Beyond Borders

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Fresh Perspectives in History of Science

Edited by

Josep Simon and Néstor Herran
with Tayra Lanuza-Navarro, Pedro Ruiz-Castell
and Ximo Guillem-Llobat

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TABLE OF CONTENTS

INTRODUCTION 1
Josep Simon and Néstor Herran

PART I: GEOGRAPHIES OF KNOWLEDGE IN EARLY MODERN EUROPE

GEOGRAPHIES OF KNOWLEDGE IN EARLY MODERN EUROPE 27
Tayra Lanuza-Navarro

BEYOND MIXED MATHEMATICS: HOW A TRANSLATION CHANGED THE STORY OF DESCARTES'S PHILOSOPHY OF MATHEMATICS 35
Danielle Cozzoli

KEPLER'S DEFENCE OF ASTROLOGY AND THE EARLY MODERN EMERGENCE OF MATHEMATICS 61
Patrick Boner

ASTROLOGY IN SPANISH EARLY MODERN INSTITUTIONS OF LEARNING 79
Tayra Lanuza-Navarro

PART II: COMMUNICATING SCIENCE AND PEDAGOGY

COMMUNICATING SCIENCE AND PEDAGOGY 101
Josep Simon

ON HOW JOHANN BERNOULLI'S LESSONS ON DIFFERENTIAL CALCULUS WERE COMMUNICATED IN EIGHTEENTH-CENTURY FRANCE AND ITALY .. 113
Mónica Blanco

THE FRANCO-BRITISH COMMUNICATION AND APPROPRIATION OF GANOT'S PHYSIQUE (1851-1881) 141
Josep Simon

PART III: POPULARIZATION OF SCIENCE

POPULARIZATION OF SCIENCE 171
Pedro Ruíz-Castell

A "NATIONAL FIESTA": TOTAL SOLAR ECLIPSES AND POPULARIZATION OF ASTRONOMY IN EARLY TWENTIETH-CENTURY SPAIN 179
Pedro Ruíz-Castell

THE BODY OF A REAL WOMAN: MEDICINE IN THE YOUNG WOMEN'S GUIDEBOOKS PUBLISHED IN FINLAND, 1890-1923 199
Tiina Männistö-Funk

LEAVING SUSPICION BEHIND: SPANISH PUBLIC DISCOURSES ON PRIVATE FUNDING OF HUMAN GENETICS 219
Matiana González-Silva

PART IV: SCIENCE AND NATION

SCIENCE AND NATION 237
Néstor Herran

THE EMERGENCE OF THERMODYNAMICS IN MID-NINETEENTH-CENTURY FRANCE: A MATTER OF NATIONAL STYLE? 249
Faidra Papanelopoulou

NATION, DISEASE AND HEALTH: MEDICAL RESEARCH IN THE PERUVIAN ANDES AND THE EMERGENCE OF "HIGH-ALTITUDE DISEASES" 269
Jorge Lossio

PART V: SCIENCE IN THE PERIPHERY

SCIENCE IN THE PERIPHERY 291
Ximo Guillem-Llobat

FOOD QUALITY CONTROLS IN THE EUROPEAN PERIPHERY. VALENCIAN SCIENTISTS AND LABORATORIES IN THE LATE NINETEENTH CENTURY 301
Ximo Guillem-Llobat

WATERS, SEEDS AND RADIATION: RADIOACTIVITY RESEARCH IN EARLY TWENTIETH CENTURY SPAIN 325
Néstor Herran

MAKING SCIENCE IN THE PERIPHERY: DETERMINATION OF CRYSTALLINE STRUCTURES IN SPAIN, 1940-1955 345
Xavier Mañes

CONTRIBUTORS 361

SELECTED BIBLIOGRAPHY 365

INDEX 373

PART II

COMMUNICATING SCIENCE AND PEDAGOGY

COMMUNICATING SCIENCE AND PEDAGOGY

JOSEP SIMON

The study of science pedagogy from a historical perspective has experienced an important revival in history of science in the last decade. This introduction intends to assess qualitatively the re-emergence of this topic, to analyse the structure and dynamics of this research field and to propose new avenues for its improvement. In this context, I will emphasize four related arguments, namely the need for a higher scholarly internationalism, and for promoting interdisciplinarity, and the interest in approaches focusing on communication, and on comparison, in an international perspective.

A major flagship of the new rise of interest in pedagogy in history of science is often considered to be represented by David Kaiser's study of the uses of Feynman diagrams and his editorship of the book *Pedagogy and the Practice of Science*, and by Andrew Warwick's path-breaking study of the Cambridge Mathematical Tripos.[1] Kaiser was also invited to contribute to a recent *Focus* section in *Isis* devoted to reflection on the need of a "generalist vision in history of science". In his paper, he argued that bringing pedagogy to the centre of historical analysis could be a way of avoiding the fragmentation afflicting our discipline. As a feature common to all scientific disciplines and central to science, culture and society in general, the study of training can connect history of science with other disciplines within the historical field, as well as in sociology and anthropology.[2]

However, as pinpointed by John Rudolph – a historian of education trained in history of science[3] – historical research on science education is fragmented in different academic compartments, such as history of science, history of education, science education and various subfields within general history, that rarely interact.[4] Rudolph's overview and a recent historiographical essay by Kathryn Olesko,[5] are perhaps the first general surveys on this topic in more than a decade.[6] From the late 1970s, historians of science such as William Brock and Roy MacLeod, and historians of education such as Edgar Jenkins, contributed to establish fruitful relations between these two academic fields in Britain.[7] However,

in the last decade, history of education has suffered significant decay in British universities through the orientation of education departments towards more immediate targets of school education. By contrast, in Continental Europe, the discipline has a more vigorous existence, and indeed there are teams of researchers developing relevant projects on the history of science education.[8] However, as I argue in this introduction, their work is not always acknowledged in the history of science, due to the existence of barriers that present difficulties in communication across disciplinary and national boundaries.

This state of affairs is well represented by Rudolph's expression – in his review of Kaiser's edited volume – of the perplexity that readers of the journal *History of Education Quarterly* would feel in remarking the narrow and unorthodox use of the term "pedagogy" in the aforementioned book.[9] And it is also well illustrated by Kaiser's and Warwick's bold and inaccurate statement in the conclusion of this book: "…although there is an enormous literature on the history of education, virtually none of it is concerned with the relationship between training and the production of scientific knowledge".[10] Further evidence can be found in Warwick's *Masters of Theory*. Despite the indisputable value and originality of this work, it is regrettable that he did not take into account contemporary literature that in fact dealt with the organization of examinations and coaching practices in nineteenth-century France.[11] In fact, the comparative assessment of educational developments happening in Continental Europe was a well-established method in nineteenth-century Cambridge through the work of educationists such as Henry Latham, fellow and tutor of Trinity Hall, who published a well-informed monograph on the pedagogical role of examinations.[12] This literature could have taken his study further, and most importantly, it would certainly have contributed to erase the too often taken-for-granted Cambridge exceptionality, integrating it into a larger framework.

The history of education emerged as a discipline in the early nineteenth century as a subfield within studies on education or pedagogy, aiming at illuminating contemporary educational research and organization through a historical perspective. The reports on foreign education cited in Josep Simon's paper in this part are examples of the early literature in this field. This disciplinary emergence in a field with immediate practical applications offers interesting comparisons with the development of other historical specialisms, such as the history of medicine and the history of science. In this context, the use of international comparisons was considered a fundamental method. Despite different epistemological challenges to this approach, comparative education is today a well-

established field. Its basic aim is to compare any activities associated with learning and teaching, whether the comparison acts in the same local or national context or across national boundaries.[13] Despite the major contemporary focus of this discipline, it has also produced valuable international studies of school systems in a historical perspective.[14] Hence, there are elements and approaches in history of education and education studies that historians of science could fruitfully exploit.

With *Pedagogy and the Practice of Science*, Kaiser's great achievement was gathering together an important and international team of historians of science, while offering an excellent account of current results and potential developments. Among the book contributors Kathryn Olesko, Graeme Gooday and the team constituted by José R. Bertomeu, Antonio García-Belmar and Bernardette Bensaude-Vincent had previously developed a long-standing research focus on science education.

Olesko has developed her research on educational organization and science pedagogy in nineteenth-century Germany since the 1980s, and communicated it through a series of excellent papers and a ground-breaking monograph on the Königsberg physics seminar, which, along with Warwick's book, constitutes an analytical and methodological model for future historians of science education and historians of science in general.[15] Despite the localized focus of her monograph study, she provided a general overview of German physics in its connection with the Königsberg seminar and its actors. Furthermore, she accurately integrated the international dimension of physics by studying the appropriation and communication of French physics performed by German physicists in reading, discussion and teaching.

Graeme Gooday is perhaps the author of the latest national account of British science education written by a historian of science. His PhD thesis mapped the rise of the physics teaching laboratory in nineteenth-century Britain. In subsequent years, he has decisively contributed to our knowledge of the practices of measurement in physics and electrical engineering by narrowing his focus through fine-grained case studies of laboratory practice, where pedagogy and training have an important place.[16] The national comparative focus of his earliest work has challenged the historiography of English experimental physics conventionally focused on developments at Cambridge. This has also been one of the aims and the major comparative stance in his editorship, in collaboration with Robert Fox, of a monograph on physics and its teaching in Oxford.[17] Despite the clear historiographical necessity of this comparative approach and the excellent overview of physics and pedagogy in the local context of Oxford offered by this work, it has inevitably contributed to reify a geography of

English physics that now assigns privileged predominance to Oxbridge in the history of the discipline in this country.[18] Their comparative effort could also have been taken beyond national borders. As argued in Josep Simon's paper in this part, educational reforms and the expansion of the sciences in the university and school curriculum took place in nineteenth-century Europe through international observation. Thus, for instance the British and French governments sent commissioners abroad to observe foreign educational systems before preparing or urging universities to undertake reforms. Furthermore, many of the physics textbooks used in nineteenth-century Oxford were French and German.[19] Understanding Oxbridge and British physics would certainly have gained from comparisons with French and German cases and the assessment of the role that international communication played in this context.

In the last decade, Bertomeu, García-Belmar and Bensaude-Vincent have developed a sustained program of recovery and study of nineteenth-century chemistry textbooks published in France and Spain. They have mapped the production of chemistry textbooks in this period and have highlighted the links between pedagogy, research and educational organization. They have coordinated international teams of historians of science and of education devoted to the use of this type of source. Drawing on the rich strand of the use of laboratory notebooks as sources, they have also begun to study student notebooks and connected them with their previous research on textbook writing.[20] Their work has dealt with the international communication of science through the study of the travels of Spanish chemistry students to France and of transnational figures.[21] Certainly they have still to challenge the Paris-centred perspective that characterizes most French historiography. Nonetheless, they are committed to undertaking comparative studies of teaching practices and textbooks through national case studies of countries belonging to the so-called European periphery.[22] However, this project is still under development.[23]

This variety of approaches was reflected in Kaiser's volume despite his ambitious editorial effort.[24] To strengthen the robustness and potential outreach of the book, he provided an introduction to the volume and – in collaboration with Andrew Warwick – a concluding essay. Their approach is based on two classical authors, Thomas S. Kuhn and Michel Foucault. Through the wide readership among historians of science of his *Structure of Scientific Revolutions*, Kuhn contributed to shape conventional ideas on scientific education in our discipline through the role he assigned to training and textbooks in the making of "normal science".[25] Foucault stressed the role of disciplinary regimes – such as those implemented in

the school – in the interconnected formation of individuals and society.[26] Kaiser and Warwick propose to enlarge Kuhn's approach by considering the role of training regimes in which the use of textbooks was inscribed, complemented by Foucault's powerfully polysemous use of "discipline".[27] Despite the high value of their respective works, this approach is neither particularly original nor challenging, although in a pragmatic way it could still be useful in maintaining interest in science education among historians of science.

The approaches of Kuhn and Foucault have obvious shortcomings. As argued by García-Belmar, Bertomeu and Bensaude-Vincent, Kuhn's conception of textbooks as repositories of "normal science" is inaccurate in assuming that the making of textbooks is an uncreative task and that its role is restricted to maintaining the "paradigm" without contributing in any other way to the making of science.[28] On the other hand, Foucault's skilful connection of the individual, society and the state through discipline is indeed valuable, but his own experience as an intellectual in the Cold War and postcolonial period probably had an important role in his overemphasis on power as an overarching category.[29] In fact, his approach often contributes rather to obscure the study of pedagogy than to illuminate its everyday mechanisms. Indeed, what Kuhn and Foucault cannot provide is a genuinely historical approach to the study of science education.

By contrast, the work of Rudolf Stichweh and Kathryn Olesko has illuminated through historical inquiry the driving agency that pedagogy has in the constitution of scientific disciplines. In their respective studies, both showed the critical role that the training of secondary school teachers had in the formation of physics as a discipline in nineteenth-century Germany.[30] The stress of Kaiser and Warwick on the role that the circulation of students and teachers trained in particular pedagogical regimes, had in the configuration of this discipline,[31] contributes to strengthen this framework. Textbooks had an important role in this context, but also a wider range of pedagogical practices that Olesko has meticulously studied through examination of course programmes and notebooks.[32] In this sense, she has not only critically undermined Kaiser and Warwick's simplistic mapping of the field through Kuhn and Foucault, but their strong reliance on Polanyi's concept of "tacit knowledge". Olesko has repeatedly argued that although this concept could describe certain situations in scientific practice and pedagogy, many pedagogical processes were perfectly explicit and can be reconstructed through historical sources and techniques.[33] To the communicational obscurity involved in the concept of "tacit knowledge" – attributed by

Olesko to the Cold War culture in which it was conceived[34] – we can oppose instead a new focus on explicit communication.

Stichweh has defined "discipline" as a social system of communication articulated through particular pedagogical practices, and through the creation of new modes of communication such as the rise and consolidation of formal practices of scientific publication, and in particular scientific journals.[35] Analogously, in her paper in this part, Mónica Blanco has shown how different modes of communication (from conversation and correspondence to journal and textbook writing, publication, and international circulation) configured differential calculus as a discipline in eighteenth-century Europe. Moreover, Josep Simon has stressed the fundamental role that the multifarious processes of communication and appropriation of Adolphe Ganot's *Physique* played in the definition of nineteenth-century physics as a discipline in a Franco-British comparative perspective.

In her recent historiographical essay on science pedagogy, Olesko has emphasized the importance of the work of Ludwik Fleck in stressing the role of education as a social process in the making of science, and the role of publishing in shaping pedagogy and science.[36] In an equally thoughtful historiographical essay on science popularization, Jonathan Topham has also highlighted Fleck's work and the role of communication in science to obtain a better historical understanding of science popularization and its relation to the making of science.[37] As expressed in the introduction to this volume, Topham's rethinking of science popularization as a history of science communication is connected to a wider perspective formulated by James Secord, intending to make communication central to our analysis. Like Topham, Rudolph has noted the consonance between the study of education and of popularization, and the fundamental characterization of education as knowledge and skills' communication. This idea is also implicit in Jonathan Rose's recent call for the conception of history of education as a history of reading.[38]

Communication is a fundamental concept, especially if, for instance, we take into account the fact that orality has a primordial role in educational practices. As stressed by García-Belmar in his study of Louis-Jacques Thénard's chemistry lectures,[39] by Olesko on her analysis of Friedrich Kohlrausch's canonical textbook,[40] and by Mónica Blanco and Josep Simon in their respective studies of the development of differential calculus and physics, textbooks were often printed appropriations of oral lessons. Orality has received much attention from historians of popular culture, anthropologists, linguists and historians of reading, with a tendency to focus in contexts related to civilizations without writing, early

stages of language learning, eighteenth and nineteenth-century social conversation, and informal education.[41] However, in an exceptional monograph – surprisingly, ignored by Anglo-American historians of science – Françoise Waquet has provided us with a long range account of the high status assigned to orality by science practitioners from the sixteenth to the twentieth century. Even in the context of nineteenth-century science – highly dominated by communication through printing and by organized systems of education – she shows that orality was considered by many scientists as the highest mode of communicating science, above its printed reproduction.[42]

In this sense, the study of communicational practices in education, extending James Secord's example of the role of literary replication,[43] can offer new avenues to study science education across different periods and national boundaries. The papers in this part are an example of this approach, in which the configuration of scientific disciplines is studied through the communication and appropriation of scientific knowledge into different formats and meanings (encompassing the oral, visual, manuscript and printed). Comparison of the eighteenth-century case study by Mónica Blanco and the nineteenth-century case study by Josep Simon gives some indication of the critical changes in Europe signalling the emergence of the journal as a mode of scientific communication, the expansion of scientific education and its state organization, the consolidation of textbooks as a form of pedagogical and scientific communication, and changes in authorship practices. Despite the differences informed by obvious contextual and temporal parameters, the two cases can be fruitfully handled through a focus on communication and appropriation, and they contribute to highlight common aspects characterizing the historical study of science education. For example, international communication is shown to have a fundamental role in the shaping of pedagogical and scientific practices, and textbooks are seen as fundamental agents of these across national and cultural boundaries. Booksellers have important agency in this circulation and – with teachers and textbook authors – they decisively contribute to shape scientific knowledge. Furthermore, textbooks are not repositories of "normal science". Their authors certainly try to reproduce scientific consensus and appropriate it for the purposes of pedagogical practices, but textbooks also display scientific disagreement and can be the subject of dispute or controversy. They contribute to illuminate the complex relations between teaching and research and they have a fundamental role in discipline building.

Hopefully, the combination of the fine-grained analysis of local cases, with tools offered by the disciplines which intersect across science

education, the macroscopic approach of comparative education and the analysis of communication processes will contribute to strengthen the historical study of science education and further its research. The papers in this part are an attempt to move in this direction.

Notes

[1] Kaiser, D. (2005). *Drawing Theories Apart. The Dispersion of Feynman Diagrams in Postwar Physics*. Chicago: The University of Chicago Press, and, ed. (2005). *Pedagogy and the Practice of Science: Historical and Contemporary Perspectives*. Cambridge, Mass.: MIT Press; Warwick, A. (2003). *Masters of Theory: Cambridge and the Rise of Mathematical Physics*. Chicago: Chicago University Press.

[2] Kaiser, D. (2005). "Training and the Generalist's Vision in the History of Science". *Isis* 96: 244-51, pp. 250-1.

[3] Rudolph is the author of a magnificent account on the configuration of science education in Cold War America. Rudolph, J. L. (2002). *Scientists in the Classroom: the Cold War Reconstruction of American Science Education*. New York: Palgave.

[4] Rudolph, J. L. (2008). "Historical Writing on Science Education: A View of the Landscape". *Studies in Science Education* 44 (1): 63-82. I am grateful to John Rudolph for sending me a copy of his essay before publication.

[5] Olesko, K. M. (2006). "Science Pedagogy as a Category of Historical Analysis: Past, Present, and Future". In García-Belmar, A. et al. eds. "Textbooks In The Scientific Periphery". *Science and Education*. Special Issue 15 (7-8): 863-80.

[6] Brock, W. H. (1990). "Science Education". In Olby, R.; Cantor, G. N.; Christie, J. R. R., and Hodge, M. J. S., eds. *Companion to the History of Modern Science*. London: Routledge, pp. 946-59; Jenkins, E. W. (1985). "History of Science Education". In Husen, T., and Postlethwaite, T. N., eds. *International Encyclopaedia of Education: Researches and Studies*. Oxford: Pergamon, pp. 4452-56.

[7] In addition to their scholarly projects, this can be seen in some of their publications. See for example Brock, W. H. (1973). *H. E. Armstrong and the Teaching of Science, 1880-1930*. Cambridge: Cambridge University Press, and (1974). "From Liebig to Nuffield: A Bibliography of the History of Science Education, 1839-1974". *Studies in Science Education* 2: 67-99; Mac Leod, R., ed. (1982). *Days of Judgement : Science, Examinations and the Organization of Knowledge in Late Victorian England*. Driffield: Nafferton; Mac Leod, R., and Moseley, R. (1978). "Breadth, Depth and Excellence: Sources and Problems in the History of University Science Education in England". *Studies in Science Education* 5: 85-106; Jenkins, E. W. (1979). *From Armstrong to Nuffield: Studies in Twentieth-Century Science Education*. London: Murray, and, "History of Science Education".

[8] Compère, M.-M. (1995). *L'histoire de l'éducation en Europe: essai comparatif sur la façon dont elle s'écrit*. Paris: INRP. See also for example the history of education service of the French National Institute for Pedagogical Research (INRP). [http://www.inrp.fr/she/].

[9] Rudolph, J. L. (2006). " [Review of *Pedagogy and the Practice of Science* by David Kaiser ed.]". *History of Education Quarterly* 46 (4): 628-30.

[10] Kaiser and Warwick. "Kuhn, Foucault, and the Power of Pedagogy". In Kaiser. *Pedagogy and the Practice of Science*, pp. 393-409, on p. 393.

[11] See for example Belhoste, B.; Dalmedico, A. D., and Picon, A. (1994). *La formation polytechnicienne, 1794-1994*. Paris: Dunod; Belhoste, B. ; Picon, A., and Sakarovitch, J. (1990). "Les exercices dans les écoles d'ingénieurs sous l'Ancien Régime et la Révolution". *Histoire de l'éducation* 46 (mai): 53-63; Belhoste, B. (2001). "La préparation aux Grandes Écoles scientifiques au XIXème siècle". *Histoire de l'éducation* 90 (mai): 101-30, and Belhoste, B., ed. (2002). "L'examen: Évaluer, sélectionner, certifier. XVIe-XXe siècles". *Histoire de l'éducation* 94 (mai).

[12] Latham, H. (1877). *On the Action of Examinations Considered as a Means of Selection*. Cambridge: Deighton, Bell and Co.

[13] See Thomas, R. M. (1990). "The Nature of Comparative Education: How and Why are Education Systems Compared". In Thomas, ed. *International Comparative Education: Practices, Issues & Prospects*. Oxford: Pergamon Press, pp. 1-21, on pp. 1-2; Epstein, E. H. (1992). "The Problematic Meaning of 'Comparison' in Comparative Education". In Holmes, B., ed. *Theories and Methods in Comparative Education*. Peter Lang: Frankfurt am Main, pp. 3-23; Arnove, R. F. (1999). "Introduction: Reframing Comparative Education. The Dialectic of the Global and the Local". In Arnove, R. F., and Torres, C. A., eds. *Comparative Education: The Dialectic of the Global and the Local*. Lanham: Rowman & Littlefield Publishers, Inc., pp. 1-23.

[14] Although the only study of this type well-known to historians of science is represented by the work of Joseph Ben David (whose defects are pinpointed in the introduction to part V in this volume), there have been other relevant publications in this field such as Vaughan, M., and Archer, M. S. (1971). *Social Conflict and Educational Change in England and France, 1789-1848*. Cambridge: At the University Press; Archer, M. S. (1979). *Social Origins of Educational Systems*. London: Sage Publications Ltd, and Green, A. (1990). *Education and State Formation. The Rise of Education Systems in England, France and the USA*. Basingstoke: Macmillan.

[15] See Olesko, K. (1985). "The Mental World of Physiklehrer: Subject and Method in History of Mathematics". *Recherches en Didactique des Mathématiques* 6 (2-3): 347-62, (1989). "Physics Instruction in Prussian Secondary Schools before 1859". *Osiris* 2nd series 5: 94-120, (1991). *Physics as a Calling: Discipline and Practice in the Königsberg Seminar for Physics*. Ithaca: Cornell University Press, (1993). "Tacit Knowledge and School Formation". *Osiris* 2nd series 8: 16-29, and (2005).

"The Foundations of a Canon: Kohlrausch's Practical Physics". In Kaiser. *Pedagogy and the Practice of Science*, pp. 323-55.

[16] See Gooday, G. J. N. (1989). *Precision Measurement and the Genesis of Physics Teaching Laboratories in Victorian Britain*. Canterbury: University of Kent. unpublished PhD thesis, (1991). "Teaching Telegraphy and Electrotechnics in the Physics Laboratory: William Ayrton and the Creation of an Academic Space for Electrical Engineering in Britain, 1873-1884". *History of Technology* 13: 73-111, (1995). "The Morals of Energy Metering: Constructing and Deconstructing the Precision of the Victorian Electrical Engineer's Ammeter and Voltmeter". In Wise, N., ed. *The Values of Precision*. Princeton: Princeton University Press, pp. 239-82, and (2004). *The Morals of Measurement: Accuracy, Irony, and Trust in Late Victorian Electrical Practice*. Cambridge: Cambridge University Press.

[17] Fox, R. and Gooday, G., eds. (2005). *Physics in Oxford, 1839-1939. Laboratories, Learning and College Life*. Oxford: Oxford University Press.

[18] The contribution by Jeff Hughes is a single exception to this pattern. Hughes, J. (2005). "Redefining the Context: Oxford and the Wider World of British Physics, 1900-1940". In Fox and Gooday, pp. 267-300.

[19] Fox, R. (2005). "The Context and Practices of Oxford Physics, 1839-77". In Fox and Gooday, pp. 24-79, on pp. 71-2.

[20] See Lundgren, A. and Bensaude-Vincent, B. (2000). *Communicating Chemistry: Textbooks and Their Audiences, 1789-1939*. Canton, Mass.: Science History Publications; Bertomeu-Sánchez, J. R.; Garcia-Belmar, A., and Bensaude-Vincent, B. (2002). "Looking for an Order of Things: Textbooks and Chemical Classifications in Nineteenth Century France". *Ambix* 49: 227-250; Bensaude-Vincent, B. ; García Belmar, A., and Bertomeu Sánchez, J. R. (2003). *L'émergence d'une science des manuels: Les livres de chimie en France (1789-1852)*. Paris: Éditions des archives contemporaines; Garcia-Belmar, A. (2006). "The Didactic Uses of Experiment: Louis Jacques Thénard's Lectures at the Collège de France". In Bertomeu, J. R., and Nieto-Galan, A., eds. *Science, Medicine and Crime: Mateu Orfila (1787-1853) and His Times*. Sagamore Beach: Science History Publications, pp. 25-53, and García Belmar, A. and Bertomeu Sánchez, J. R. (2004). "Les cahiers d'élèves sources pour une histoire des contenus et des pratiques de l'enseignement de la chimie". In *Le cours magistral: modalités et usages* [http://www.inrp.fr/she/cours_magistral/expose_thenard/expose_thenard_complet.htm].

[21] García Belmar, A. and Bertomeu Sánchez, J. R. (2003). "Constructing the Center from the Periphery. Spanish Travellers to France at the Time of the Chemical Revolution". In Simoes, A.; Carneiro, A., and Diogo, M. P., eds. *Travels of Learning. A Geography of Science in Europe*. Dordrecht: Kluwer Academic Publishers, pp. 95-139; Bertomeu and Nieto-Galan. *Science, Medicine and Crime*.

[22] On the centre-periphery model see introduction to part V in this volume.

[23] Bertomeu Sánchez, J. R., et al. (2006). "Textbooks in the Scientific Periphery: Introduction". In García-Belmar, et al. "Textbooks In The Scientific Periphery", pp. 657-65.
[24] This was pointed out by knowledgeable reviewers like John Rudolph.
[25] Reference to Kuhn in this context is still conventional nowadays. Like Kaiser and Warwick, excellent scholars such as Robert Fox and Graeme Gooday refer to his work to stress the importance of studying training in science. Fox, R., Gooday, G., and Simcock, T. (2005). "Physics in Oxford: Problems and Perspectives". In Fox and Gooday, pp. 5-6; Kuhn, T. S. (1962). *The Structure of Scientific Revolutions*. Chicago: University of Chicago Press.
[26] Foucault, M. (1975). *Surveiller et punir: Naissance de la prison*. Paris: Gallimard.
[27] Warwick, A. and Kaiser, D. "Kuhn, Foucault, and the Power of Pedagogy". In Kaiser. *Pedagogy and the Practice of Science*, pp. 393-409.
[28] García-Belmar, A., Bertomeu-Sánchez, J. R. and Bensaude-Vincent, B. (2005). "The Power of Didactic Writings: French Chemistry Textbooks of the Nineteenth Century". In Ibid., pp. 219-51, on pp. 220-2.
[29] Seigel, M. (2005). "Beyond Compare: Comparative Method after the Transnational Turn". *Radical History Review* 91 (Winter): 62-90, p. 64; Olesko. "Science Pedagogy", p. 868.
[30] Stichweh, R. (1992). *Zur Entstehung des Modernen Systems Wissenschaftlicher Disziplinen: Physik in Deutschland*. Frankfurt: Suhrkamp, and (1994). "La structuration des disciplines dans les universités allemandes au XIXe siècle. *Histoire de l'éducation* 62 (mai): 55-73; Olesko. *Physics as a Calling*.
[31] Kaiser. *Drawing Theories Apart*, pp. 60-7; Warwick. *Masters of Theory*, pp. 254-64.
[32] See also Olesko. "The Mental World of Physiklehrer", and "The Foundations of a Canon".
[33] Olesko "Tacit Knowledge and School Formation", pp. 16-7, and "Science Pedagogy", n. 3 p. 878.
[34] Olesko. "Science Pedagogy", pp. 865, 871.
[35] Stichweh. *Zur Entstehung des Modernen Systems*, pp. 7-93, and (2003). "Differentiation of Scientific Disciplines: Causes and Consequences". In *Encyclopedia of Life Support Systems*. Paris: UNESCO.
[36] Olesko. "Science Pedagogy", pp. 872-4.
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