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The Periodic System and the Nature of Science: The History of the Periodic System in Spanish and Norwegian Secondary School Textbooks

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Abstract. This essay analyses 31 science and chemistry textbooks from Spain and Norway with respect to their presentations of the history of the periodic system and what these presentations can teach students about the Nature of Science (NOS). The analysis is based on the SOURCE framework, where each letter in SOURCE represents an element from the history of science and corresponding attributes of NOS. Our comparative analysis reveals large differences in the role of history of chemistry between the Spanish and Norwegian teaching contexts, and similar differences in their inclusion of historical aspects in curricula and textbooks. We argue that the lack of references to women, to errors or failures in the history of the periodic system represents missed opportunities to discuss chemistry as a tentative, collective and socio-cultural enterprise.

Keywords. Periodic System, History of Chemistry, Chemical Education, Textbooks, Nature of Science.

INTRODUCTION

The periodic system is one of the best-known and most-used icons of science. It figures in every lecture hall where chemistry is taught, and it is hard to imagine chemistry teaching and chemistry textbooks without it. For chemistry students (and chemists) it might also be difficult to grasp that the periodic system was developed without knowledge of the structure of the atom, which we take for granted today. The history of the periodic system would certainly enlighten students about the particularities of its development, but also give them insight into the nature of scientific development in general. It has been argued that studying chemistry (or science) in a historical context may contribute to the understanding of chemistry as a dynamic process rather than a static set of theories or laws, as a diverse endeavour that relies on intuition as well as logic and clearly depends on the humans involved in the processes.[1,2,3,4] Aspects such as these are captured in the concept 'Nature of Science', which we will introduce below.

Teaching science should therefore be more than just explaining models, theories and laws, and the history of science can help unveil a fuller picture of the scientific enterprise. For the historian, the end products, theories and facts must be understood as temporary end products of a long process. It is now generally acknowledged that knowledge about the process itself can provide very interesting insights about science. Despite greater consciousness about science as a process among science educators from the 1960s onwards, the emphasis in school curricula has not radically shifted away from teaching established "facts" or end products to instead exploring how this knowledge was constructed.[5] As McComas and colleagues put it, when summarizing reports from the 1990s, 'the ideas put forth in textbooks and school science concerning the nature of science are almost universally incorrect, simplistic, or incomplete'.[6] Although new aspects have been added to more recent curricula, in our experience the use of historical material is still limited; which clearly contrasts with the increased importance attributed to history in science education research in the past few decades.[7]

The aim of this essay is to explore to what extent and how the history of the periodic system is presented in recent textbooks, and which aspects of the nature of science are conveyed to students through the historical presentations. We will compare texts published in the last 13 years from two different teaching contexts: those of secondary schools in Spain and in Norway. Before presenting the methodology, our analyses and conclusions, we will introduce the concept of Nature of Science in science teaching, the theoretical framework based on that concept, and the contrasting curricular traditions in Spain and Norway when it comes to including the history of science. The aspects of the history of the periodic system that we have selected for our analyses will be introduced in the Materials and methods section.

Using history of science to teach the Nature of Science (NOS)

When science is taught, teachers and students create various images of science. This wide range of images is made up of values, features and conceptions about how science works. In the context of science education, learning the Nature of Science (NOS) refers to understanding presuppositions, values, aims, and limitations of science, and how knowledge is created and established.[5] Analyses of science curricula reveal that even though NOS is usually not explicitly mentioned, several objectives, contents, skills and evaluation criteria are deeply connected with NOS themes in many ways.[8] Studies of the history of science content in textbooks have, furthermore, provided insight into how NOS is presented in textbooks and teaching.[9] Although NOS is itself a dynamic area with no fixed list of attributes, a pragmatic 'consensus view' has been compiled, including the most important agreed-upon elements describing science as a process. This consensus view holds that science or scientific endeavour is tentative (always evolving), empirical (relies on observation, experimental evidence, arguments, scepticism), explanatory (attempts to explain natural phenomena), communicative (open and subject to peer review), structured in laws and theories (though they serve different roles in science), both evolutionary and revolutionary, interrelated with technology (a two-way relationship), diverse or multifaceted (there is no one scientific method), to a certain extent subjective (influenced by personal values and prior experiences), creative (involving imagination), and socio-cultural (influenced by cultural and social contexts).[5,9,10,11] Table 1 compares some of the different ways these NOS aspects are communicated in the literature. The selected aspects given in Table 1 will be used as a basis for our analyses of Spanish and Norwegian textbooks.

In 1974, in a paper entitled 'Should the history of science be rated X?' published in *Science*,[12] the historian of science Stephen G. Brush critically stated that 'the teacher who wants to indoctrinate his students in the traditional role of scientist as a neutral fact finder should not use historical materials of the kind now being prepared by historians of science: they will not serve his purposes'.[13] His point was that science teachers wanted to keep their success stories, and that the history of science challenged them. Although Brush's irony is evident,

Table 1. A comparative connection between DiGiuseppe's (2014)[10] and McComas-Kampourakis's (2015)[9] NOS aspects.

DiGiuseppe's NOS aspects	McComas-Kampourakis' NOS aspects Science (is)
Tentative	a way of knowing
	addresses questions about the natural and material world
	open to revision
Empirical	based on data and empirical evidence
Subjective	
Creative	a human endeavour
Socio-cultural	
Structured in laws and theories	assumes an order and consistency in natural systems
	models, laws and theories explain natural phenomena
Diverse	uses a variety of methods

he touched upon a dilemma, as the histories of scientific development presented through a history of science might, indeed, destroy the many ‘hagiographic’ (heroic) tales that are commonly used in textbooks and classrooms. Thirty years later, the philosopher and historian of science (and science educator) Douglas Allchin published a paper entitled ‘Should the sociology of science be rated X?’, echoing Brush’s article from 1974.[14] While the ‘new’ history that Brush discussed took heroes of science down from their pedestals, Allchin discussed how a sociology of science threatens the image of the ‘idealized and impersonal scientific method found in textbooks’.[15] Indeed, (degrees of) subjectivity and tentativeness are among the attributes of the ‘consensus view’ that do challenge the authority of science – which is why science educators do not always embrace all aspects of NOS. Allchin stressed that idealized, or romanticized, science is a lie. For this reason, he argued, science educators should distinguish between the normative and the descriptive elements of NOS in their teaching. Allchin also argued that science educators indeed should include errors or failed attempts from the history of science when teaching about the Nature of Science. In Allchin’s words, ‘teaching science without error is like teaching medicine without disease or law without crime’.[16]

In order to identify the sorts of historical narratives that introduced a misrepresented NOS in the teaching context, in another article Allchin used the term ‘pseudohistory’ of science (pHS).[17] He argued that the historical narratives in science education must present the history of science without idealizing past science. From Allchin’s approach, historical narratives become pHS when they verge on myth. One such myth in the history of the periodic system might be that Dmitri Mendeleev (1834–1907) was the sole discoverer of the system and that it was conceived during one ‘eureka’ moment. Since every history of science teaches nature of science, science educators need to be wary of mythic narratives (what we have called NOS from pHS approach in Table 2). They need to use historical narratives that portray NOS more informatively (what we have called NOS from HS approach in Table 2).[17,18] One of the strategies proposed by Allchin is to neutralize mythical historical narratives of science by going from the source of the problem to the source of the solution, as we summarize in Table 2.[18] This so-called SOURCE approach allows teachers to recognize myths and control their effect on students. We will use this approach when analysing Spanish and Norwegian textbooks.

In recent years, science education literature has given some attention to the use of the history of the periodic system in chemistry teaching. In 2015, McComas

Table 2. Main features of NOS according to the SOURCE approach, based on Allchin (2003).[18] Every letter in the word SOURCE corresponds to an attribute from pseudo-history of science (pHS) as well as to an attribute from history of science (HS).

NOS from pHS approach	NOS from HS approach
Science-made	**S**cience-in-the-making
Overinflated genius	**O**pportunities
Unqualified Universality	**U**ncertainties
Retrospect	**R**espect for historical context
Caricatures	**C**ontingency, complexity, controversy
Expected results and Excuses	**E**rror Explained

and Kampourakis used Mendeleev’s periodic table as an example of a historical case which shows that laws and theories represent distinct kinds of scientific knowledge (the NOS aspect ‘structured in laws and theories’).[9] As Bensaude-Vincent had pointed out almost three decades before, Mendeleev developed a periodic law which enabled new data to be discovered and phenomena to be explained, and which atomic theory later explained.[19] Furthermore, the knowledge of the development of the periodic system was among the topics in a questionnaire used by Franco-Mariscal, Olivia-Martínez and Amoraima-Gil in 2016 to analyse how Spanish high school students understood the idea of chemical element and its periodic classification.[20] Based on a review of analyses of the history of the periodic system in textbooks in the USA and Latin America, in 2016 Niaz suggested several guiding principles for teaching the periodic system using a history of science approach. Among them were how the classifications of the elements could be based on atomic mass, the important role of other co-discoverers of the periodic table, and what role predictions played for acceptance of the periodic law.[21] Similar aspects have been selected for the present analyses and will be presented under Materials and methods.

History of chemistry in Spanish and Norwegian teaching contexts

During the past decades, the field of history of chemistry has undergone a significant consolidation and renovation.[22] However, the history of chemistry is still conspicuous by its absence in many teaching contexts. Spain and Norway represent different local contexts when it comes to the institutionalization and teaching of history of chemistry at different levels. Two surveys of the prevalence of the teaching of history of chemistry in Europe, stemming from 2007 and 2015, respectively, reveal that in fact, the situation with respect to history of chemistry teaching is not at all comparable in the two countries. In 2007, history of chemistry was taught for chemistry students at 14 of the 39 universities offering graduate, postgraduate and doctoral studies in Spain, most of them as special history of chemistry courses. In Norway, two of the four universities in the country offered teaching in history of chemistry, either as part of the chemistry curriculum or as part of a history of science course for prospective teachers. Although representatives from both countries in 2015 expressed worry about the lack of institutionalization of the field, history of chemistry is much more prevalent in Spain in terms of the history of chemistry groups, journals and teaching offered than is the case in Norway.[23] If we assume that the knowledge and use of history of chemistry at secondary school level echoes the situation at university level, we would expect a major prevalence of the history of chemistry in the Spanish curriculum. The analyses of the curricula in Norway and Spain have supported that.

The Spanish chemistry curriculum contains a few competency objectives on the history of chemistry at secondary school level. Five history of chemistry issues can be found: atomic models, classification of the chemical elements, acid-base theories, laws of chemical combinations and the origin of organic chemistry.[24,25] Among them are the 'importance of the periodic system for chemistry development'[26] and the 'historical development of the classification of the chemical elements'.[27] Both are part of the upper secondary chemistry curriculum (16–18 year-old students). The history of the periodic system is not explicitly mentioned in the lower secondary school chemistry curriculum (ages 14–16). A recent study on the history of chemistry in Spanish secondary education pointed out that several curricular elements make explicit the tentative (evolving), controversial (diverse and multifaceted), creative (involving imagination), under-construction (evolutionary) and social-cultural (influenced by cultural and social contexts) NOS for both lower and upper secondary education.[28]

In Norway, history of chemistry has had a less prominent role in the chemistry curriculum, which is not surprising given how little attention is paid to history at university chemistry level. A survey from 2004, before the most recent curriculum reform in Norway was launched, reveals that students who opted for chemistry in upper secondary school liked 'historical chemistry' least of all chemistry topics listed in the survey.[29] As of 2006, the national science and chemistry curricula hardly include any history of chemistry. The only specific competency objective for history of chemistry is related to the historical development of the atomic model and the concept of atoms, which is a topic that falls under the main area of 'Language and models in chemistry' in upper secondary school.[30] Another competency objective in the chemistry curriculum that is related to NOS aspects and might allow for some historical reflections, revolves around scientific method and explanatory models not compatible with chemical-scientific explanations (as part of the main content area, the meta-subject 'Research').[31] As a topic in chemistry, the periodic system is part of the curriculum for the integrated science course in lower secondary school in one competency objective for grades 8–10 (i.e. ages 13–15).[32] The periodic system is not explicitly mentioned in the curriculum for upper secondary school (ages 16–18), but might be taught as part of other topics if considered relevant and needed, though treated as 'repetition'. A new curriculum, which will be implemented from autumn 2020, follows the current curriculum in placing the periodic system as part of lower secondary science, and with no competency objectives for history of chemistry.[33]

MATERIALS AND METHODS

Although the curriculum is the formal guide to teaching at different levels in Spanish and Norwegian schools, in practice textbooks serve as the real guides when teachers prepare their teaching, as Park and Lavonen have pointed out for the American and Finnish cases.[34] For this reason, textbooks are well suited to inform us about teaching practices and what content is being taught in chemistry at different levels in school. Also, since competency objectives in curricula are few and general, textbook authors must interpret the curriculum and therefore, their texts will go beyond the curricula themselves. An example is the history of the periodic system, which as noted is not an explicit part of the lower secondary school curriculum in Spain, yet textbooks include it. This also applies to other historical topics. Likewise, the periodic system is mentioned in chemistry textbooks for upper secondary school in Norway, although it is not part of the curriculum for that level. In both samples textbooks in science/chemistry at lower and upper secondary school levels are included, for the years in which the periodic system is mentioned.

In the Spanish case, textbooks for compulsory lower secondary education, CSE (*Educación Secundaria Obligatoria-ESO*) and upper secondary education, USE (*Bachillerato*) from five recognized publishers have been analysed: *Anaya* (S1); *Santillana* (S2); *Vicens Vives* (S3); *McGraw-Hill* (S4); *Oxford* (S5). The sample is made up of 20 textbooks from four educational levels: five textbooks

Table 3. The SOURCE approach adapted to the history of the classification of the chemical elements. For an explanation of S, O, U, R, C and E, see Table 2.

Research items (I)	NOS aspects			HS aspects
Textbooks mention…	Allchin (SOURCE approach)	DiGiuseppe	McComas & Kampourakis	
I1. Different classifications of the chemical elements before and after Mendeleev's periodic system	Science-in-the-making vs. Science-made	Creativity	Human endeavour	Collective
I2. The work of women behind the periodic system	Opportunities vs. Overinflated genius	Socio-cultural		Equal
I3. Mendeleev predicted atomic weights and properties of several elements which were later corroborated	Uncertainties vs. Unqualified universality	Tentativeness	Open to revision	Non-hagiographical Non-teleological
I4. Mendeleev's periodic system gradually evolved	Respect for the historical context vs. Retrospect	Creativity		Contextualized
I5. The differences between Mendeleev's and Meyer's approaches to the classification of the elements	Contingency, complexity & controversy vs. Caricatures	Diverse	Variety of methods	Controversial
I6. Not all of Mendeleev's predictions were successful	Error explained vs. Expected results and excuses	Tentativeness	Open to revision	Non-hagiographical

for the third course of compulsory lower secondary education (14–15 year-old students, CSE3), five textbooks for the fourth (and last) course of compulsory lower secondary education (15–16 year-old students, CSE4), five textbooks for the first course of upper secondary education (16–17 year-old students, USE1) and five textbooks for the second (and final) course of upper secondary education (17–18 year-old students, USE2). All of these textbooks were widely used in Spanish upper secondary schools between 2007 and 2016. Moreover, these textbooks have been published by some of the most prestigious publishing houses for education (S1-S5), according to the Spanish ranking of the Scholarly Publishers Indicators in Humanities and Social Sciences Project.[35]

The Norwegian textbook sample consists of, first, four sets of science textbooks for compulsory lower secondary school (ages 13–15), grade 8 (CSE8) and for most of them, grade 9 (CSE9), which are the books that present and discuss the periodic system (seven books in total): *Tellus* (N1), *Trigger* (N2), *Eureka!* (N3), *Nova* (N4), published by four different publishing houses. Secondly, the first year of the specialized chemistry course in upper secondary school (year 2, USE2) uses three textbooks from three different publishers: *Kjemi 1* (N5), *Aqua Kjemi 1* (N6), *Kjemien Stemmer 1* (N7). In the first year there is a compulsory integrated science course, and in year 3 the periodic system is not discussed. Thirdly, as a reference we have included the textbook *Kjemi for lærere* (Chemistry for teachers, N8), used in the study programme for prospective science teachers in primary and lower secondary schools who have no prior knowledge of chemistry.[36] This study programme takes place either in a university college or at university (varies from city to city). For simplicity, we call it College Education (CE) in this article.

Framework and research items for textbook analyses

The methodological framework for our analyses of the history of the periodic system in textbooks is presented in Table 3. Here, we use the SOURCE approach proposed by Allchin (Table 2), where each letter in SOURCE stands for an aspect of NOS, and connects it with NOS aspects based on work by DiGiuseppe, and McComas and Kampourakis (Table 1). We will present the historical background for each research item separately.

<u>I1: Different classifications of the chemical elements before and after Mendeleev's periodic system.</u>

Far from being a product of a single man's flash of genius, the periodic table was the result of a collective aim which developed over a long period of time. Already in the beginning of the 19th century, after John Dalton (1766–1844) had introduced his atomic theory and characterized different atoms by their weight, attempts were made to group elements according to their atomic weights. The German chemist Johann Wolfgang Döbereiner (1780–1849) organized the elements into groups of three elements with related chemical properties (like reactivity) called triads, where the atomic weight of the central element of the triad was the mean value of the atomic weights of the first and the last elements of the triad. Several chemists identified triads, and the idea of triads has been highlighted as an important point in the history of the periodic system because it hinted at a relationship between numerical criteria (the atomic weight) and the properties of the elements.[37]

Atomic weight determinations continued over the course of the 19th century; however, discrepancies existed. The question of which system one should base the atomic weight determinations on was taken up at the first international chemistry congress held in Karlsruhe in September 1860. It is thus not by chance that several classifications of the elements emerged in the early post-Karlsruhe context. The British chemist William Odling (1829–1921), the German chemist Lothar Meyer (1830–1895) and Mendeleev were all present at the Karlsruhe congress, after which they had a basis on which to build a system of the elements.[38, 39] Twenty years after his first periodic system had been published, Mendeleev recognized the importance of the Karlsruhe meeting for his work on the elements, as '[o]nly such real atomic weights [proposed at Karlsruhe] – not conventional ones – could afford a basis for generalization'.[40] A total of six independent discoverers of the periodic system have been identified: The French geologist Émile Béguyer de Chancourtois (1820–1886), who in 1862 presented his *Vis tellurique* (a periodic helix), and the British chemist John Newlands (1837–1898), known for his 'law of octaves', are among them, along with the American chemist Gustavus Hinrichs (1836–1923), Odling, Meyer and Mendeleev. The development of periodic systems also continued after Mendeleev's famous 1869 system. In fact, between 1782 (with Louis Bernard Guyton de Morveau's simple table) and 1974, many hundred classifications and representations classifications and representations of the 'periodic law' appeared, including tables, zigzags, lemniscates, helixes and spirals.[41] All of these clearly show why the history of the periodic system can be considered as a history of shaping and sharing.

<u>I2: The work of women behind the periodic system</u>

In the 1860s, 63 chemical elements were known. Many new elements were identified from the 1870s onwards and in particular in the first decades of the 20th century. While it is well known that many (male) scientists contributed to the discoveries of elements, histories of women discoverers are rarely communicated. Recognizing that women from different backgrounds and in various roles have contributed to discoveries of elements and to the development of the periodic system is another way of conveying that science is a collective human enterprise where people from all cultures have taken part. By spotlighting women, such stories can also highlight that science is equal, an endeavour for both women and men.

Element discoveries demanded high-level analytical-chemical competence, and in some cases expertise on radioactivity. Examples of element discoveries by women, either alone or on research teams, are polonium and radium (1898), by Marie (1867–1934) and Pierre Curie (1859–1906), protactinium (1918) by Lise Meitner (1878–1968) and Otto Hahn (1879–1968), rhenium (1925) by Ida (1896–1978) and Walter Noddack (1893–1960), with the help of Otto Berg, and francium (1939) by Marguerite Perey (1909–1975). Women were also involved in work that led to positioning the elements in the right place (see I4 for the example of Julia Lermontova) and in revealing nuclear processes leading to a better understanding of the atom.[42]

<u>I3: Mendeleev predicted atomic weights and properties of several elements which were later corroborated, and I6: Not all of Mendeleev's predictions were successful</u>

Even though Mendeleev's classification underwent several modifications, one of the known features of all of Mendeleev's periodic systems was that he left blank spaces for as yet unidentified elements. He also predicted their atomic weights and foresaw some of their properties. Although the predictions that were later fulfilled influenced the acceptance of the periodic system, it has been argued that the importance of the predictions must be reconsidered.[43] For example, in 1882, Mendeleev and Meyer were both recognized by the Royal Society of Chemistry with the Davy Medal because of their contribution to the development of the classification of the elements, but no mention was made of Mendeleev's successful predictions. Also, it should be noted that Mendeleev had many failed predictions. Coronium, ether, eka-cerium, eka-molybdenum, eka-niobium, eka-cadmium, eka-iodine and eka-caesium were elements predicted by Mendeleev which were never found. Eka-boron (scandium), eka-aluminium (gallium) and eka-silicon (germanium) are examples of elements predicted by Mendeleev which were later identified and which properties turned out to fit well with what Mendeleev had foreseen.

<u>I4: Mendeleev's periodic system gradually evolved</u>

The different versions of Mendeleev's classifications were more than a succession of changes in shape. Chemists continued to refine their analytical methods in order to obtain more accurate atomic weights. In the 1870s, the Russian chemist Julia Lermontova (1846/47–1919) worked on the separation of the platinum metals in minerals so that more accurate atomic weights could be determined. This was necessary since the atomic weights of the platinum metals were close in value, and so were their chemical properties; hence it was difficult to place them in the right order in the periodic system.[44] Another example is the difficulty in positioning tellurium and iodine in the periodic system. In 1871, Mendeleev assumed an atomic weight of 125 for tellurium although weights up to 128 had been determined, since placing tellurium before iodine (127) constituted a better match in terms of chemical properties than *vice versa*.[45] Thirty-three years later, in 1904, Mendeleev presented both elements with the same atomic weight (127) in his periodic table. In fact, tellurium had been found to have a slightly higher atomic weight than iodine (127.6 vs. 126.85), but there was nevertheless no doubt about which family they belonged to in the system – evidence that atomic weight could not be the primary criteria for ordering the elements.[45,46] Other changes can also be observed by comparing Mendeleev's different periodic systems: Some elements disappeared from the system (like didymium, Di) and others appeared (like group zero gases – now known as the noble gases in group 18) in subsequent classifications.

The periodic system as a table also continued to develop after Mendeleev's time. In 1905, for example, two years before Mendeleev died, the Swiss chemist Alfred Werner (1866–1919) reorganized the periodic table, separating the lanthanides so they occupied a separate place in the table similar to the placement of the transition metals in our current long periodic table. In subsequent decades, the British chemist Friedrich Adolf Paneth (1887–1958) moved the lanthanides beneath the main table. Likewise, in 1945 the American chemist Glenn Theodore Seaborg (1912–1999) added a separate group of elements beneath the table, the actinides, thereby moving elements 89–96 from the main table to the new group. The justification of the concept of 'atomic number' by the British physicist Henry Moseley (1887–1915) in 1913 was also an important milestone in the history of the periodic system after Mendeleev's work. The introduction of the atomic number as a better ordering principle for the elements than atomic weight and the irruption of quantum physics in the study of subatomic structure also had an important influence on the development of the periodic system to the present day.

<u>I5. The differences between Mendeleev's and Meyer's approaches to the classification of the elements</u>

As noted above, in 1882 Lothar Meyer and Mendeleev were awarded the Davy Medal jointly. As with the systems of Mendeleev and the other co-discoverers, the elements in Meyer's periodic systems were organized by increasing atomic weight. Both chemists developed their periodic systems while preparing a textbook.[47] However, Meyer's and Mendeleev's approaches were different. Mendeleev thought chemical properties should take precedence over physical criteria, except for atomic weight. Mendeleev also made elaborate predictions for still unidentified elements (not all successful, as stated above) and suggested revisions to what he presumed were inaccurate atomic weights.[48] Meyer, too, left blank spaces for as yet undiscovered elements and made interpolations for the atomic weights of unknown elements' based on the values for neighboring elements, but he did not make extensive predictions for unidentified elements like Mendeleev did. Instead, Meyer explored the concept of periodicity through a graph where atomic volume was plotted as a function of atomic weight, making visible trends in atomic volume as a property of atoms.[49]

Scoring system

For our content analyses we have defined a scoring system to indicate the extent to which selected aspects of the history of the periodic system have been addressed in the named textbooks (Table 4). The scoring system is inspired by Niaz.[21]

The mention has been considered satisfactory (SM) if the textbook:

(SM-I1) presents the classifications of the chemical elements as a collective and creative challenge for several chemists before (as well as after) Mendeleev.

(SM-I2) is inclusive in the sense that women are mentioned, e.g. as discoverers of elements.

(SM-I3) uses Mendeleev's 'correct' predictions in order to emphasize chemistry-in-the-making instead chemistry as a static corpus of knowledge, but not as a way to emphasize his role as a 'hero of chemistry'.

(SM-I4) refers to post-1869 developments of the periodic system, such as changes in the positioning of elements, introduction of new elements or disappearance of others, the introduction of the atomic number by Moseley or the interpretation of the periodic law based on quantum theory.

Table 4. Recording instrument. I1-I6 refer to historical items presented above. The scoring system includes the following scores: SM, satisfactory mention; NS, non-satisfactory mention; NM, no mention.

Textbook	I1	I2	I3	I4	I5	I6
Score	SM	SM	SM	SM	SM	SM
	NSM	NSM	NSM	NSM	NSM	NSM
	NM	NM	NM	NM	NM	NM

(SM-I5) emphasizes that although Mendeleev and Meyer had important roles in the emergence of the periodic system, their approaches offer similarities and differences.

(SM-I6) notes the failed predictions of Mendeleev as an opportunity to show that scientific development is not linear, but includes errors and blind alleys.

RESULTS AND DISCUSSION

The results of the categorization of the texts based on the aforementioned methodological framework are presented in two tables: the Spanish textbooks in Table 5, and the Norwegian textbooks in Table 6, followed by analyses of the results by country.

Spanish textbooks

The history of the classification of the chemical elements in Spanish textbooks is usually a part of the atomic structure unit, running up to two of four pages. Overall, as can be deducted from Table 5, Spanish textbooks lack references to women in the history of the periodic system and the discovery of the elements (I2) and to the failed predictions of Mendeleev (I6). The texts also tend to neglect the differences between Mendeleev's and Meyer's approaches (I5). Meyers system is mostly considered identical to Mendeleev's, but independently made. Those textbooks that mention the difference between Meyer's and Mendeleev's approaches point out that 'Meyer used atomic volume as a criterion for his classification of the chemical elements' (*Santillana* (S2) *1º Bachillerato,* p. 92; *Santillana* **2º** *Bachillerato,* p. 53). Other textbooks present Meyer as 'a less audacious chemist' (*Oxford* (S5) *1º Bach,* p. 97) or Mendeleev as a chemist that 'garnered Meyer's success' (*Oxford 2º Bach.*, p. 59). All of these non-satisfactory mentions neglect the differences in approaches of Mendeleev and Meyer that have been previously indicated, such as the role of prediction or the inclusion of elements with non-established atomic weights.

The historical narratives of the classification of the chemical elements presented in the Spanish textbooks include pre-Mendeleevian proposals (I1). References to

Table 5. Results from categorization of Spanish texts on the history of the periodic system. SM, satisfactory mention; NSM, non-satisfactory mention; NM, no mention.

Level \ Research item	I1	I2	I3	I4	I5	I6	Publisher
CSE3 (*3º ESO*) 14-15 year-old students	NM	NM	NM	**SM**	NM	NM	**S1**
	NSM	NM	**NSM**	NM	NM	NM	**S2**
	NM	NM	**NSM**	NM	NM	NM	**S3**
	NM	NM	NM	NM	NM	NM	**S4**
	NM	NM	NM	NM	NM	NM	**S5**
CSE4 (*4º ESO*) 15-16 year-old students	**NSM**	NM	**NSM**	NM	NM	NM	**S1**
	NM	NM	NM	NM	NM	NM	**S2**
	NM	NM	**NSM**	NM	NM	NM	**S3**
	NM	NM	NM	NM	NM	NM	**S4**
	NSM	NM	**NSM**	NM	NM	NM	**S5**
USE1 (*1º Bachillerato*) 16-17 year-old students	**SM**	NM	NM	**NSM**	NM	NM	**S1**
	SM	NM	NM	**NSM**	**NSM**	NM	**S2**
	NM	NM	**NSM**	NM	NM	NM	**S3**
	NM	NM	NM	**SM**	NM	NM	**S4**
	SM	NM	**SM**	**SM**	**NSM**	NM	**S5**
USE2 (*2º Bachillerato*) 17-18 year-old students	**SM**	NM	**SM**	**SM**	NM	NM	**S1**
	SM	NM	**NSM**	**SM**	**NSM**	NM	**S2**
	NSM	NM	**NSM**	**NM**	NM	NM	**S3**
	SM	NM	**NSM**	**SM**	NM	NM	**S4**
	NSM	NM	**SM**	**SM**	**NSM**	NM	**S5**
Books which mention research items (out of total)	11/20	0/20	12/20	9/20	4/20	0/20	

Döbereiner's triads and Newland's octave law are quite common, especially in upper secondary education textbooks (*Bachillerato/Bach.*). One textbook (*Santillana* (S2) *2º Bach.*) mentions Chancourtois' *vis tellurique* from 1862. The inclusion of a such a helical periodic system may help give nuance to the traditional tale of the periodic system as a table and table only. Likewise, the mention of several contributors before Mendeleev helps to highlight the periodic system as a collective endeavour. That many scientists were involved in its development is explicitly mentioned in one textbook, which indicates that 'the history of the periodic table is a reflection of the work of a large number of scientists and the effort of the scientific community' (*Santillana* (S2) *2º Bach.*, p. 52). The history of the pre-Mendeleev classifications in Spanish textbooks emphasizes the creative and collective NOS.

References to Mendeleev's correct predictions (I3) were also found in Spanish textbooks. These predictions could be interpreted as an opportunity to show chemistry as a dynamic activity instead of a static corpus of knowledge. However, most of the textbooks introduce hagiographical and teleological images of the history of chemistry, which make some of these texts unsatisfactory. Several qualifiers are used to present Mendeleev as a prophet of chemical order. Lower secondary chemistry textbooks, for example, mention Mendeleev's correct predictions as a way to present Mendeleev as a 'genius' (*Santillana* (S2) *3ºESO*, p. 104) or to emphasize 'the boldness of his work' (*Anaya* (S1) *4ºESO*, p. 200) and 'his great intuition' (*Vicens Vives* (S3) *4ºESO*, p.162). In upper secondary chemistry textbooks, Mendeleev's predictions are presented as 'the culmination of his career' (*Vicens Vives* 1º Bach., p. 240), 'a milestone' (*Santillana* 2º Bach., p. 53), 'a great merit' (*Vicens Vives* 2º Bach., p 15.), 'a brilliant confirmation' (*McGraw-Hill* (S4) *2º Bach.* p. 28) and as an example of 'his sagacity' (*Oxford* (S5) *2º Bach.*, p. 58). Textbooks often refer to the discoveries of what Mendeleev had called eka-boron (Sc), eka-silicon (Ge) and eka-aluminium (Ga), which are easy to locate in our current periodic system. One textbook (*Santillana* 2º Bach.) refers to eka-manganese (but using the current name, technetium). Mendeleev's wrong predictions are, however, completely neglected. This adds to the narrative of the periodic system and Mendeleev as a success story. A mention of failed predictions could have contributed to a more critical and less idealized approach of the NOS in science teaching.

Approximately half of Spanish textbooks analysed describe the evolution of the periodic system after Mendeleev's periodic table (I4). References to the contribution of the English physicist Henry Moseley, the Swiss chemist Alfred Werner, the Austrian-born British chemist Friedrich A. Paneth and the American physicist Glenn T. Seaborg have been found in several books. All of these reveal the periodic system as an expanding model shaped by several scientists in different historical contexts. This is a satisfactory NOS conception, which emphasizes tentativeness as an important feature of science. Finally, it should be noted that no significant differences between publishers have been found. Furthermore, more references to the history of the periodic system have been observed in chemistry textbooks for higher levels (USE).

Norwegian textbooks

As noted above, the history of the periodic system is not part of the Norwegian curriculum at any level in school. It is therefore up to the textbook authors and their publishers to include aspects from the history of chemistry if considered useful, and also to select which aspects are relevant. According to the curriculum, the periodic system is to be taught during lower secondary school as part of the integrated science course, but in which year is not specified. Most of the authors responsible for the textbooks at this level have included it in grade 9 (the second year of lower secondary school). A few authors have included a brief introduction of the system in grade 8, and delve more deeply into the topic in grade 9. One textbook presents the periodic system only in grade 8 (N4). Likewise, a few textbooks for the optional chemistry course in upper secondary school describe the periodic system briefly, even though it is not part of the curriculum. But even where the periodic system is explained in these textbooks, the history of the system is not necessarily touched upon. For example, *Kjemien stemmer 1* (N7) includes no history at all, but most of the textbooks mention Mendeleev and a brief history of the system. Some include the mention only in a figure caption, others as part of the main text – usually between a paragraph and a page long (three and a half pages for *Kjemi for lærere*, N8).

Overall, the historical descriptions in the Norwegian textbooks are scarce. No textbook mentions any women in the history of the periodic system (I2), nor do they mention Meyer or any other co-discoverer (I5) or Mendeleev's failed predictions (I6). One textbook from lower secondary school (*Eureka!* 9, N3) and one from upper secondary school (*Kjemi 1*, N5) are the only textbooks hinting that any pre-Mendeleevian history might exist (I1). *Eureka!* 9 simply states that 'many people have contributed to solving this difficult task' (p. 10), while *Kjemi 1* explains that Mendeleev 'combined earlier scientists'

Table 6. Results from categorization of Norwegian texts on the history of the periodic system. SM, satisfactory mention; NSM, non-satisfactory mention; NM, no mention.

Level \ Research item	I1	I2	I3	I4	I5	I6	Book series
CSE8 (*Grade 8*) 13-14 year-old students	NM	NM	NM	NM	NM	NM	**N1**
	NM	NM	NM	NM	NM	NM	**N2**
	NM	NM	NM	NM	NM	NM	**N3**
	NM	NM	**NSM**	NM	NM	NM	**N4**
CSE9 (*Grade 9*) 14-15 year-old students	NM	NM	**NSM**	NM	NM	NM	**N1**
	NM	NM	**NSM**	NM	NM	NM	**N2**
	NSM	NM	NM	**NSM**	NM	NM	**N3**
USE2 (*2^{nd} year of Upper secondary school*) 17-18 year-old students	**NSM**	NM	**NSM**	NM	NM	NM	**N5**
	NM	NM	**NSM**	NM	NM	NM	**N6**
	NM	NM	NM	NM	NM	NM	**N7**
CE (teacher education at college level)	**SM**	NM	**NSM**	**SM**	NM	NM	**N8**
Number of books which mention research items (out of total)	3/11	0/11	6/11	2/11	0/11	0/11	

works into an original and genial system' (figure caption, p. 22). The textbook for teacher trainers (*Kjemi for lærere*, N8) is the only one giving a satisfactory account on the periodic system as a collective effort. In this book Döbereiner's triads are mentioned, as are Odling's groups of elements and the discussion around atomic weight determinations leading up to 1860 (p. 77). But Odling is not credited as co-discoverer of the periodic system. That the system did take different forms is, however, exemplified by Frederick Soddy's spiral system of 1911 (p. 80), giving insight into the many possible ways of organizing the elements periodically, based on the same principles.

The most represented topic among our historical items (in 6 out of 11 books) are Mendeleev's 'correct' predictions (I3). However, none present the predictions as a complex process including trial and error, not even the textbook for teacher trainers, which states:

Mendeelev set aside spaces in the periodic system for new elements which would likely be discovered. He predicted which properties these new elements and their compounds would have, and the predictions later turned out to fit very well (p. 78).

Nova 8 (N4) is more cautious, informing readers that 'most' predictions were successful, not all (p. 102). *Tellus* 9 (N1) adds that the predictions of Mendeleev helped scientists in their 'hunt' for new elements, since the properties of these elements were known. This is how germanium was discovered, the authors state (p. 14).[50] Another book (*Kjemi 1*, N5) gives gallium as an example (p. 22). Two textbooks also include tables comparing Mendeleev's predictions for 'eka-silicon' from 1871 with Clemens Winkler's (1838–1904) descriptions after his discovery of germanium in 1886, to show how good Mendeleev's predictions were (*Kjemi for lærere* (N8), p. 79; a simplified version is presented in *Aqua Kjemi 1* (N6), p. 28). This 'success approach' of the history of the periodic system is in line with traditional, popular accounts of the periodic system of today, which often emphasize linear (Whiggish) history and explain Mendeleev's success on the basis of his predictions.

Only two textbooks mention that Mendeleev's periodic system continued to be developed after his time (I4). *Eureka!* 9 (N3), the textbook for lower secondary school, simply states that '[t]he periodic system has been improved in the course of the last 140 years, but has much in common with the one Mendeleev devised' (p. 10). *Kjemi for lærere* (N8) mentions the problems of accommodating rare earth elements (what we today know as lanthanoids) and how this challenge was solved with the use of the concept of 'atomic number', introduced by H. Moseley in 1913 (p. 79).

Discussion

Even though Norway and Spain represent different teaching contexts, the history of the periodic system presented in textbooks in these countries share some similarities. Both Spanish and Norwegian textbooks neglect the role of the women in the history of the discovery (I2) of the chemical elements and Mendeleev's failed predictions

(I6), not surprisingly perhaps, since these aspects have not been highlighted in international textbooks on history of chemistry at university level either. Nevertheless, this neglect can be interpreted as a missed opportunity to foster an equal and non-hagiographical approach to the history of science in school. In Spanish textbooks, as well as in Norwegian ones, references to the history of the periodic system before Mendeleev (I1) and after his time (I4) can be found. However, Spanish textbooks offer a wider range of references to historical actors and classifications than do the Norwegian textbooks. Such mentions may contribute to a view of science as a collective and creative enterprise. Mendeleev's successful predictions (I3) can be found in Spanish and Norwegian textbooks. However, textbooks tend to address this historical issue unsatisfactorily, if it is mentioned at all. Instead of presenting chemistry as a complex and tentative activity that is always subject to revision, textbooks use Mendeleev's successful predictions merely to present a success story, just as Brush observed in the 1970s. Little or no reference to Meyer's and Mendeleev's different approaches (I5) further adds to the depiction of an individual-centred science and thus neglects to illustrate how several approaches to the same phenomena often coexist in science. The political dimension in the history of the periodic system is also neglected in historical narratives in the chemistry textbooks. Cases such as the controversies around the name or symbol of some elements (like wolfram and tungsten for element 74 or rutherfordium and kurchatovium for element 104) could have been one way of including such aspects.

Even though the periodic system has a natural place in today's chemistry teaching, our analyses have pointed out that authors of current textbooks in Spain and Norway do not take the opportunity to teach about the Nature of Science (Table 7). Of the 31 textbooks that we have analysed, only eight (7/20 in Spain and 1/11 in Norway) refer to post-Mendeleev developments of the periodic system, such as the introduction of the atomic number by Moseley or the reinterpretation of the periodic system based on quantum theory. Seven textbooks (6/20 in Spain and 1/11 in Norway) present the classification of the chemical elements as a collective and creative challenge for several chemists before Mendeleev, while all but three texts (3/20 in Spain and 0/11 in Norway) use Mendeleev's successful predictions as a way to emphasize his role as a 'hero of chemistry'. Using the SOURCE approach, we can draw the conclusion that these historical narratives do paint an image of science as a process (S) with uncertainties (U) and developed in a historical context (R), not just as a corpus of knowledge (science as a product). However, the other parts of SOURCE (O, C, E) are neglected (Table 7). As Brush predicted many years ago, textbook authors prefer to present science as a work of bright and successful men. Nothing could be further from the stories presented by historians of science and NOS scholars in science education.

Table 7. SOURCE approach applied to Norwegian and Spanish textbook analysis. SM, satisfactory mention; NSM, non-satisfactory mention; NM, no mention.

Research item	SM	NSM	NM	NOS implication
I1	7	7	17	**S**cience-in-the-making and science-made combined
I2	0	0	31	**O**verinflated genius
I3	3	15	13	**U**nqualified universality and uncertainties
I4	8	3	20	**R**espect for the historical context
I5	0	4	27	**C**aricature and **C**ontroversies unattended
I6	0	0	31	**E**xpected results and Excuses – **E**rror dimension missed

CONCLUSION

In this essay, we have explored the extent to which the history of the periodic system is presented in recent textbooks, and which aspects of the nature of science can be taught based on historical narratives of the periodic system. Our analyses have pointed out that textbooks in Spain and Norway (though to various extents) introduce three historical contexts: developments before Mendeleev's periodic system, in Mendeleev's time and after his contributions. These aspects, if sufficiently described, may contribute to a portrayal of science as a creative endeavour based on a collective effort. However, the textbooks in our samples seem to miss the opportunity to give a fuller picture through references to women discoverers of chemical elements and to Mendeleev's failed predictions. We may argue that the way the historical narratives are presented in these textbooks contributes to masking the tentative and socio-cultural aspects of NOS as a human endeavour. Likewise, textbooks in Spain and Norway tends to be less concerned with the differences between Meyer's and Mendeleev's approaches, losing an opportunity to show the diversity in NOS – that scientists use different methods to achieve the same goal.

The history of the periodic system offers a wide range of possibilities for teaching chemistry – if teachers, textbook authors and publishers are willing to use it. The textbooks in our sample explore only a few of these possibilities. We argue that the uses of the history of the periodic system in textbooks for secondary school could be explored further by introducing women as well as men, and errors as well as successes – as Allchin has argued. Finally, it should be noted that rather than aspiring to present a complete and exhaustive history of the classification of the chemical elements at any level in school, textbooks should instead adjust the content to specific teaching contexts and curricula, and introduce small changes which could contribute to a more nuanced image of science. Hence, the history of the periodic system has the potential to endow science teaching with a collective, creative, diverse, tentative and inclusive portrayal of chemistry. To this end, world-wide initiatives such as the International Year of the Periodic Table can help to bring less well-known aspects and recent scholarship to the fore, for the benefit of young people, their teachers and the general public.

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51. Publications such as the forthcoming volume in women and elements (ref. 42) may contribute to make women's contributions more visible in the future.

APPENDIX: TEXTBOOK SAMPLES

Norwegian textbooks

(N1) P. R. Ekeland, O-I Johansen, S. B. Strand, O. Rygh & A-B Jenssen, *Tellus: Naturfag for ungdomstrinnet,* **2007,** Aschehoug, Oslo.
(N2) H. S. Finstad, E. C. Jørgensen & J. Kolderup, *Trigger,* **2008**, Damm, Oslo.
(N3) M. Frøyland, J. Haugan & M. Munkvik *Eureka! Naturfag for ungdomstrinnet*, **2006**, Gyldendal undervisning, Oslo.
(N4) E. Steineger & A. Wahl, *Nova: Naturfag for ungdomstrinnet*, **2014**, Cappelen Damm, Oslo.
(N5) H. Brandt & O. T. Hushovd, *Kjemi 1*, **2010**, Aschehoug, Oslo.
(N6) B.-G. Steen, N. Fimland & L. A. Juel, *Aqua1: Kjemi 1 Grunnbok*, **2010**, Gyldendal undervisning, Oslo.
(N7) T. Grønneberg, M. Hannisdal, B. Pedersen & V. Ringnes, *Kjemien stemmer 1,* **2012**, Cappelen Damm, Oslo.
(N8) M. Hannisdal & V. Ringnes, *Kjemi for lærere,* 2nd ed., **2013**, Gyldendal akademisk, Oslo.

Spanish textbooks

CSE-3 (*3º ESO*)

(S1) S. Zubiaurre, A. M. Morales, J. M. Arsuaga & A. Pérez, *Física y Química 3. Educación Secundaria*, **2011**, Anaya, Madrid.
(S2) M. C. Vidal-Fernández, F. Prada, J. L. García & P. Sanz Martínez, *Física y Química 3. ESO: Proyecto Los Caminos del Saber*, **2011**, Santillana, Madrid.
(S3) À. Fontanet & M. J. Martínez, *Física y Química 3. Educación Secundaria: Proyecto Nuevo Ergio*, **2012**, Vicens Vives, Barcelona.
(S4) A. Peña, A. Pozas, J. A. García-Pérez, A. Rodríguez & A. J. Vasco, *Física y Química 3. ESO*, **2007**, McGraw-Hill, Barcelona.
(S5) I. Piñar-Gallardo, *Física y Química 3. ESO: Proyecto Adarve*, **2011**, Oxford, Madrid.

CSE-4 (*4º ESO*)

(S1) S. Zubiaurre, A. M. Morales, F. Gálvez & I. Molina, *Física y Química 4. Educación Secundaria*, **2012**, Anaya, Madrid.
(S2) M. C. Vidal-Fernández, F. Prada, J. L. García & P. Sanz-Martínez, *Física y Química 4. ESO: Proyecto Los Caminos del Saber*, **2011**, Santillana, Madrid.

(S3) À. Fontanet & M. J. Martínez, *Física y Química 3. Educación Secundaria: Proyecto Nuevo Ergio*, **2012**, Vicens Vives, Barcelona.
(S4) A. Cardona, J. A. García, A. Peña, A. Pozas & A.J. Vasco, *Física y Química 4. ESO*, **2008**, McGraw-Hill, Madrid.
(S5) I. Piñar-Gallardo, *Física y Química 4. ESO: Proyecto Adarve*, **2012**, Oxford, Madrid.

USE-1 (*1º Bachillerato)*

(S1) S. Zubiaurre, J. M. Arsuaga, J. Moreno & B. Garzón, *Física y Química 1. Bachillerato*, **2014**, Anaya, Madrid.
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(S5) M. Ballestero & J. Barrio, *Física y Química 1. Bachillerato: Proyecto Tesela*, **2008**, Oxford, Navarra.

USE-2 (*2º Bachillerato)*

(S1) S. Zubiaurre, J. M. Arsuaga & B. Garzón, *Química 2. Bachillerato*, **2012**, Anaya, Madrid.
(S2) C. Guardia, A. I. Menéndez-Hurtado & P. Prada, *Química 2. Bachillerato: Proyecto La Casa del Saber*, **2011**, Santillana, Madrid.
(S3) À. Fontanet, *Química 2. Bachillerato*, **2014**, Vicens Vives, Barcelona.
(S4) A. Pozas, R. Martín, A. Rodríguez & A. Ruiz, *Química 2. Bachillerato*, **2009**, McGraw-Hill, Madrid.
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