's contribution to our field has been continuous though, through a subsequent volume—focusing on interpretations proper—and a second edition of his first book, published in the 1980s as volume 12 of 'The History of Modern Physics, 1800–1950' series by the American Institute of Physics (Jammer, 1966, 1989, and 1974; Heilbron, 1968, p. 92; Kuhn, 1967, pp. 416–417; Beller, 1999, p. 11).

A wide range of sources and conceptual frameworks was therefore available to write the history of quantum physics. This was a mine for doctoral research. The 1970s saw the publication and up to four reprints of Daniel Kevles' *The Physicists* (based on his Ph.D. dissertation), conceived as a big picture of a scientific community or generation of successful American physicists. In the 1980s, a strand of research in the history of science took special interest in building the big picture of the community of practitioners of physics and its subdisciplines in Europe and the United States. Contributions typically paid equal attention to conceptual, institutional, research, and teaching aspects. They were equally inspired by works such as Kevles' and the more socially laden side of Kuhn's *Structure of Scientific Revolutions*.

Stanley Goldberg's overview of special relativity is a good example. Another one is Katherine Sopka's survey of quantum mechanics in the United States, published as volume 10 of 'The History of Modern Physics 1800–1950' series. Books like those by Kevles, Goldberg, and Sopka were considerably descriptive, but they are still major sources to understand how a modern community of physicists was configured in the

US, and the production of textbooks was an important activity for them. They proposed analytical focuses such as the role of doctoral and postdoctoral training and fellowships, seminars and symposia, European physicists' lecturing in the US, and American physicists' training in Europe, that became standard in the historiography of physics. Analogous efforts to those of Goldberg and Sopka to put the US on the map of quantum mechanics history were subsequently made by scholars from other national contexts, such as Kenji Ito for Japan. Their goal of characterizing whole communities of physics practitioners would prevail later on in big pictures such as Kragh's *Quantum Generations* and Staley's *Einstein's Generation* (Kevles, 1971; Forman *et al.*, 1975; Goldberg, 1984; Kragh, 1985 and 1999; Sopka, 1988; Ito, 2002 and 2005; Staley, 2008).

In the same period, another line of research, well-illustrated by doctoral students such as John Hendry (Ph.D., 1978) and Mara Beller (Ph.D., 1983), took off from Jammer's previous work to provide well-balanced research on historical and philosophical grounds. Hendry's book was arguably one of the first to have the term 'dialogue' in its title. He pinpointed that dialogue between historians and physicists was much required and that dialogue between Bohr and Pauli had been essential to the making of quantum mechanics. But 'dialogue' was not a central concept in his analysis of the philosophical implications of Bohr's research. Beller's doctoral dissertation and some of her early publications hinted at the term but did not develop from it. She was undoubtedly inspired by Hendry's work and more than a decade of thought maturation, before she published *Quantum Dialogue*. While proposing *dialogue* as a central analytical tool, her book preserved the ambition of her doctoral dissertation to understand both quantum physics and quantum physics history interpretations (Hendry, 1984; Beller, 1983 and 1985).³

With Beller, correspondence was not only a (Bohr) principle, but also a historical source, and as such an object that required historical problematization. Moreover, she crossed genres and connected them, by showing that physicists' conversations that might have started face-to-face or through correspondence, would continue through papers. Thus, letter writing was connected to paper writing—these were just different instances of the overall process of knowledge creation. From sources to conceptual interpretations, this meant that overall the making and communicating of science were intimately related—an argument developed by other historians of science with regard to other type of sources (Holmes, 1987; Waquet, 2003; Secord, 2004). In one way, Beller swam against the current: she considered that participant interviews such as those produced by the SHQP project were 'often unreliable' as historical sources—a question well known to historians: the difference between memory and history (Nora, 1984; Portelli, 1999). In other aspects, in spite of the innovative character of her methodological and historiographical approach, Beller was typically Kuhnian, from the subtitle of her book to her reluctance to consider textbooks also as sites of knowledge creation (Beller, 1999).

³ Klein (1970) also used that term but did not make it central to his analysis. Beller did not use the term explicitly in her publications until 1992.

For Beller, as for many historians of science wrapped in the Kuhnian mantle, textbooks were dogmatic and static sources. For this reason, they were useless in unveiling the actual movement of a scientist's creative thoughts. Paradoxically, Frederick L. Holmes' discussion of the difference between the contexts of discovery and justification, and its concurrence in the writing of research papers shows (*pace* Kuhn), that the 'falsification' of the research practice process through writing is as characteristic of pedagogical literature as of investigative pathways (Holmes, 1987; Simon, 2013). But it was time to focus on other types of sources.

The new *fin de siècle* would see the advent of a 'science-notebook historiographical revolution'. Starting with Kathryn Olesko and following with Andrew Warwick and David Kaiser, historians of physics produced some of the most innovative work in the history of science, by a thorough analysis of student and teacher notebooks, lecture notes, and examinations. Their methodologies and focus on science pedagogy brought a breath of fresh air to our discipline. The work of Seth on Sommerfeld mentioned at the start of this chapter can be placed in this framework. However, this 'revolution' partly relied on a classic paradigm, where authors such as Warwick and Kaiser revived the work of classics such as Kuhn and Foucault, and henceforth proposed narrow concepts of discipline and pedagogy—which once again relegated textbooks to the end of the line. There were, however, other competing perspectives that have furthered new approaches to the study of science education and textbooks (Olesko, 1991 and 2006; Warwick, 2003; Kaiser, 2005a and 2005b; Simon, 2011, 2013, and 2015).

In this context, some new contributions have started to develop more thorough case studies on quantum mechanics pedagogy and textbooks, but there is still a long way to go to define the role of pedagogy and textbooks in the conceptual, epistemological, and institutional foundation of this field of physics (Kaiser, 2007 and 2020; Badino and Navarro, 2013; Badino, 2019). Unfortunately, it is still a common trope to consider that 'scientific revolutions are rendered invisible by subsequent textbook treatments written from the perspective of the new paradigm', where history is constantly falsified by physicists and their textbooks (Gooday and Mitchell, 2013, p. 752).

This and other historiographical 'revolutions' are a sign of the vitality of the history of physics as a discipline. But perhaps a more accurate and objective measure of the temperature of our field can be obtained by taking a look at one of the oldest, more abundant, and arguably more methodologically and historiographically discussed genres in the history of science, that is, biography (Söderqvist, 2011; Nye, 2015; Forstner and Walker, 2020). Let's cite a number of representative examples (regarding quantum physics) across three decades: Heilbron's (1986) and Hoffman's (2008) Planck, Walter Moore's (1989) Schrödinger, Helge Kragh's (1990) Dirac, David Cassidy's (1992 and 2009) Heisenberg, Kostas Gavroglu's (1995) London, Silvan Schweber's (2000 and 2012) Oppenheimer and Bethe, Maria Rentetzi's (2007) Meitner and Blau, Michael Eckert's (2013a) Sommerfeld, and Olival Freire's (2019) Bohm. All of them give an important share in their narratives to education and pedagogy, but, most importantly, most of them consider it relevant to discuss the role of textbook reading and writing in the intellectual and professional career of their historical characters.

28.2 QUANTUM TEXTBOOK GENERATIONS

The year 1900 has been dubbed the 'turning point' in physics history where natural philosophy muted into modern physics, as we know it today (Forman *et al.*, 1975; Buchwald and Hong, 2003; Kragh, 1999). However, the early-1900s textbook world looked much more as its 19th-century counterpart than as a new era. When Max Planck created the equation that bore his name, it soon appeared in two textbooks that set the standard. The first was Orest Chwolson's *Lehrbuch der Physik*—a late 19th-century multi-volume work originally written in Russian, and successively updated and translated into German, French, and Spanish. Its second volume in German appeared in 1904. The second, Adolf August Winkelmann's *Handbuch der Physik*, a multi-authored encyclopedia whose first edition appeared during the last decade of the previous century. Its second edition (1903–1909) included a volume devoted to electricity and magnetism (published in 1906) which covered literature up to 1904 and had a contribution on radiation by Leo Graetz (a former student of Planck) referring to Planck's equation as well. These were extensions of the 19th-century textbook physics tradition, which had in Germany representatives such as Johann Müller, Adolf Ferdinand Weinhold, and Adolf Wüllner. Planck's youth, and his turn-of-the-century research on the radiation of the black body, was inspired by reading works such as Müller's physics treatise and John Tyndall's textbook *Heat Considered as a Mode of Motion* (German translation, 1876). Sommerfeld contributed himself to an *Enzyklopädie der mathematischen Wissenschaften* (managed by Felix Klein, 1898–1933) by editing its international multi-authored volume on mathematical physics, and contributions to the organization of its volume on mechanics. This was the textbook physics world in which physicists like Planck and Sommerfeld (who had their doctorates and *habilitation* before the new century) grew up. In their ascent from students to *privatdozenten* and assistants, and from there to professors, research institute directors, and research school leaders, they had also to comply with tasks such as the weekly taking of detailed notes of lectures (for themselves or their professors) (Kangro, 1976, pp. 8, 230; Wilson, 1912; Simon, 2013; Eckert, 2013a, pp. 49, 60, 99–108; Gispert, 1999).

Many of the aforementioned textbooks originated between the 1850s and 1870s; by successive additions and editions, they typically grew into five-volume works, such as contemporary handbooks, and lived up to the first decades of the 20th century. Many of them survived their original authors, and were run by successive teams of editors. However, between the 1910s and 1920s, their capacity to absorb new matter in relation to the fast-growing field of physics was proving ever more unfeasible. Their unstoppable growth had made them monstrous, both due to size and lack of coherence, and it was as problematic for physicists as for publishers to keep such works in shape and at a reasonable price (Simon, 2013). This meant disruption and transition in the communication system shaping the disciplinary substance of modern physics (in which

textbook physics had a relevant agency). Consequently, a new subfield or specialization emerged through the production of new textbooks specifically devoted to quantum mechanics. In its turn, as has been suggested by Jammer, the making of quantum mechanics as a new tradition or subdiscipline of physics required completeness (and coherence), and textbooks had a major role in this process. As we saw in the introduction to this chapter, Seth has proposed a similar pattern, although less explicitly, in using Sommerfeld's, Heisenberg's, and Dirac's textbooks as scaffolds for his *Handbook* chapter narrative (Simon, 2013; Stichweh, 1996 and 2001; Weisz, 2006; Jammer, 1966, pp. 366–370; Seth, 2013).

A combination of several communication genres (lectures, encyclopedia articles, journal papers, and textbooks) constituted the standard system of communication of physics research at the time. Not surprisingly, there was a crossbreeding of these genres that contributed to the invigoration of discipline building. Thus, in 1916, after submitting his paper 'Zur Quantentheorie der Spektrallinien' to *Annalen der Physik* and resuming his lecturing duties, Sommerfeld began to think about the mission of writing a textbook on the topic.⁴ With its almost 140 pages and its publication over two issues of the journal, Sommerfeld's paper was by far the largest, most prominent work in a journal which had in 1916 published only slightly more than twenty issues, and whose average article length was between 10 and 30 pages that year. Needless to say, publishing in the *Annalen* was not easy, and it surely had a budget related to the length of each issue and its printing production costs.

As indicated by Sommerfeld, his paper was based on two communications submitted between the previous year and early 1916 to the Akademie der Wissenschaften zu München. He had also presented this research at the weekly colloquium of his research institute. Munich had several options for discussion on advanced physics topics, of which Sommerfeld made the most: the traditional monthly Sohncke Colloquium (a joint effort of physicists at the University and the Technical University), a newer Colloquium which eventually was called after Sommerfeld, and more informal student seminars, regular and special lectures, and guest lectures in other university departments. Sommerfeld's training in this communication system was shaped since his days as a student in Klein's research centre at Göttingen. During the first years of his professorship at Munich, there were innovations such as the aforementioned weekly colloquia and seminars. Starting in this period, Sommerfeld's publishing endeavours began to be more tightly connected to his lecturing schedule, and participation in a varied array of research presentation venues addressed to physicists as well as colleagues in other faculties.

As has been worked out in detail by Michael Eckert, it was in this overall context and not just sparked by a lecture to an audience of 80 people (including 12 physicists, the rest being mainly chemists, medical professors, and philosophers), that the goal of producing a textbook crystallized in Sommerfeld's mind. Historians of physics have

⁴ On Sommerfeld, most of the time I follow Michael Eckert's narrative, but the interpretation is mine.

often literally followed Sommerfeld's remark on that specific audience, on his intention to produce a book representing the printed form of the lectures he was giving 'popularly, i.e., without mathematics, only conceptually presented', and on his repeated qualification of the work he was writing as a 'popular book'. Accordingly, Eckert has stated that Sommerfeld's *Atombau und Spektrallinien* was in fact not a textbook. However, Sommerfeld also indicated that his book was 'in its main part for chemists, in the appendices also for physicists', depicting a mixed but clear readership (Eckert, 1993, pp. 59–60; Eckert, 2013a, pp. 155, 164–166, 205–214, and 2013b; Sommerfeld, 1916).

In fact, in spite of increasing specialization, between the 19th and mid-20th century most physics textbooks were explicitly addressed to an assorted spectrum of readers. This was a reflection of a diverse and fragmented educational framework, a highly competitive publishing market, and the publishers' and authors' intention to capture the largest body of customers, in a readership pool in expansion but still small compared to that of other fields of knowledge. We should also not forget that *Annalen der Physik und Chemie* had only relatively recently dropped the 'chemistry' in its name (by 1900), that there were numerous research areas in the new physics (including quantum mechanics) at the intersection of physics and chemistry, and that for a long time the history of contemporary physics has unfairly been biased towards theoretical and mathematical physics. In addition, Sommerfeld is well known for being more preoccupied in his lectures and pedagogical writing with the physical problems than with mathematical foundations. Finally, in order to understand Sommerfeld's authorial intentions and the genre of his work, we should first understand what 'popular' and 'popularization' actually meant at the time (Simon, 2011, 2013, and 2009; Seth, 2010).

For this purpose, it is particularly appropriate to use the work of Ludwik Fleck, who was a medical student at the time, and through his experience as a researcher proposed in the 1930s concepts such as *Denkstil* and *Denkkollektiv*. Fleck's conceptualization of scientific practice through 'thought collectives' configuring and constrained by a 'thought style', and their subdivision into small 'esoteric circles' and large 'exoteric circles', stressed the transformative and multidirectional role of communication in the making of science. In addition, he offered a useful characterization of the carriers of scientific knowledge and agents of scientific communication through the definition of three major genres. According to him, a 'thought style' is represented by '*vademecum science*', as the carrier of common expert knowledge and the tool binding a 'thought collective'. It is opposed to '*journal science*' in that it is comprehensive and consensus-based. It differs from '*popular science*' in that it is critical and organized. However, the character of the *vademecum* is also determined by the fact that every communicative action—including those leading to its configuration—makes knowledge more exoteric. Thus, communication always transformed knowledge, and it acted towards the constitution of 'thought styles' based on social and intellectual consensus. In this framework of intensive communication processes between exoteric and esoteric circles, for Fleck the quality of the 'standard' applied to a work is in fact one of the qualities of the 'popular'. Popularizing thus did not consist uniquely in communicating to lay

audiences, but also to specialized scientists belonging to other disciplines and sub-disciplines within the sciences—a characteristic of the modern system of scientific disciplines, according to Rudolf Stichweh. In spite of their differences, *vademecum*, textbook, or handbook science met *journal* and *popular* science in the making of those works that we can consider as standard, canonical, or classic by the quantitative and qualitative testimony of its readers. In this framework, due both to its conception and its documented uses, Sommerfeld's *Atombau* was obviously a textbook, and as we are going to see in the following, it represented the quantum physics canon and soon became a classic (Fleck, 1979, pp. 39–41, 51, 98–9, 109–113; Simon, 2009; Fyfe, 2002; Olesko, 2005; Stichweh, 2001).

Intensive lecturing was closely related to the university profession. A major source of income for both *privatdozenten* and professors, their prestige was not only shaped by research production, but also by pedagogical and lecturing skills. Disdain of teaching over research, and a restrictive and mystifying association of the latter with genius, have been retrospective narrative tools often used by physicists themselves, but hardly corresponding to how physical knowledge was made (Ben-David, 1971, pp. 108–138; Busch, 1963; Jungnickel and McCormmach 1986, vol. 2; Waquet, 2003; Sopka, 1988, Appendix B; Kapitza, 1973, p. 755). Other major examples of textbooks arising from their authors' activity and experiences as lecturers, and essential both to research and pedagogy are for instance: Max Born's *Vorlesungen über Atommechanik* (Julius Springer, 1925), its second volume by Born and Pascual Jordan, *Elementare Quantenmechanik* (Julius Springer, 1930) and Born's *Probleme der Atomdynamik* (*Dreissig Vorlesungen gehalten im Wintersemester 1925/26 am Massachusetts Institute of Technology*) (Julius Springer, 1926; trans. in English: *Problems of Atomic Dynamics*, MIT Press, 1926), Erwin Schrödinger's, *Abhandlungen zur Wellenmechanik* (J. A. Barth, 1926), and Paul Dirac's *The Principles of Quantum Mechanics* (Oxford University Press, 1930). All clearly belonged to the textbook genre, but there are differences between them. For instance, while Schrödinger's textbook is simply a compilation of papers, and Born's *Problems* arose from a series of just ten lectures held on an American tour, his *Elementare Quantenmechanik* was a much elaborated text aiming to endow the field with a matrix mechanics foundation. Even more can be said of Dirac's *Principles*, as one of the major textbooks providing completeness and coherence to quantum mechanics. It is a matter of further research determining how quantum physics lecturing fed into textbooks and vice versa. Nonetheless, writing a quantum physics textbook, or being mentioned in one of them, had undoubtedly a major role in furthering physicists' academic status and professional career. Consequently, textbooks were a matter not only of collaboration, but also of fierce competition (Mehra and Rechenberg, 1982, pp. 252–253, 281–282; Giulini, 2013; Jammer, 1966, p. 366; Eckert, 1993, pp. 94–95, 260–261).

An important part of the meaning and status of these textbooks depended on the perspectives of students, colleagues, reviewers, and other types of readers. Thus, for instance, in spite of the relevance of Born and Pascual's *Elementare Quantenmechanik*, Wolfgang Pauli criticized the difficult reading and one-sided nature of the

mathematical foundation proposed by that textbook for quantum mechanics. According to him, it limited the use and interest of the book to a restricted readership. In contrast, some quantum physics textbooks were soon characterized as classic or canonical works. A common designation for those textbooks was referring to them as the 'Bible' of modern physics. Sommerfeld's textbook was called like that by fellow physicists and chemists such as Max Born, Hermann Weyl, Friedrich Paschen, and Exum Percival Lewis. It was highly praised by numerous colleagues (e.g. Lorentz and Röntgen), who emphasized Sommerfeld's textbook wealth of data, together with its clear and precise structure, arrangement, language, and conceptual exposition. In contrast to his review of Born and Pascual's book, Pauli valued the fourth edition of Sommerfeld's textbook especially because it did not rely on any particular atomic model, thus making it useful for a comprehensive range of quantum physicists. Alfred Landé and Friedrich Hund considered that it was one of the 'great standard works' and as such was known to any theoretical physicist—certainly, *Atombau* was a major agent in drawing young students towards the study of quantum mechanics. By reading *Atombau*, a generation of students and young researchers complied with a rite of passage to become part of the international community of theoretical physicists. In the early 1920s, during a six-month lecturing tour across the US, Sommerfeld was considered an 'oracle' by some American colleagues, in relation to the knowledge contained in his textbook and conferences, and Paul Ehrenfest called him—not without irony—'St. Sommerfeldus, the quantum Pope' (Mehra and Rechenberg, 1982, p. 282; Eckert 1993, pp. 59–60, 85, 94–96, 139, 260–261; Eckert, 2013b, pp. 118, 127–128, 131; Eckert, 2013a, p. 256).

The Bible is a canonical work in the Christian religion. It can be interpreted variously and contains a wealth of different voices, but it is a fundamental and standardized repository of Christian creed, and a universal classic of literature. The use of this designation for Sommerfeld's textbook expresses its canonical and standard character, as testified by a wide and international range of its readers (it was translated into at least English, French, and Russian) and by successive editions (1919, 1921, 1922, 1924, 1931, 1944, and a second volume of the textbook: 1929, 1939, 1944). It also shows that *Atombau und Spektrallinien* neither belonged to Sommerfeld as its author, nor was it just a manifesto of his research school: it was a collective work belonging to all its highly appreciative readers, and to the world community of physics and science practitioners at large. Further cases of major collective textbook writing, even across national frontiers, can be found in other examples of physics textbooks, handbooks, and encyclopedias mentioned in this chapter, or in other canonical works in the history of science such as Berzelius' *Lärbok i Kemien* (1808–1818). The 'bible' epithet was subsequently used to characterize some other quantum physics textbooks, for instance Dirac's *Principles*. It is a value that does not apply to any type of publication, but exclusively to the classics—among which science textbooks have a larger presence than is usually acknowledged (Eckert, 1993, p. 127; Eckert, 2013b, p. 117; Jammer, 1966, p. 366; Simon, 2009 and 2013; Blondel-Mégrelis, 2000).

28.3 TEXTBOOK FOUNDATIONS

In the closing sentence of his Ph.D. thesis, John Heilbron confided that: 'Most quantum physicists appear to think in terms of space-time pictures when working on everyday problems and only trot out the "official" interpretation when writing text-books or philosophy. But that is another story'—where 'official' stands for 'Bohr's complementarity' (Heilbron, 1964, p. 419).

In his survey of quantum physics teaching in the United States, David Kaiser has pinpointed that between the 1940s and 1950s—the period in which a major historian of science such as Heilbron, and his 12-year-elder adviser Thomas Kuhn, were studying physics—textbook narratives abandoned the historical or genealogical mould in favour of a toolkit approach. Kaiser contrasts the structure and contents of the first textbooks and some of the early lectures (which between the late 1920s and 1940s paid equal attention to mathematical formalism and philosophical interpretation), to the emerging trend a decade later.⁵ By the mid-1950s, across the country's major universities, physics graduate students saw examination questions that previously dealt typically with matters of interpretation, being replaced by questions testing competence in standard calculations. Kaiser further reinforces his argument by comparing the unequal fate of two of the major American textbooks of the period: Leonard Schiff's *Quantum Mechanics* (1949) (representing the toolkit approach) and David Bohm's *Quantum Theory* (1951) (representing the philosophically laden approach). In spite of the illustrative power of such comparison, it is only partially relevant, as it explicitly circumvents more rigorous arguments acknowledging the historical contingencies of Bohm's career. Kaiser extends the development of this trend at least up until the 1970s, although he admits that in that decade, due to lower pressure of enrolments, some textbooks started to combine a larger number of calculation questions with some qualitative essay-type ones (Kaiser, 2020).

Heilbron's witness perception, riveted by Kaiser's historical sketch, is in many ways a historian of physics' favourite. Helge Kragh's textbook *Quantum Generations* frequently refers in its pages to the idea (outlined in Beller's citation at the head of this chapter) that textbooks do not reflect the change in worldview discussed in frontier theoretical physics, because this is how they 'usually are: They are by nature conservative and cautious in their attitude toward modern ideas' (Kragh, 1999, p. 10).⁶ This view is common, and new adherents follow successively a similar Kuhnian route to

⁵ Textbooks by Condon and Morse, Ruark and Urey, Landé, and Kemble. Lectures at Berkeley and Caltech, by Oppenheimer and Bloch.

⁶ It is Kragh himself who defines his book as a 'textbook'. Kragh (1999), pp. xi–xiii. See also Purrington (2018).

textbooks (Kaiser, 2005b, pp. 393–409; Badino and Navarro, 2013; Badino, 2019, p. 6).⁷ If such is the reality of textbooks, how would they engage in open and not consensual questions of philosophical interpretation, instead of focusing on more direct matters of quasi-mechanical mathematical calculation, as sketched by Kaiser?

According to Hendry, 'Between 1928 and 1933 the dominant position of the Copenhagen interpretation was confirmed and consolidated through the publication of a long series of textbooks and review papers, written by its adherents. Among the authors were Heisenberg, Dirac, Weyl, Born and Jordan, Kemble, Pauli, and von Neumann'. Von Neumann's *Mathematische Grundlagen der Quantenmechanik* (1932) contributed to cement this consensual framework by providing the Copenhagen interpretation with a solid mathematical foundation and endorsing it too with an explicit philosophical approach (Hendry, 1978, p. 169). Analogous attributions are given by other authors to other textbooks, although these lay especially on the mathematical and theoretical formalism side, since philosophical interpretation was rather implicit than explicit in most textbooks. Major examples are the textbooks by Dirac, Heisenberg, Born and Jordan, and even de Broglie, as major agents both in the establishment of a predominance of the Copenhagen spirit, and inauguration of a new era in which pedagogical efficiency concealed the public exposition of philosophical quarrels or the promotion of interpretative pluralism among quantum physicists. Both aspects came together, because—as it has been noted—many textbooks did not care about introducing Bohr's complementary principle while providing space for Heisenberg's uncertainty principle and especially for everyday quantum physics practice (Gandarias Perillán, 2011, pp. 243–248; Howard, 2013; Kragh, 2013 and 1999, pp. 211–212). However, a closer look at textbooks such as von Neumann's shows that it differed in important ways from Bohr's views. It introduced, for instance, a different interpretation of the measurement process (a distinction that would become clear decades later). It contributed thus to the sustained defiance of quantum orthodoxy, and indirectly, to the constitution of a research field devoted to the foundations of quantum physics (Freire, 2015, pp. 141–149).

We cannot ignore that frontier quantum physicists wrote textbooks, but most often they interest us only when they were written in times of *crisis*. In those times, the standard historian thinks that textbooks displayed disagreement, pluralistic views, confusion, and even periodical changes in perspective (see for instance successive editions of Sommerfeld's textbook and its airing of disputes with Bohr on the foundations of quantum theory). These textbooks contributed to shape *normal science*. The *normal* quantum mechanics package included a basic conceptual framework coined 'the Copenhagen interpretation'. Subsequently, new textbooks became standard and somewhat dogmatic pieces of work exclusively aimed at this type of disciplinary

⁷ On the limitations and historical contingency of Kuhn's perspective on textbooks, see Simon (2013) and (2016). Kaiser and Warwick have non-casually shown their strictly Kuhnian take on textbooks, and a pragmatic Kuhnian reformism on other pedagogical matters. Badino and Navarro are in practice—*pace* Kuhn—essentially inspired by Kaiser and Warwick.

indoctrination that we call scientific training. With more or fewer nuances, this framework conforms to the views of all the aforementioned authors, and in practice, it is perfectly Kuhnian. It works for certain cases, but this chapter's aim is to show that nevertheless, it is insufficient. Furthermore, does not it sound too good to be true, as an allegedly 'simple textbook narrative'? In several ways, claiming some diversity and epistemological agency for quantum physics textbooks is more akin to admitting the relevance for quantum physics of conceptual dissidence and foundations research than most scholars have traditionally been willing to accept.

In contrast, historians of physics are more open minded and sympathetic to pedagogy and textbooks when producing proposals to improve current quantum physics teaching through updated history and philosophy of science contents and approaches. There is a general agreement about the fact that it is usual to find well-packed but naive (and especially inaccurate) historical content in current physics textbooks (in particular on quantum mechanics). However, researchers typically work with a few illustrative textbook examples, and although this is likely to be a dominant trend, we are still in need of more general surveys. Furthermore, we could perhaps proceed inversely, and look for those exemplary textbooks that have already made proper use of history and philosophy of science. Finally, historians and philosophers of science in dialogue with science education researchers have come to accept that, very often, historical complexity does not easily match with pedagogical effectiveness. In spite of this, a considerable number of scholars agree that science education and (quantum) physics learning would benefit from interdisciplinary collaboration in the production of teaching materials as rigorous on pedagogical as on historical and philosophical grounds. It is thus possible to shape the ontology and epistemology of quantum mechanics through textbook science (Brush, 1974; Kragh, 1992; Lautesse *et al.*, 2015; Franklin, 2016; Greca and Freire, 2014; Hentschel, 2018; Mohan, 2020). If this is possible for current teaching and textbooks, in a time of no particular crisis for quantum mechanics, how would it be—if we keep to a strict Kuhnian vision—that it might not have happened before in the already long history of quantum textbook physics?

If we stay Kuhnian, the case of David Bohm's textbook, previously mentioned, would then feature as an exception (although obviously not the only one) in a textbook landscape apparently dominated by normative aphoristic quantum mechanics. If we pay attention to the inspiring dialogue between historians, philosophers, and educators, it can be instead a major example, among others, showing us that there is historical life beyond the Kuhnian paradigm. To understand the neglect of Bohm's alternative approach over the dominant Copenhagen interpretation, James T. Cushing appealed to historical contingency. Much in the way of Paul Forman's famous thesis, he expounded the social, political, and cultural factors that shaped both Bohm's philosophical views, and their failure to become more widely adopted among physicists at the time of their publication (Cushing, 1994; Hiley, 1997).

In his classic paper, Forman revealed the changing thoughts of physicists in the Weimar Republic, through a wide range of literature genres that accounted for what physicists heard, read, talked about, and believed: written accounts of public lectures,

academic addresses, correspondence, articles in handbooks, general science periodicals, newspapers, and specialized scientific journals, and popular philosophy books. In many ways, Forman's article could be seen as a history of reading and lecturing. It has neither this historiographical approach, nor that of book history though. It focuses on ideas and intellectuals. Thus, it considers publication genres as insignificant containers and diverts from a thorough analysis of readerships and audiences. Forman's meticulous reconstruction of the intensive lecturing schedule of the leading German physicists, on broad scientific and philosophical subjects, has fairly won him an eponymous thesis. His approach has generously showed how philosophical, artistic, educational, and scientific debates were related, and how cultural and political circles (if separable at all) interacted and intersected. Forman's thesis was a ground-breaking and courageous stance in a time in which historical, philosophical, and sociological perspectives on science were at war (Rossi, 1986). Its valuable historical finesse has lived up to the present day. Nonetheless, with the present nuances of our discipline, Forman's thesis might be hampered by exceptionalism in several ways. The most important is in fact the downside of Forman's sophisticated historical contingency: the communication practices that he describes in minute detail only happen in (particular) hostile environments, as a way for scientists to regain (previously lost) social prestige. It is therefore a result of crisis, and therefore would not apply in (Kuhnian) *normal* times. In comparison, theses such as Fleck's see in analogous communication processes as those outlined in Forman's paper the standard rule that characterizes how scientific knowledge is produced.

Thus, for instance, Forman tells us that 'Heisenberg published a popular article retailing his conclusions even before his "technical" paper was printed', because of 'the physicists' general anxiousness to carry the good news to the educated public' (Forman, 1971, p. 105). As if this publication practice was exceptional or rare. Conversely, if we bring in Fleck's historical epistemology (outlined in section 28.2): a characteristic Weimar physics style was possible because of the intense communicative interaction between esoteric and exoteric circles of knowledge and between several types of science genres, including specialized journal papers (*journal science*), but also reference works (*vademecum science*), educational works (*textbook science*), and general and popular science periodicals, newspapers, and best-selling philosophy books (*popular science*) (Simon, 2009; Olesko, 2020). Furthermore, saying that quantum mechanics knowledge became popular equates to saying that it became standardized, since both qualities arise from the same processes driving the making of quantum meaning. In this framework, Heisenberg's intersectional reading and writing can be seen as common practices in the making of scientific knowledge, and not just peculiar or extraordinary concessions to the general public. Again, we can see here the relationship between form and meaning at play, but also the tension between historical, sociological, and philosophical approaches, as connected but distinct perspectives on science.

Regaining contingency through Forman's example, we can go back to that new classic of modern quantum mechanics, American dominance of the field during the second half of the 20th century: in fact, Kaiser's central argument in his overview of US

quantum physics textbooks is excessively focused on the role of decaying university enrolments (a central argument in his Ph.D. thesis). He brings in one of Forman's lines of thought (also exploited by subsequent historians, such as Olesko), but neglects other major cultural and conceptual sides of the problem. For instance, in the 1960s and 1970s many influential American physicists and textbook authors were against the integration of historical and philosophical perspectives in textbooks, because they thought—among other things—that they were *tout court* not useful to physics learning. In any event, as with the debate over the applicability of Forman's thesis beyond Weimar, we should discuss if Kaiser's US picture would apply to other cases. It might have been a general trend, but it is arguably not a universal Kuhnian truth that applies to all countries or authors of quantum physics and general physics textbooks (Stambler, 1971, pp. 236–250; Rudolph, 2002; Simon, 2019). As historians, we are also left with the question of deciding if Forman's or Fleck's theses can be applied anytime and anywhere, which includes an ever zealous methodological effort to distinguish exceptional from standard, exemplary, or comparable cases, and to tune our claims to the nature of the historical sources and interpretations we use to build them. It is clear though, that in choosing effective ways of communicating quantum mechanics, pedagogical, historical, and philosophical priorities have to be negotiated.

28.4 CONCLUSIONS

Dealing with quantum mechanics textbooks in a national or international perspective would require a more precise genre ontology than we currently have: for instance, are we only talking about books having 'quantum mechanics' in their title, or any book designed for teaching having adjectives 'quantum', 'atomic' or 'nuclear' in their title? Taking into account the powerful disciplinary force of textbooks, a characterization of quantum mechanics as the theoretical framework underlying atomic, molecular, and nuclear physics is too overtly gross, as it would be to think that engineering is just applied science. We know too well that each of these disciplinary fields embodies a distinct and partly sovereign way of making knowledge, while holding intense inter-actions and intersections with the others. We should also bear in mind that there is a century-long pedagogical tradition in textbook physics going back to the mid-19th century which predominantly favoured experimental and technological perspectives, while theoretical physics was gaining power in its impetuous march towards the mid-20th century. These might be relevant arguments to consider in discussing the absence or nature of foundational and interpretative questions in quantum physics textbooks. We surely still require more research and more of this pluralistic historical contingency, to produce more accurate analyses of the role of textbooks in quantum mechanics. It is this methodological and historiographical urge that this chapter has insistently been asking for in this field of research.

In this chapter, I have provided an overview of the place of textbooks in the history and historiography of quantum physics. This is just a first glimpse into a field in need of serious development. Recent works such as Badino and Navarro's edited volume and Kaiser's brief incursions into American physics textbooks offer a range of materials on major case studies of quantum physics textbooks by a range of experienced scholars in the history of contemporary physics. Through volumes like these and relevant sections in the wealth of available biographies on quantum physicists, the interested reader can already find relevant insights on textbooks such as those by Max Planck, Fritz Reich, George Birtwistle, Arnold Sommerfeld, Max Born, Paul Dirac, John Van Vleck, Pascual Jordan, Otto Sackur, and Paul Drude, among others.

In this chapter, I have taken a different approach, emphasizing the importance of refining our historiographical and methodological approaches on science textbooks—in particular, quantum physics textbooks—in the framework of a rigorous problematization of historical sources and scientific literature genres. In this context, I have reclaimed a more central and higher status for textbooks within the history of quantum physics, by demonstrating the relevance of their historical and historiographical agency. By using a selection of case studies, I have discussed the nature of textbooks, their major role for quantum physics research, teaching, and popularizing, the ways in which standard sources for quantum physics history such as journal papers, conference proceedings, letters, lecture notes, or interviews relate to textbooks, and how they interact between them. I have advocated for the study of how scientific literary genres cross over, and how their dynamics relates to the enterprise of making and unmaking scientific disciplines. Furthermore, I have shown how we can attribute the quality of standard, classic, or canonical to a number of science works—especially textbooks—and not just elite journal papers or esoteric treatises.

Future histories of quantum textbook physics will have to look more deeply at the epistemological role of textbooks in the making of the quantum physics discipline—a topic that, to be fair, I have scarcely dealt with in this chapter. They will also have to connect pedagogical philosophy with the economies of writing and publishing, and their socio-political parameters. Moreover, in this chapter I have focused on the disruption in the communication system of physics that drove the discipline to division and specialization, and hence the emergence of a new genre: quantum textbook physics. I have not dealt with the subsequent process of disciplinary integration that by the mid-20th century pushed for the assimilation of modern physics (mainly quantum mechanics and relativity) into general physics textbooks, to supersede the outdated nature of the introductory textbooks from the 1930s and 1940s.

Finally, the history of quantum physics textbooks has hitherto exclusively concentrated on textbooks belonging to the heroic or discipline-shaping period of quantum physics, and to the historically, historiographically, and geopolitically dominant schools. In addition to those already cited in this chapter, the reader will surely be familiar with names such as Haas, Tomonaga, Rojansky, Gurney, Groenewold, Mandl, Kramers, Pohl, Houston, Dicke and Wittke, Merzbacher, Powell and Crasemann, Matthews, Trigg, Mott, White, Landau and Lifshitz, French and Taylor, Saxon, Sakurai, Jauch, or

Rubinowicz. Most of them do not have monograph studies on their textbook work, yet, but the old historiography of quantum physics textbooks will eventually fulfil this goal.

Undoubtedly, the new historiography of quantum textbook physics will also have to include in its research horizon the study of translations, cross-national textbook writing, and different criteria of relevance for analysing the making of quantum textbook physics, leading to names such as Dushman, Persico, Cini, Bandini, Messiah, Cohen-Tannoudji and Laloë, Blokhintsev, Leite Lopes, Kogan and Galitsky, Kompaneetz, Davydov, Sokolov, Loskutov and Ternov, Goldman and Krivchenkov, Abers, Ortiz Fornaguera, Garrido, Aréjula, de la Peña, Ghoshal, Rojo Asenjo, Galindo and Pascual, Gasiorowicz, Taketani, Kotani, ... Is there any historian there, who might have heard of them? Will historians of quantum physics textbooks depart from neoclassic intellectual history? Where is the place where the form and meaning of quantum ideas promiscuously dialogue to produce new historiographies?

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