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Science Education and the Material Culture of the Nineteenth-Century Classroom: Physics and Chemistry in Spanish Secondary Schools

Josep Simon · Mar Cuenca-Lorente

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Abstract Although a large number of Spanish secondary schools have preserved an important scientific heritage, including large scientific instrument collections, this heritage has never been officially protected. Their current state is very diverse, and although several research projects have attempted to initiate their recovery and use, their lack of coordination and wide range of methodological approaches has limited their impact. This paper presents a case-study integrated in a new project supported by the Catalan Scientific Instrument Commission (COMIC) whose final aim is the establishment of a research hub for the preservation, study and use of Spanish scientific instrument collections. Major aims in this project are promoting a better coordination of Spanish projects in this field, and furthering international research on science pedagogy and the material culture of science. The major focus of COMIC is currently the recovery of secondary school collections. This paper provides first, a historical account of the development of secondary education in Spain, and the contemporary establishment of physics and chemistry school collections. Second, we focus on a case-study of three Spanish schools (Valencia, Castellón, and Alicante). Finally, we provide a brief overview of current projects to preserve Spanish school collections, and discuss how COMIC can contribute to help to coordinate them, and to take a step forward interdisciplinary research in this context.

1 Introduction

A large number of Spanish secondary schools have preserved an important scientific heritage, tracing back to the pedagogical and scientific practices developed in these

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J. Simon (✉) · M. Cuenca-Lorente
Instituto de Historia de la Medicina y de la Ciencia 'López Piñero', Universitat de València—CSIC, Palau Cerveró, Plaça Cisneros, 4, València 46003, Spain
e-mail: josicas@alumni.uv.es

institutions since their establishment in the mid nineteenth century. This heritage includes physics, chemistry and natural history collections, archives, and libraries. These collections have never been officially protected and, in general, they are barely regarded as a relevant part of cultural heritage by the political administrations in which the schools are inscribed.[1] As a result, their state (cataloguing, preservation, exhibitions, accessibility, curatorship, associated research projects, etc.) is very diverse (Simon Castel et al. 2005; Simon et al. 2009). Stable school premises and several generations of teachers, with scarce economic and moral support from the administration, have been the major agents contributing to their preservation.[2] A certain number of local and regional projects aimed at preserving and promoting the use of these collections have been developed in the last decades yielding some publications (catalogues, preliminary studies, research dissertations) and temporary exhibitions.[3] These initiatives often originated from the celebration of institutional commemorations. Subsequently most collections returned to their original settings and no general preservation measures have emerged. Some of these collections have been catalogued, but the lack of coordination has hindered the development of common patterns of data collection and processing, which could allow comparison and in-depth research, in an area possessing a rich corpus of sources and a promising context for research on the past and present of science and its pedagogy.[4]

A new project to create online resources for the preservation, study, and use of Spanish scientific instrument collections has recently emerged with the establishment of the Catalan Scientific Instrument Commission (COMIC), supported by the Catalan Society for the History of Science and Technology (SCHCT).[5] This project integrates several instrument collections covering generously science, technology, and medicine, and secondary education, universities and medical practice in the Catalan, Valencian and Balearic regions. The COMIC project is currently focusing in the digitization of secondary school physics and chemistry collections, and the creation of associated resources for research and educational use. A major aim in this project is promoting a better coordination of Spanish projects in this field, and furthering international research on science education and the material culture of science.

[1] Unfortunately, this situation is still very common all over Europe (Chamoux 2002; Lourenço 2005).

[2] Invariably, the most common cause of collection disappearance or destruction has been the relocation of schools in new premises.

[3] Some schools have managed to establish permanent exhibitions in their premises. However, these are a minority, and access to the collections is in general difficult. The COMIC resource portal includes a database of past and ongoing projects and related publications. Major projects had already been developed in many provincial cities across the country. A sample of these is available in the bibliography. A new project has been recently established in Madrid, which will probably unveil important collections. We thank Leoncio López-Ocón and Pedro Ruiz-Castell for this information (Aparici Sos 2002; Delgado Criado 2004; García del Real 2001; García Horcaude 1988; García and Villada 2000; Guijarro Mora 2002; Instituto de Teruel 2001; Lancis Saez 2002; López Martínez and Delgado Criado 2003; López Martínez 2007; Narváez Bueno 2008; Pascual 2007; Simon Castel 2002, 2004, 2008; Simon et al. 2005; Sisto Edreira 1999; Tiana Ferrer (coord.) 2008; Vidal de Labra 2002, 2008; Villalonga 2008).

[4] COMIC aims at covering a wide range of approaches, including the preservation and study of school collections for historical research, but also for pedagogical and museological research and practice. However, in this paper we focus on a macrohistorical analysis of Spanish school collections, as a preparation for future work using the collections in museological, historical and pedagogical practice. The literature dealing with the use of instruments and experimental replication is wide, but is not the main focus in this paper. See for instance (Blondel and Dörries 1994; Cavicchi 2008; Heering 2000; Heering and Müller 2002; Heering 2007; Sibum 1995; Usselman et al. 2005)

[5] See www.instrumentscientifics.com, and http://www.iecat.net/schct/.

The purpose of this paper is to present the COMIC project and to reflect on the potential of its research agenda. This aim is developed through a pilot case-study focusing on the physics and chemistry collections of three Spanish secondary schools. Thus we consider the interest of developing research which promotes the interaction of approaches from a wide range of disciplines, including history of science, history of education, scientific instrument studies and education studies. This paper is divided in three sections. First, we provide a historical account of the development of secondary education in Spain, and the contemporary establishment of school collections in physics and chemistry. In this context, we provide a map of Spanish school collections, which characterizes their main features and differences through the analysis of historical records such as collection inventories. Second, we focus on a case-study of three schools in the Valencian region (comprising the provinces of Valencia, Castellón, and Alicante) and combine the analysis of printed sources with scientific instrument collections preserved in these schools. Finally, we provide a brief overview of current projects to preserve Spanish school collections and discuss how COMIC can contribute to help to coordinate them, and to take a step forward research on science education and material culture.

2 The Establishment of Secondary Education in Spain and the Development of Science Collections

The creation of school collections in physics and chemistry was central to the endeavour of establishing a national secondary school system in Spain. The provision of cabinets and laboratories was undertaken almost simultaneously with the organization of secondary schools, the publication of a national curriculum, the preparation of textbooks, and the establishment of a national institution aimed at training science teachers.

The idea of national 'secondary education' was developed and implemented across Europe and the Americas during the nineteenth century. The earliest developments in this field happened in France and the German states (Anderson 2004; Green 1990). The Spanish mid nineteenth-century educational reforms followed closely the French example. In this period, the French educational system was already mature, and it had an influential role in the advancement of physics and chemistry as disciplines (Anderson 1975; Simon 2009, chapter 2).

Spanish secondary education had also distinctive features. First, the government tackled the problem of providing schools with appropriate science collections, contemporaneously with the establishment of secondary schools. Second, the national curriculum included a new subject "Física y Química" which coupled the teaching of physics and chemistry, and thus provided a disciplinary space for these subjects distinct from mathematics.[6] Finally, the scheme designed to train teachers for secondary education gave a strong emphasis to the training of teachers in the physical sciences. The wide range of educational initiatives implemented by the Spanish government yielded uneven results. Nonetheless, by the 1860s, physics and chemistry were subjects firmly established in the Spanish secondary school curriculum. They were taught in most schools across Spain, and most schools had a physics cabinet and chemistry laboratory.

[6] During the first three decades of the French secondary school system, the physical sciences were in general annexed to the teaching of mathematics, as this subject and its teachers had a higher status in the school curriculum and professional system, and there were not many teachers prepared to teach physics and chemistry. This situation had started to change from the 1830s. (Simon 2009, 34–38).

The first Spanish secondary schools were established during the 1830s and 1840s, through isolated, but overall coherent initiatives ran by municipal political forces, after the disentailment of religious property by the Spanish Liberal government. Between 1835 and 1844, twenty-four secondary schools, called *institutos*, were established. In 1845, an educational reform promoted by the *Ministro de Gobernación* (Home Secretary) Pedro Pidal, and its officer Antonio Gil de Zárate, provided secondary education with a legal framework, and gave rise to the establishment of additional schools. In 1868, the number of *institutos* amounted to sixty-six, of which forty-nine were located in the capitals of the Spanish provinces (the administrative structure of the country), and seventeen were established in other resourceful towns (Gil de Zárate 1855, II, 61ff.; Viñao Frago 1982, 335 ff.; Sirera 2009).[7]

The status of these schools was uneven, and related to their funding capacity. There were eleven *institutos* aggregated to universities (Madrid (where there were two), Barcelona, Granada, Oviedo, Salamanca, Santiago, Sevilla, Valencia, Valladolid and Zaragoza) which were the only ones offering the whole secondary school curriculum. This consisted of five years constituting the elementary secondary school curriculum, followed by two additional years presenting two options (literary and scientific) and giving access to university studies. Provincial *institutos*, located in the province capitals, were funded by the budget of provincial administrations. Most of them (around thirty by mid-century) were able to offer the complete elementary curriculum. Local *institutos* had to rely on funding provided by their town councils or foundations established in them, and were often unable to offer more than the first four years of secondary education. In this context, the teaching of physics and chemistry was addressed to a minority of students (Delgado Criado 2004; Díaz de la Guardia 1988, 461–467; Gil de Zárate 1855, II; Viñao Frago 1982, 338 ff.).

The first official syllabus of the subject 'Física y Química' was published during the 1840s, covering the whole spectrum of experimental physics (mechanics, hydrostatics and hydrodynamics, acoustics, heat, optics, electricity and magnetism), together with some lectures on "notions of chemistry". The distinctive coupling of physics and chemistry had its origins in the first Spanish liberal education reforms taking place in the 1830s. In France this coupling had briefly existed after the Revolution, and, like in other countries, in the nineteenth century, physics and chemistry were often taught together within a more generic subject termed 'physical sciences' (Simon 2009, chapter 2; Sisto Edreira 2007, 183 ff.).

The creation of physics cabinets and chemistry laboratories was a high priority for the Spanish government.[8] To this end, shortly after 1845, centralized purchases were organized, in order to establish collections which would contribute to the development of the teaching of the physical sciences in the *institutos*. The first purchases were organized thanks to the initiative of Antonio Gil de Zárate.[9] Before joining the state administration, Gil de Zárate had been educated in France, attending subsequently experimental physics lectures at the *Reales Estudios de San Isidro* in Madrid, and returning to to Paris to pursue his preparation. However, he did not succeed in becoming a physics teacher in Spain due to adverse political upheavals (Gil de Zárate 1850, iv–xvi). His educational background was

[7] We are grateful to Carles Sirera for providing us with a copy of his thesis.

[8] A good overview, whose selection of historical facts is congenial to that in this paper is provided by López Martínez (2008).

[9] Some *institutos* had already collections, though. The *institutos* located in university towns, used initially the university cabinets. Other *institutos*, such as that of San Isidro, in Madrid, inherited important collections held by previous eighteenth-century and early nineteenth-century institutions.

crucial in his contribution to the reform of Spanish university and secondary school education.

After surveying Spanish university collections, in 1846, a reference catalogue of physics and chemistry collections was compiled by a commission of university professors appointed by the Spanish government (Pidal 1846). At the end of that year, Gil de Zárate, accompanied by Juan Chavarri, professor of physics at the Faculty of Sciences of Madrid, travelled to Paris to organize the purchase of physics and chemistry instruments for the universities. There, they met Mateu Orfila (1787–1853), a Spaniard who developed a successful career in France as professor of medical chemistry and dean of the Paris Medical Faculty (Bertomeu Sánchez and Nieto Galan 2006). Thanks to Orfila's advice, Gil de Zárate obtained the services of four Parisian instrument makers: "Messrs. Pixii and Deleuil for the physics instruments; Lizé & Clech for the glassware and porcelain, and the brothers Rousseau" for chemistry substances and instruments. The importance of the purchase allowed the Spanish commissioners to negotiate a deal and to acquire more instruments than initially expected, thus expanding the range of recipient institutions (Gil de Zárate 1847; Gil de Zárate 1855, III, 255–257; Simon Castel et al. 2005).

By the same token, in the same period a reference catalogue had been established to equip secondary school with physics cabinets and chemistry laboratories (Gil de Zárate 1846). The list of instruments was based on the catalogues of the French makers Lerebours and Pixii, including 152 physical instruments (valued at 9,531 fr.) and 133 chemical items (valued at 6,448 fr) (Gil de Zárate 1846). However, the collection was subsequently reduced, particularly in the case of chemistry, for which the funds were cut down to 10% of the initial amount. The collection of physics instruments was reduced to 116 items only, although for almost half the price of the original amount (see Table 1). The fields better represented in the physics list of the 1847 model catalogue for the *institutos* were electricity and magnetism (39), mechanics (15) and pneumatics (19) (Pastor Díaz 1847a, b).

In the making of the reference catalogue, Gil de Zárate had considered that the teaching of the physical sciences in secondary education should not only be based on oral presentations, but include the examination of instruments and the performance of experiments and manipulations, as well. Moreover, teachers should not limit themselves to teaching, but they should also get involved in research, in order to contribute to the patriotic advancement of the country. As a result of Gil de Zarate's dealings in Paris a certain number of instruments from the university purchase were distributed in some *institutos*, and his

Table 1 Size and price of the physics and chemistry collections recommended by the French and Spanish governments during the first half of the nineteenth century

Reference Catalogue	N° Physics instruments	N° Chemical items	Price (physics)	Price (chemistry)	Total price
French *collèges* (1821)	115	882	15,900 fr.	5923 fr.	21,823 fr.
French *collèges* (1842)	185	1196	10,000 fr.	4142.64 fr.	14,142.64 fr.
Spanish universities (1846)	149	133[a]	9531 fr.	6448.26 fr.	15,979.26 fr.
Spanish *institutos* (1847)	116	40[b]	5000 fr.	600 fr.	5600 fr.

The values presented in this table are extracted from (Conseil royal de l'instruction publique 1821a, b, 1842; Gil de Zárate 1846, 1847; Pastor Díaz 1847a, b)

[a] The Spanish university catalogue refers only to chemical apparatus though. However, the university collections included obviously collections of chemical substances as well

[b] See notes 15 and 17

negotiations with makers such as Pixii, contributed to make the purchase of university and school equipment cheaper. In 1847, the chemistry syllabus was considerably reduced, and, as a consequence, it was deemed appropriate to limit also its associated collections (Pastor Díaz 1847a, b).[10]

By the mid nineteenth century, nineteen secondary schools had a complete cabinet of physics, eleven other cabinets were almost complete and only five secondary schools were ill equipped.[11] A few years later, Gil de Zárate proudly remarked that many *institutos* (such as Palma de Mallorca, Girona, Lleida, and Orense) had larger collections than those prescribed by the government reference catalogue (Gil de Zárate 1855, II, pp. 80–161). Thus, how important was the impact of the Spanish government's reference catalogue in the quantitative and qualitative constitution of the *institutos*' physics collections? And what were their main characteristics across the Spanish territory?

In the early 1860s, most *institutos* published inventories of their teaching collections, in the yearly reports submitted by every school to the government and displayed in their annual *Memorias*.[12] The state of the *institutos*' collections was heterogeneous.[13] The school collections followed, in general, the foundational pattern provided by the 1847 government reference catalogue, but they had introduced some upgrades, replacements and additions. Most *institutos* located in university towns had collections which tripled the number of items recommended in the 1847 school reference catalogue and doubled those in the reference catalogue for Spanish universities (1846) and in a similar catalogue previously established in France for the French *collèges* (1842). A considerable number of provincial *institutos* had also managed to increase their collections beyond the recommendations of the Spanish university and school catalogues. But many others could only match or approach the recommendations made more than a decade earlier. This was also the case for most local *institutos*.

The reference catalogue for the *institutos* published by the Spanish government in 1847 was a reduced version of that published the year earlier for the universities. The two catalogues were roughly similar both quantitatively and qualitatively, but the university catalogue contained almost a third more physics instruments and tripled the number of

[10] Gil de Zárate had followed similar procedures to those promoted a few years earlier in France by Louis-Jacques Thenard. In 1842, Thenard had initially sent copies of the catalogues of instrument makers Deleuil and Pixii to all French schools, followed by a centralized survey of their collections and the publication of a reference catalogue. Pixii had also been one of the major instrument makers recommended by the French government in its previous reference catalogue, published in 1821. Both the 1821 and 1842 French reference catalogues suggested that, although the major aim in the development of collections was pedagogical, if possible schools should also purchase instruments intended for research work by their physical sciences teachers (Belhoste et al. 1995; Conseil royal de l'instruction publique 1842, pp. 181–191).

[11] According to a governmental report, which appeared in the *Gaceta de Madrid*, 7 September 1850, pp. 1–3. It did not include the University secondary schools and the secondary schools in which physics and chemistry was not taught.

[12] On the functions of the *Memorias* as an annual school publication see (Simon Castel 2008). The *instituto* of Valencia has preserved in its library a large set of *Memorias* of almost all the schools in Spain, which has allowed us to compare the instrument catalogues of a large number of them. On the potential of publications like the *Memorias* to reconstruct nineteenth-century school life see Olesko's analysis for the German case (Olesko 1985).

[13] We have worked through comparison with a set of printed collection catalogues published in 1861–1862 in the *institutos Memorias*. The set includes four university *institutos* (Granada, Oviedo, Salamanca, and Valencia), twenty provincial *institutos* (Alicante, Badajoz, Baleares, Burgos, Cáceres, Castellón, Ciudad Real, Cuenca, Gerona, Huelva, Huesca, Jaén, León, Lérida, Logroño, Málaga, Orense, Palencia, Pamplona, Pontevedra, Soria) and two local institutos (Figueras, Monforte de Lemos). The complete bibliographical references of these catalogues are available in the bibliography at the end of this paper.

chemistry items (see Table 1). The university collection allowed exposing a wider range of physical and chemical phenomena. Furthermore, the school reference collection was cheaper, indicating that university instruments were probably of better quality and more sophisticated, expecting a use not only in teaching but, in certain cases, also in research. Examples can be found, for instance, in the range of thermometers, barometers, telescopes and electric machines, included in the two catalogues. Moreover, the university catalogue included items such as a polariscope and an apparatus to demonstrate the development of magnetism by rotation, both devised by François Arago, which were more closely connected to contemporary research (Levitt 2009).

On the other hand, comparing the 1846 Spanish university and the 1842 French *collège* catalogues shows that the French school reference model contained a fifth more physics instruments, but a similar number of chemistry items.[14] The French reference collection contained a larger number of barometers and thermometers, more advanced instruments for the study of heat, and electricity and magnetism, and recent industrial applications such as magneto-electric apparatus. Many of these instruments were related to research work conducted in Paris by physicists such as François Arago, Alexandre-Edmond Becquerel and Macedonio Melloni. The Spanish catalogue was very poor in acoustics instruments in comparison to the French. In contrast, the latter had a low number of instruments to illustrate mechanics of solids, surely because in France mechanics was considered to be a subject independent from general physics. In many respects, the 1847 Spanish *instituto* catalogue was similar to a catalogue produced in 1821 for the French *colleges*. These model collections were constituted by a limited number of instruments aimed at illustrating simple physical phenomena (Conseil royal de l'instruction publique 1821a, b 1842, 1843; Pastor Díaz 1847b; Pidal 1846).

By the early 1860s, the state of the physics collections in the Spanish *institutos* was diverse. The analysis of the collection catalogues of a sample of twenty-seven *institutos* shows that, quantitatively, those located in university towns had in general tripled the number of instruments recommended in 1847, and doubled that of the reference collection for the universities, suggested a year earlier. Their collections were by then also larger than the physics collection of the 1842 model catalogue for the French *collèges*.[15] Some provincial *institutos* were in this range as well (Orense, Lérida, Baleares). A similar number of provincial schools were above the Spanish university catalogue but below the French *collège* model (Pontevedra, Gerona, Burgos, Pamplona). A larger number of these type of schools were above the Spanish school reference catalogue but below the university catalogue model (Logroño, Figueras, Soria, Ciudad Real, Alicante, Málaga, Castellón). Thus, almost three quarters of the *institutos* had increased their collections above the 1847 government recommendations. However, only half of these had increased their collection considerably, and surpassed even the recommendations made in 1846 for Spanish

[14] The inventories of the Spanish universities and institutos often included only reference to chemical apparatus, but not to chemical substances. The number of chemical instruments referenced was similar in the Spanish and French model catalogues. But the latter provided greater detail in describing also collections of chemical substances (Conseil Royal de l'Instruction publique 1843). The inventories of some large institutos such as that of Valencia do provide lists of their chemical substances collection which was – like in the French case—in the order of several thousands. However, local institutos had probably smaller chemical collections in the order of hundreds.

[15] This was the case of Valencia, Salamanca and Oviedo. Granada was an exception, which still needs explanation. In 1861, the number of physics instruments of the Granada *instituto* was lower than that recommended in the 1847 reference catalogue for Spanish schools. This might be because the *instituto* was using the university collections, or because it had financial and professional problems in relation to its professorship of 'physics and chemistry', which we have not been able to elucidate yet.

universities. Only a select number of *institutos* located in university and provincial towns excelled in their update of their physics cabinets, by largely exceeding the size of the collections recommended in previous Spanish and French government reference catalogues.[16]

There were also differences in the ways in which the *institutos* updated their collections in the twenty or so years between their establishment in the 1830s and 1840s and the general survey of 1861–1862. Around 1860, the pattern of the 1847 reference catalogue could be clearly seen in all the Spanish secondary school collections in physics. The largest *institutos* had built on this pattern, and increased and updated their collections. The smaller collections had a size and structure similar to the 1847 model or still tried to match it, a decade and a half later. Thus, it is out of doubt that the initiative of Gil de Zárate had a major impact in the making of the Spanish school collections.[17] However, there were also differences which did not only affect the largest schools, but most *institutos*.

The largest *institutos*, in university towns and some provincial capitals, were able to increase their collections with a large number of instruments, especially in electricity, but also in optics and heat. These additions allowed diversifying the range of natural phenomena that teachers could demonstrate in the classroom. This included for instance phenomena of light polarization, thermo-electricity and electromagnetic induction which had been investigated for the first time in the previous decades. Many smaller *institutos* which did not have a great purchasing capacity to cope with recent advances in physics, showed an interest in updating their collections as well. Thus, for instance, many schools introduced polarimetry instruments such as Arago's polariscope (Oviedo, Salamanca, Burgos, Baleares, and Gerona, but also Ciudad Real and Cuenca) and Norremberg's polarimeter (Salamanca, Baleares, Burgos, and Gerona, but also Málaga, Cuenca, and Monforte de Lemos—a local school), induction apparatus such as Ruhmkorff's coil (Valencia, Salamanca, Lérida, Baleares, Gerona, Alicante, Pontevedra) and instruments for the study and illustration of discharges in gases such as Geissler tubes (Lérida, Baleares, Gerona—provincial but not university *institutos*). The smaller *institutos* had to be selective in their purchases. Thus they often focused the update of their collections only in one branch of physics, which would typically be electricity. Most schools expanded the range of batteries in their collection and included some illustrations of industrial or commercial applications of electricity such as a telegraph model, an electro-medical apparatus or electromagnetic motor models. Other typical additions, which had an explicit pedagogical purpose, were stereoscopes, magic lanterns and photographic cameras.

Size, political location and economic affluence are not the only parameters which explain collection composition. For instance, in this period, the only galvanometers available in Spanish schools were to be found not in the largest university or provincial *institutos* (with the exception of Salamanca), but in small schools such as that of Logroño

[16] In chemistry, however, only a few *institutos* (Valencia, Oviedo, Salamanca, Lérida, Soria) appear to have matched or surpassed the recommendations published in the 1840s for the Spanish universities and French colleges, and many of them only matched those for the *institutos*. However, these results are more preliminary, since chemistry collections are more difficult to count. The chemistry catalogues are more heterogeneous and less systematized. In our analysis we have not taken into account chemical substances, which in many catalogues were not recorded.

[17] It is a question for further research determining how common the 1847 Spanish model collection was in the international context of physics teaching. In this paper, a first attempt has been made to compare it with the French government school pattern, showing differences in the number of instruments in mechanics and acoustics in both models and a lower capacity in Spanish collections to update in relation to recent research. However, further comparative work is still required.

and especially Huesca and Monforte de Lemos. Many *institutos* increased their collections of thermometers and barometers considerably, and they acquired high precision instruments in relation to their meteorological stations, which were part of a national network, coordinated by the Astronomical Observatory in Madrid. Small schools such as Cuenca, Huesca, and León could thus increase their instrument collections. The meteorological instruments of the *institutos* often made an exception to the general pattern of dependence on the French instrument trade, which was not challenged by a timid emergence of a Spanish instrument industry. In many schools with large meteorological collections such as Oviedo, Salamanca and Burgos, many of the instruments were made by leading London makers of Italian origin such as Casella, and Negretti & Zambra (Ruiz Castell et al. 2002; Williams 1994).

3 Three Secondary Schools: Valencia-Castellón-Alicante

The Valencian Region, in central-eastern Spain, was divided in three administrative provinces (Valencia, Castellón, Alicante) by the administration of the nineteenth-century Spanish state. An *instituto* was established in the capital of each of them, after Pidal's educational reform of 1845. The *instituto* of Valencia was linked to the university of the city, while those in Castellón and Alicante were the major educational institutions in their respective provinces.

In Valencia, the *instituto*'s physics and chemistry collection was first constituted with instruments from the university, with those of the abolished Jesuit schools in which the school had established its premises, and with the centralized purchases promoted by the Spanish government in the 1840s. For more than a decade, the *instituto* shared the cabinets and laboratories of the university. It became an independent institution in 1859 (Sanchis y Barrachina 1882). Between the late 1850s and the early 1860s, Valencia had an Industrial School, providing training for commerce and industrial professions as well. The elementary part of its syllabus was integrated as a branch of secondary education and, as a result, the Valencia *instituto* provided teaching in subjects such as applied mechanics and chemistry. With the closure of the Industrial School in 1865, its teaching collections were distributed among the *instituto* and university cabinets (Cano Pavón 2001). During the 1870s, the director of the Valencia school repeatedly complained about the lack of funding to cope with the required increase and update of the *instituto*'s collections. However, from 1877, secondary schools were authorized to keep student fees under their administration, enabling them to increase their investments in equipment (Instituto de Segunda Enseñanza de Valencia 1874, 1875, 1876, 1877, 1878, 1882). In this context, Jaime Banús y Castellví, the secretary and professor of physics and chemistry, and applied mechanics at the Valencia *instituto*, could increase and update the school collections on a more consistent base.

Banús y Castellví had joined the Valencia *instituto* after teaching natural history and physics at the secondary school of Gerona. He was one of the few secondary school teachers trained in the Escuela Normal de Filosofía, an ephemeral institution devised on a French model by the Spanish government, in order to provide secondary education with science teachers (Simon et al. 2009). In the Escuela he met José Monlau, who became natural history teacher at the *instituto* Balear (Elías de Molins 1895; Ovilo y Otero 1859). A few years later Monlau translated Adolphe Ganot's *Traité élémentaire de physique expérimentale et appliquée* into Spanish, which in spite of the serious competition of major Spanish textbooks, became one of the main works used in Spanish secondary schools.

During his tenure of the Valencia school professorship of physics and chemistry, the physics textbook recommended by Banús y Castellví was the Spanish translation of Ganot's book.[18]

By the late 1870s, a provincial commission visited the cabinets of the *instituto* and expressed admiration for the importance of its collections, mainly based on purchases to foreign instrument makers. The commissioners considered that the collections were in tune with the most recent advances in science, and that in some aspects they could be superior to those of certain institutions of higher education (Banús y Castellví 1879).

By the early 1880s, the Valencia *instituto* had a collection of 10,176 items covering physics, chemistry, and natural history (Sanchis y Barrachina 1882). Among these were more than 300 physics instruments and 3,000 chemical items, comprising instruments, glassware, and substances. The size of the Valencia collections was characteristic of an *instituto* located in a university town, doubling or trebling that of most provincial or local *institutos* and surpassing the government recommendations made for the universities in 1846. The subject with most additions was electricity and electromagnetism, which was with 79 instruments one of the largest. There were also many additions in optics and heat. Although additions in solid and fluid mechanics were considerable, they preserved the pattern of the reference catalogue recommended by the Spanish government in 1847.

Banús y Castellví was able to update his teaching collection with instruments which had appeared in previous years in the context of research. It included, for instance, telephones, a microphone, and a Crookes radiometer, all apparatus appeared in research during the 1870s. It also included an apparatus designed in the 1860s by John Tyndall to illustrate the transformation of work into heat, which gained acceptance with the spread of the principle of energy conservation in physics throughout the 1870s. In addition, a university *instituto* like that of Valencia possessed a variety of instruments which could be used for the same pedagogical demonstrations, such as several electrostatic machines, microscopes and telescopes, while smaller schools only possessed a single item of each type (Anon. [post-1873]).

Like the *instituto* of Valencia, those in Alicante and Castellón were established around 1845. These towns had at least half the population of Valencia, and their *institutos* were the highest educational institutions in their provinces, which did not have a university (O'Shea 1865, 461–491). Their physics and chemistry collections were also smaller and in general less updated. In 1861, in Alicante, there were 121 physics instruments and 34 chemistry apparatus, although these numbers increased considerably during the following decade (Anuario 1873, 31–54; Senante 1862). In Castellón, the collections were only slightly smaller (Herrero 1861). These collections were thus smaller compared to those in Valencia.

The physics collections in Valencia, Alicante, and Castellón followed a similar pattern in their distribution by subjects. The best represented areas of physics were electricity and mechanics, followed by optics. This distribution matched the pattern established by the Spanish government reference catalogue of 1846. Furthermore, the area with a higher increase was electricity, due to a considerable number of additions, particularly concentrated on electromagnetic apparatus. The composition of these Spanish collections differed significantly from the pattern established in France through the 1842 government reference catalogue, in which the provision of apparatus for the study of heat was only second to that of optics, and more important than that of electricity.

[18] A list of recommended textbooks appeared in the *Memorias* of each *instituto*. On the international success of Ganot's textbook see Simon (2009).

However, in 1861 neither Alicante, nor Castellón had managed to increase their collections significantly beyond the recommendations made by the Spanish government more than a decade earlier. These *institutos* were afflicted by the lack of funding. Between 1845 and 1875, Alicante had three different professors of 'physics and chemistry'. Teachers used the Alicante *instituto* as a temporary position in a long-term career towards more prestigious and better equipped *institutos*.[19] They published physics and chemistry textbooks which served their pedagogical needs and their strategies of professional promotion. They also contributed to the improvement of the *instituto*'s scientific collections. However, their subsequent transfer to other schools prevented a more consistent impact of their initiatives in the development of the physics and chemistry collections in Alicante.[20]

In contrast, at the *instituto* of Castellón, the same professor taught physics and chemistry for almost half a century. Between 1846 and 1884, Francisco Llorca y Ferrandiz taught physics, chemistry and natural history in this *instituto*, and was its director for most of the period (Centenario 1947). But the Castellón school had to struggle to provide a sufficient budget for the increase and update of its teaching collections, and failed to do so in many occasions (Sanz Bremon 1898, 9). In fact, in 1861, the physics collections of Alicante and Castellón differed in a significant aspect. Although both had a similar size, the former displayed a capacity of updating, since many novel instruments showing electromagnetic phenomena were added. Additions to the Alicante collection included a larger number of batteries, a model of telegraph and a sample of submarine telegraphic cable, and major apparatus such as a Ruhmkorff induction coil and a photo-electric regulator. In optics, additions were less, but included for instance a stereoscope and a solar spectrum with Fraunhofer and Becquerel lines. In contrast, in Castellón the only significant additions were a small number of batteries and a photo-electric regulator (Herrero 1861; Senante 1862).

4 COMIC and the Material Culture of Spanish School Science

During the last years, members of COMIC have worked in the cataloguing of the physics and chemistry collections currently preserved at the *institutos* of Valencia, Castellón, and Alicante.[21] These collections have been digitized and are currently being uploaded in the COMIC resource portal. The analysis of the extant collections confirms some of the patterns established through the study of printed and manuscript inventories. The area of physics best represented in these collections is electromagnetism (20–30%), followed by solid and fluid mechanics (10–15%), optics (ca. 10%), and heat (ca. 10%). The study of sound is poorly represented in the three collections, as in the Spanish 1846 reference catalogue, and in contrast to the contemporary recommendations for French school collections. Even though the Valencia collection was bigger originally, about the same number of instruments have survived in the three collections. While Valencia and Alicante have preserved around 300 and 240 physics instruments, respectively, Castellón surpasses

[19] This phenomenon seems similar to that of physics teacher mobility in nineteenth-century France. See Balpe (1997).

[20] The physics and chemistry professors in Alicante were José María Guillén (1845–1847), Rafael Chamorro (1848–1869), and Basilio Márquez y Chaparro (1869–1875). Both Chamorro and Márquez published textbooks.

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this number with a collection of ca. 400 items from physics. In Castellón and Valencia, between 100 and 300 items from chemistry, made of glass and terracotta have been preserved. In Alicante, like in many other Spanish schools, items from chemistry have disappeared through recycling or destruction.

These patterns cannot be explained without taking into account several issues: the importance of each of these areas in nineteenth-century science education (lectures and textbooks), the prolonged and intensive use of certain instruments (interfering with their preservation), the relative importance of demonstrations in each area (some lecture subjects requiring more instruments than others), instrument prices and school budgets, the availability of instruments in each period, the size, materials and fragility of instruments (a major issue in the case of chemistry), and the perceived cultural and aesthetic value of the pieces, among others.

Focusing on the first of these issues, the subject distribution in the three collections, matches reasonably well that of Ganot's *Traité élémentaire de physique expérimentale et appliquée*, which was a major standard textbook in the same period, in Spain, France and elsewhere. By mid-century, the largest chapters in Ganot's physics were those on heat and light, followed by that on dynamical electricity.[22] In the following decades, the latter expanded to equal the size of the former. In the late 1880s the three chapters still had a similar length, but the chapters on heat and light usually displayed a lower number of instruments than those on electricity, since instruments for the study of light or heat were often part of several experimental set-ups. However, the chapters on static and dynamical electricity were together longer than any other area in this standard physics textbook (Simon 2009, chapter 5).

Furthermore, the analysis of these extant collections offers new avenues to explore the development of pedagogical and scientific practices in secondary education. It is striking, for instance, that there are items in the Valencia, Alicante, and Castellón collections which clearly depart from the exclusively educational function commonly attributed to school collections. The Valencia collection includes for instance a Deprez galvanometer (Catalogue number L-0089), which was an item specifically designed for high precision measurements. Castellón has preserved a resistance box and a Thomson galvanometer built by the English maker Elliott Brothers (Catalogue numbers R-0033 and R-0018). The Alicante collection includes a five-fold finger reaction apparatus with stopper contacts (Catalogue number JJ-0030), marketed by the Leipzig maker E. Zimmermann, who had a major role in the development of Wilhelm Wundt's programme of experimental psychology (Benschop and Draaisma 2000). The presence of these items suggests that the *institutos* were not only spaces for pedagogical communication, but might have also been sites for research. Furthermore, the presence of items by English, German, and Spanish instrument makers in these collections, although lesser than the French contribution, helps to qualify the traditional idea of a complete dependence of nineteenth-century Spanish education and science, on French developments.

5 Conclusion

The early development of Spanish school collections through state intervention offers an interesting opportunity to map teaching collections in regional and national perspective and

[22] In the second edition of Ganot's *Traité*, the chapters on Heat and Light represented 20% of the book respectively, while the chapter on Dynamical electricity represented 14% (Ganot 1853).

to use them for research. Comparison of different collections and their associated printed and manuscript sources, through the development of tools of analysis showing their commonalities and differences, can help us to characterize educational and research practices developed in the school context. Spanish secondary schools possess a rich scientific heritage which makes this task possible and highly rewarding. Several projects have started to work in this direction by cataloguing and producing preliminary descriptions of these valuable collections. Their methodological approaches are diverse and respond to a wide range of approaches and interests, which cover the space between museology, education, and history. Their impact has been limited by the inevitable time constraints of research projects and funding. The dispersion of these laudable efforts has unfortunately contributed to hinder a serious effect on national policies to achieve better conditions for the preservation, study, and use of school collections. In this paper, we have argued for the need of better and more efficient coordination, which could be attained with methodological tools such as those proposed by COMIC and its current online project. Furthermore, we are calling for a more efficient integration of historians of science, historians of education, science educationists, and museologists. The preservation and use of secondary school collections can bring new life to each of these fields, and an integrated solution to their current situation requires collaboration and dialogue between all of them. Moreover, it can play a major role in understanding the nature of science and technology, in encouraging the work of teachers and students, and in communicating science to society.

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