The social semiotic construction of chemical periodicity: A multimodal view*

YU LIU and AYLANDA DWI-NUGROHO

Abstract

Chemical periodicity is widely recognized as one fundamental idea in science and much of the existing research attempts to discover one periodic table most accurately depicting the natural order. This article adopts a multimodal perspective on the periodic system by analyzing its historical evolution and the constructed nature of periodic tables. The analysis indicates that chemical periodicity was culturally shaped as specialized functionalities for classifying elements by their similar chemical behaviors. We argue that tabular representations have powerful yet constrained modal affordances to interpret scientific phenomena and that social semiotics provides a preliminary meta-language for teaching and learning chemical periodicity.

Keywords: *chemical periodicity; periodic table; multimodality; social semiotics; grammar; modal affordances*

1. Introduction

Science is strongly characterized by its integrated use of multiple channels of communication in which visualization plays a vital role in representing abstractions (Gilbert 2005). Among all the scientific visual displays, the periodic table in chemistry seems to have special status as an icon due to its significance in both professional research and science education. On the one hand, scientists were able to make spectacular chemical discoveries based on the periodic table instead of empirical laboratory work, as evidenced by Mendeleev's successful predictions of the existence and the properties of new elements including germanium, gallium, and scandium (Scerri 2007). On the other hand, in science education context, the periodic table is such an important curriculum component that it occupies one whole unit of chemistry textbooks (e.g., Onn et al. 2006).

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The central role of the periodic table in chemistry has attracted considerable attention from scientists (e.g., Kibler 2007), philosophers (e.g., Scerri 2007), and educationalists (e.g., Jensen 2003). Despite their different research backgrounds, these scholars generally regard chemical periodicity as a matter of fact and attempt to discover one periodic table whose grouping of the elements can best reflect the natural order. Closely related to this view is the dominance of the "rhetoric of conclusions" (Schwab, cited in Erduran 2007: 249) in chemistry classrooms, where students are taught a collection of facts about the periodic system, but not how the knowledge is constructed.

Taking for granted the absolute truth of chemical periodicity, however, might not contribute to "science as inquiry," which emphasizes development, evaluation, and revision of current theories, models, and explanations about the natural world (Erduran 2007: 248). Furthermore, the lack of a systematic semiotic account of periodic tables poses a serious challenge to the development of students' "multiliteracies" (Cope and Kalantzis 2000; Unsworth 2001), which are shaped through an orchestration of verbal, visual, symbolic, and other modalities. Given that periodic tables have a specialized visual design and do not make transparent meaning, it will be very difficult for young learners to acquire chemical periodicity based on their everyday sensory experience.

In an attempt to bridge these research gaps, the present study makes a social semiotic analysis of chemical periodicity. The argumentation is organized as follows. First, we introduce the relevant key tenets of social semiotics before discussing the historical evolution of the periodic system. Second, drawing on O'Toole's (1994) grammatical model of displayed art, we suggest a framework for analyzing tabular representations. We then investigate what meanings are made in one copy of periodic table taken from a recently published science textbook for Singapore's junior secondary school students (Onn et al. 2006). Finally, we critically demonstrate that tabular forms have limited meaning potentials to arrange elements with similar chemical properties.

2. Social semiotic approach

Social semiotics is the study of sign systems where each choice is not an isolated entity in itself but acquires its meaning against the background of other signs in the context of specific social situations (Halliday 1978; Halliday and Hasan 1985). Earlier social semiotic research concentrates on the sign system of language and is known as systemic functional grammar (hereinafter SFG, see Halliday 1994 [1985]). As Halliday and Matthiessen (1999: 17) point out, social semiotics adopts a constructivist view of language. This means, in contrast to the realist attitude that there is a preexisting objective truth in the outside world and that scientific discourse is just a passive reflection; Social semiotic research regards language as a powerful meaning-making resource to construe realities.

SFG is centrally concerned with how the organization of language is related to its use in social context (Martin 1997: 4). Social context and language are modeled as two complementary semiotic systems, which constitute each other at different levels of abstraction while their mutual determination is probabilistic rather than categorical. On the one hand, a particular context makes predictions that some semantic patterns are more likely than others to be selected for linguistic construction; on the other hand, language patterns at a more concrete level play an important role in determining the social context. In this way, language construes, is construed by and over time re-construes social context (Martin 1999: 35). Moreover, social semiotics adopts a meaning-based approach to scientific literacy. That is to say, scientific knowledge is interpreted as semantic patterns realized through the organization of lexicogrammatical[1] resources (Halliday and Matthiessen 1999: x). For instance, a scientific interpretation of material phenomena (e.g., iron rust) can be made through the use of a technical term "iron (III) oxide," which contributes to specialized meaning beyond the reach of natural human senses.

Apart from language, other representational systems are also conceptualized as semiotic resources shaped by the social context to fulfill three metafunctions[2] at the same time (Baldry and Thibault 2006; Kress et al. 2001; Lemke 1998): to construct a presentation of "goings-on" in the world (ideational meaning), to take a stance towards the presentation and to the reader/viewer (interpersonal meaning), and to organize related elements into a coherent message (textual meaning). Pioneering social semiotic studies have investigated how experience is modeled in the grammar of displayed art (O'Toole 1994), visual design (Kress and van Leeuwen 2006 [1996]), mathematical images and symbolism (O'Halloran 2005), and action (Martinec 1998), to name just a few. From a multimodal perspective, the notion of grammar is not confined to a system of formal linguistic rules of correctness, but refers loosely to "the structures of relations of elements in a specific mode, and between modes"[3] (Kress et al. 2001: 12).

The social semiotic modeling of context and grammar provides a dialectic approach to the nature of chemical periodicity. In the following section, we review the historical evolution of chemical periodicity to explain what functionalities of the periodic system were conditioned by the social context. Then we make a grammatical analysis of one instance of periodic tables to reveal how those functionalities are fulfilled through specialized grammatical strategies. It is important to note that adoption of both contextual and grammatical analyses of the periodic system sheds light on their mutual construal and reconstrual relations.

3. The genesis of periodic tables

There are popular legends that Mendeleev mysteriously conceived chemical periodicity in the course of a dream or playing cards. While recognizing Mendeleev as the champion of the periodic system, historians and philosophers (e.g., Brock 1993; Scerri 2007) attributed the genesis of periodic tables to strenuous research undertaken by generations of scientists. According to Scerri (2007: 4), the theoretical origin of chemical periodicity might be dated back to the late eighteenth century when Lavoisier proposed the empirical view of elements as simple substances rather than abstract primary matter. Lavoisier's anti-metaphysical theory of elements laid the foundations of modern chemistry and provided a new principle to systemize the chemical nomenclature (Brock 1993: 114–116). For example, "oil of vitriol" was renamed as "sulfuric acid" to reflect the elemental composition. From a social semiotic view, the change of chemicals' names is not merely a process of "rewording," but involves the re-construal of experience from folk chemistry to scientific taxonomy (Halliday and Martin 1993).

Dalton further developed Lavoisier's theory by hypothesizing that different elements have their own atoms, and there exists no unity of all matter (Scerri 2007: 34). Meanwhile, following Lavoisier's famous law of conservation of matter and drawing on Richter's research on elements' equivalent weights, Dalton managed to measure the values of relative atomic weights and identified them as a bridge between the realm of unobservable atoms and the world of observable properties (Brock 1993: 135). The measurement of relative atomic weights significantly paved the way for a new ordering of elements because atomic mass, which is beyond the reach of bodily senses, constitutes the crucial criterion for scientific taxonomies.

When quantification of chemistry became increasingly important in the nineteenth century, scientists began to discover interesting numerical relationships between elements with similar chemical properties. For example, Döbereiner found the triads among the halogen elements in 1829, and Newlands proposed the law of octaves in 1865 (Scerri 2007). However, chemical periodicity had largely been regarded as a fanciful coincidence until it was theoretically justified as a scientific law by Mendeleev. Mendeleev fully recognized that relative atomic weights were the only unchanged attribute in chemical reactions and thus should be taken as the fundamental principle in the classification of elements (Scerri 2007: 105). When chemists improved the accuracy of relative atomic weights and used the novel technique of spectroscopy to discern elements, research on chemical periodicity gained the explosive development in the 1860s. Finally, Mendeleev produced a relatively mature periodic table that was powerful not only to accommodate the discovered elements but also make successful predictions of unknown substances.

The preceding historical account indicates that the birth of the periodic table underwent three stages from Lavoisier to Mendeleev. At the first stage, Lavoisier's empirical view of elements provided a new principle to classify chemical compounds. Thus the effervescence of vernacular names was considerably reduced to a definite set of technical terms. At the second stage, Dalton's theory of atoms stepped further to classify elements by their relative atomic weights, which implied that elements were essentially characterized by their submicroscopic attributes of quantity. At the third stage, Mendeleev made at least two crucial contributions to building the scientific taxonomy of elements. First, he explicitly attributed the nature of elements to relative atomic weights, and theoretically clarified the classificatory principle of the periodic table for the first time (Scerri 2007). Furthermore, while Dalton mainly used relative atomic weights to distinguish between elements and explain their different chemical behaviors, Mendeleev linked certain elements together based on the numerical relations of their atomic weights to explain their similar properties.

Through the three-staged evolution, chemical periodicity was culturally shaped as social functionalities for classifying elements by their respective atomic mass to explain their similar chemical properties. However, these functionalities seem to outstrip the meaning potential of language. As Kress et al. (2001: 16) note, communicative modes have unique modal affordances or different functional specialization, and no single modality can make all the meaning needed in scientific communication. For example, language, especially spoken language, possesses the logic of time, and thus is good at putting things in a sequence (e.g., telling a narrative). By contrast, visual design, which possesses the logic of space and simultaneity, is more powerful than language to classify a large number of chemical elements in an economical and unambiguous way.

In addition, when relative atomic weights became the crucial criterion to classify chemical elements, scientists needed a semiotic resource to describe their quantitative patterns. However, compared with mathematical symbolism, language is much poorer to construe the semantic realm of quantity (O'Halloran 2005). It therefore follows that chemical periodicity needs to be modeled as multimodal (rather than pure linguistic) representations through specialized grammatical resources.

4. The grammar of periodic tables

Tabular representations play a crucial role in scientific discourse (Baldry and Thibault 2006; Guo 2004; Lemke 1998). In fact, Lavoisier's chemical nomenclature, Dalton's atomic theory and Mendeleev's periodic system all took the form of tables (Scerri 2007). As Halliday (1994 [1985]: 15; Halliday and

Martin 1993: 12) points out, grammar is the powerhouse to produce meaning and construe knowledge. The present section proposes a systemic functional (hereinafter SF) framework to analyze visual grammar in scientific tables and explore how chemical periodicity is realized through the multimodal construction of tabular modes.

4.1. *SF framework for scientific tables*

Social semiotic research on visual grammar is best exemplified by O'Toole's (1994) analysis of displayed art and Kress and van Leeuwen's (2006 [1996]) account of visual design. Both demonstrate that similar to language, images are powerful semiotic resources to construe ideational, interpersonal, and textual meaning. Hence, meta-functions constitute the first key dimension in the following grammatical analysis of scientific tables.

Moreover, drawing on Halliday's (1994 [1985]) hierarchical typology of linguistic units[4], O'Toole (1994) proposes an explicit system of rank scales including Work, Episode, Figure, and Member to investigate the structural organization of visual displays. The notion of rank scale is important for analyzing tabular modes in scientific discourse where the basic constituent unit is a cell. Cells in the form of a square or rectangle could be welded with each other in geometrical patterns such as rows and columns (Kress and van Leeuwen 2006 [1996]: 54), and different grouping of cells represents different levels of generality in scientific taxonomies. In this way, O'Toole's (1994) rank-based visual analysis provides a preliminary but productive approach to the classificatory hierarchy in scientific tables.

Although O'Toole's (1994) original framework was suggested to analyze the visual grammar of displayed art, its applicability in scientific discourse can be justified because historically humanities and science have had major engagement with each other in visual design (Davis, cited in O'Halloran 1996: 160). In fact, preliminary studies have been made to extend O'Toole's (1994) model to analyze specialized visual displays in mathematics (O'Halloran 1996, 2005), biology (Guo 2004), and chemistry (Liu 2011; Liu and Owyong 2011).

In particular, Guo (2004) suggests an SF framework to analyze numerical tables in which the main tabular body is examined at the ranks of Table and Cell. Although his research sheds light on the meaning potential of tabular modes, a two-level grammatical analysis might not sufficiently explicate the complex visual design of the periodic table, considering that the scientific knowledge of chemical periodicity is characterized by deep taxonomies (Eggins 2004 [1994]: 107). To make an adequate account of the periodic system, the present study proposes Table, Episode, Cell, and Part as four basic constituent ranks down the scale in tabular forms.

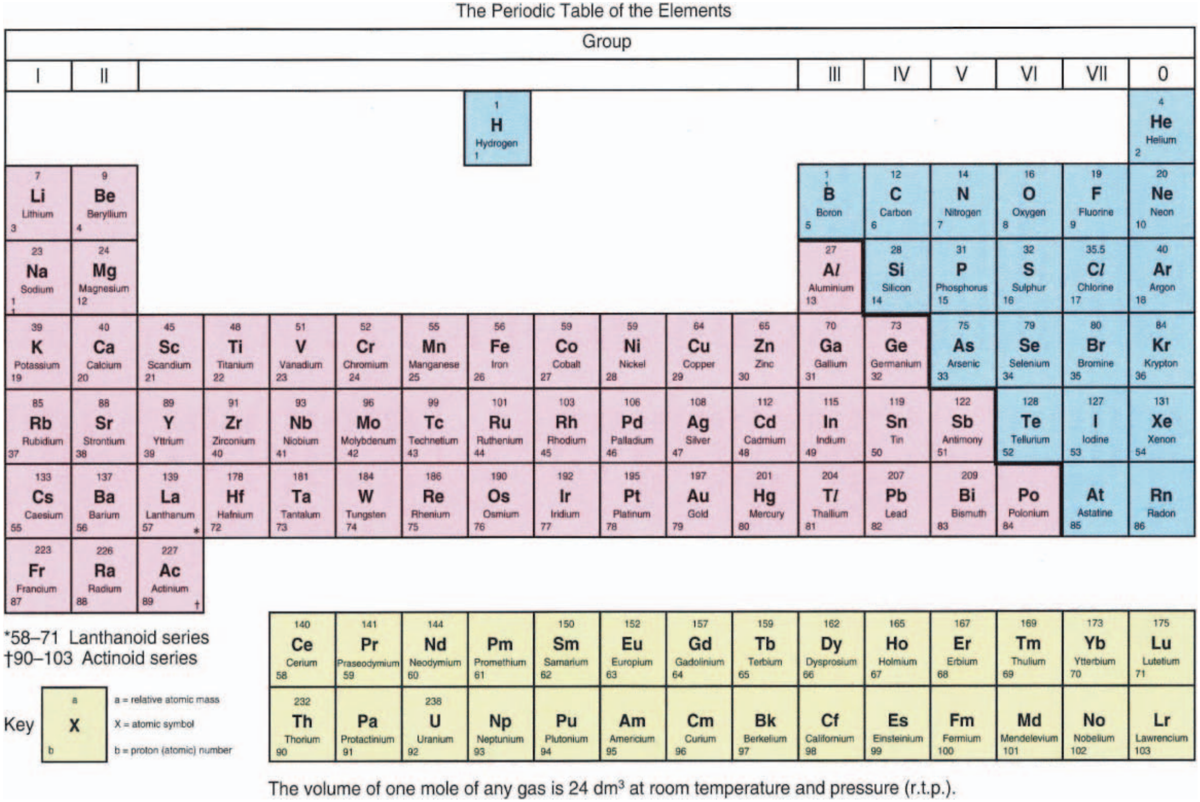
Table 1. *Functions and systems for analyzing scientific tables* (based on O'Halloran 1996: 161)

Ranks	Meta-functions		
	Representational	Modal	Compositional
Table	– Macroscopic meaning – Submicroscopic meaning – Interplays of Episodes	– Color – Reading Path – Metaphorical Narrative – Line Width, Shading, Line Solidarity, Slope, Arrows – Framing – Rhythm – Labeling – Modality	– Gestalt: Framing, Horizontals, Verticals and Diagonals – Perspective (2D, 3D) – Cohesion (e.g., Ellipsis, Parallelism, Contrast)
Episode	– Interplay of Actions – Taxonomic Relations	– Relative Prominence (e.g., Size, Color, Labeling, Framing)	– Alignment – Line
Cell	– Participants	– Prominence of Individual Cells (e.g., Position, Size, Color, Labeling, Framing)	– Inter-semiotic Adoption – Labeling of Cell
Part	– Title – Labels – Numbers	– Conventionalization – Stylization	– Textual Markedness (e.g., Font, Color, Size)

To be consistent with the existing rank-based SF research on visual displays (e.g., O'Toole 1994; O'Halloran 1996, 2005; Guo 2004), our grammatical analysis of tabular modes adopts O'Toole's (1994) terms of "Representational meaning," "Modal meaning," and "Compositional meaning," which correspond to "ideational meaning," "interpersonal meaning," and "textual meaning" respectively (Halliday 1994 [1985]). Also following O'Toole (1994), the first letter of the ranks, functions, and systems for scientific tables is capitalized in the present study. The proposed analytical framework is shown in Table 1.

4.2. *Grammatical construction of the periodic table*

It is important to note that periodic tables take a wide range of different forms such as the medium-long form and the long form, and they do not share a unified labeling manner (Scerri 2007: 11). Although all those periodic tables can be selected for analysis with the SF semiotic framework in Table 1, the present section only focuses on one periodic table in the medium-long form (see Figure 1), which is being widely used in Singapore's secondary school science classrooms. Singapore has a high reputation for successful mathematics and science education where textbooks are mainly used as the primary teaching resource



The Periodic Table of the Elements

Group																	
I	II											III	IV	V	VI	VII	0
							1 H Hydrogen 1										4 He Helium 2
7 Li Lithium 3	9 Be Beryllium 4											11 B Boron 5	12 C Carbon 6	14 N Nitrogen 7	16 O Oxygen 8	19 F Fluorine 9	20 Ne Neon 10
23 Na Sodium 11	24 Mg Magnesium 12											27 Al Aluminium 13	28 Si Silicon 14	31 P Phosphorus 15	32 S Sulphur 16	35.5 Cl Chlorine 17	40 Ar Argon 18
39 K Potassium 19	40 Ca Calcium 20	45 Sc Scandium 21	48 Ti Titanium 22	51 V Vanadium 23	52 Cr Chromium 24	55 Mn Manganese 25	56 Fe Iron 26	59 Co Cobalt 27	59 Ni Nickel 28	64 Cu Copper 29	65 Zn Zinc 30	70 Ga Gallium 31	73 Ge Germanium 32	75 As Arsenic 33	79 Se Selenium 34	80 Br Bromine 35	84 Kr Krypton 36
85 Rb Rubidium 37	88 Sr Strontium 38	89 Y Yttrium 39	91 Zr Zirconium 40	93 Nb Niobium 41	96 Mo Molybdenum 42	99 Tc Technetium 43	101 Ru Ruthenium 44	103 Rh Rhodium 45	106 Pd Palladium 46	108 Ag Silver 47	112 Cd Cadmium 48	115 In Indium 49	119 Sn Tin 50	122 Sb Antimony 51	128 Te Tellurium 52	127 I Iodine 53	131 Xe Xenon 54
133 Cs Caesium 55	137 Ba Barium 56	139 La Lanthanum 57 *	178 Hf Hafnium 72	181 Ta Tantalum 73	184 W Tungsten 74	186 Re Rhenium 75	190 Os Osmium 76	192 Ir Iridium 77	195 Pt Platinum 78	197 Au Gold 79	201 Hg Mercury 80	204 Tl Thallium 81	207 Pb Lead 82	209 Bi Bismuth 83	Po Polonium 84	At Astatine 85	Rn Radon 86
223 Fr Francium 87	226 Ra Radium 88	227 Ac Actinium 89 †															

*58–71 Lanthanoid series
†90–103 Actinoid series

140 Ce Cerium 58	141 Pr Praseodymium 59	144 Nd Neodymium 60	Pm Promethium 61	150 Sm Samarium 62	152 Eu Europium 63	157 Gd Gadolinium 64	159 Tb Terbium 65	162 Dy Dysprosium 66	165 Ho Holmium 67	167 Er Erbium 68	169 Tm Thulium 69	173 Yb Ytterbium 70	175 Lu Lutetium 71
232 Th Thorium 90	Pa Protactinium 91	238 U Uranium 92	Np Neptunium 93	Pu Plutonium 94	Am Americium 95	Cm Curium 96	Bk Berkelium 97	Cf Californium 98	Es Einsteinium 99	Fm Fermium 100	Md Mendelevium 101	No Nobelium 102	Lr Lawrencium 103

Key

a = relative atomic mass
X = atomic symbol
b = proton (atomic) number

The volume of one mole of any gas is 24 dm^3 at room temperature and pressure (r.t.p.).

Figure 1. *The periodic table of chemical elements (reproduced from Onn et al. 2006: 225)*

(Mullis et al. 2004). Thus, a detailed grammatical analysis of one copy of periodic table from an approved science textbook for junior secondary students (Onn et al. 2006: 225) will suffice to explore how multiple semiotic resources (i.e., language, visual design, and symbolism) are combined to shape the curriculum content of chemical periodicity for novice learners.

Also noteworthy is that the selected copy of periodic table only presents one of many different interpretations of chemical periodicity, and this research does not claim that the multi-semiotic design of Figure 1 is the perfect or the best representation. On the contrary, both its strong points and limitations can be made explicit through an SF grammatical analysis. Furthermore, the following social semiotic account of Figure 1 assumes the reading position of the designers rather than that of the young pupils who are learning chemical periodicity. We fully acknowledge the significance of research on novices' different readings of the periodic table in situated use and do not imply that there should be only one kind of interpretation of Figure 1. However, drawing on the research approach of Bezemer and Kress, the present study considers Figure 1 to be the designers' specific multimodal shaping of chemical periodicity and focuses on its meaning potentials which "allow an unlimited (in number) yet constrained (in semantic scope) number of readings" (Bezemer and Kress 2008: 171). Admittedly, Figure 1 is quite different from Mendeleev's first published periodic table in 1869. Seen from a social semiotic perspective (Martin 1997), the changed multimodal design indicates that the social context of chemical periodicity has been re-construed after about one hundred and forty years of theoretical development.

4.2.1. *Analysis of the rank of Table.* Modally, the periodic table presents a "Metaphorical Narrative" (O'Halloran 1996: 164) where the Episode of metals complements the Episode of nonmetals. This narrative draws the viewers' attention through the Prominence of Individual Episodes, especially through the choice of Color. For example, the Color red (in the original) in addition to the largest Size and central Position most likely makes viewers engage with the Episode of metals immediately even when they have a casual look at the periodic table. Furthermore, the interaction between the Episodes of metals and nonmetals is marked through the choice of Line Width. Significantly, the weighted Staircase line constitutes a Diagonal axis. As Diagonals are Compositional resources to cause tensions (O'Toole 1994: 23), a narrative is created between the Episodes of metals and nonmetals. Further to this, the Staircase line indicates a left-to-right direction and thus suggests a particular Reading Path for viewers.

Compared with metals and nonmetals, the two rows of elements labeled lanthanoid and actinoid series are less prominent in terms of the Modal meta-function and constitute the examples of "Minor Episodes" (O'Halloran 2005: 140). For example, they take up relatively smaller space and are represented in less eye-catching Color (in the original). Also, the two Episodes' less central Position and separation from metals and nonmetals considerably reduce their Prominence.

While Color modally marks the two main Episodes of metals and nonmetals in the periodic table, other Compositional and Modal systems operate for a different organization of Episodes. With regard to the grammatical resource of Gestalt, Horizontals and Verticals are dominant at the rank of Table, both of which contribute to a stable and harmonious Rhythm (O'Toole 1994: 23). Furthermore, Verticals attract more attention than Horizontals because the former are framed with headers above and labeled "Group." That is to say, each of the sixteen columns constitutes an Episode of Group, and eight of them gain Prominence of Individual Episodes through the Labeling of Roman numerals from I to VII and zero. The ascending order of the Roman numerals also denotes a Reading Path from the left to the right. The Episodes of Group are vertically parallel to each other and this compositional pattern suggests a stable interrelation between the sixteen Groups. By contrast, the Staircase line between metals and nonmetals creates a dynamic Interplay between the two Episodes.

Horizontals, despite the lack of Labeling in Figure 1, constitute another chemically significant unit in the periodic table and each of the seven rows represents a Period. It is important to note that the intersection of Horizontals and Verticals at the rank of Table bears a resemblance to a Cartesian coordinate. So each element gains two semantic values simultaneously like an ordered pair. For instance, the element of oxygen is assigned two coordinate values: Period 2 and Group VI.

If trans-coded into full linguistic clauses (e.g., *the element of oxygen is in Group VI and Period 2*), description of over one hundred elements in the periodic table will turn into many pages. As Baldry and Thibault observe, "tables show a high degree of thematic-semantic condensation in which the principle of ellipsis is carried to the extreme" (Baldry and Thibault 2006: 64). It seems that tabular modes develop powerful Compositional resources such as Horizontals and Verticals to maximally condense the meaning, which is not possible by using language. Also noteworthy is that the Spatial Position of an element in the periodic table is implicitly connected to the Representational meaning. For instance, the Spatial Position of oxygen (i.e., Period 2 and Group VI) implies that an oxygen atom has two electron shells and six valency electrons. This knowledge is crucial to explain the chemical behaviors of oxygen.

The semantic values assigned to Horizontal and Vertical axes at the rank of Table also indicate the experiential re-construal of chemical periodicity. Given that the Group number is determined by the number of valency electrons and the Period number by that of electron shells (Onn et al. 2006: 226–227), the modern periodic table attributes the nature of chemical properties to elements' electronic configurations rather than their relative atomic mass suggested by Mendeleev in the nineteenth century. In this sense, the social context of periodicity has been re-construed in the past one hundred and forty years.

Similar to relative atomic weights, electronic configurations are not accessible to human bodily senses and thereby construe scientific realities only recognizable by those with disciplinary knowledge. By contrast, the Episodes of metals and nonmetals are classified on the basis of both physical and chemical properties. For instance, metals differ from nonmetals not only in terms of observable features such as whether they are hard and shiny in appearance, but also in terms of imperceptible characteristics including whether they tend to lose electrons to form positively charged ions (Onn et al. 2006: 242).

Thus seen from the perspective of semantics, submicroscopic meaning is the sole criterion to classify the Episodes of Group whereas both macroscopic meaning and submicroscopic meaning need to be considered to distinguish the Episode of metals from that of nonmetals.[5] These different semantic orientations further complicate the Interplays of Episodes at the rank of Table. In fact, Figure 1 houses three kinds of Interplays of Episodes. The first are the Interplays between the Episodes of metals and those of nonmetals, and the second are those among the sixteen Episodes of Group. The third are the Interplays between the Episodes of metals and nonmetals and those Episodes of Group. One instance of the last kind is the Interplay between the four Episodes of Group (i.e., from Group III to Group VI) and the Episodes of metal and nonmetals, as marked by the Staircase line and the contrast of Color. It is important to note that none of those four Groups can be classified as metals or nonmetals. To illustrate, the elements of carbon, silicon, germanium, tin, and lead are members of Group IV because all of them share the valence of four and have similar chemical properties. However, regarding macroscopic physical properties, carbon is identified as an element of nonmetals whereas tin and lead are prototypical metals.

The third type of Interplay indicates that despite some overlapping (e.g., the Episode of metals comprises the Episode of Group II), the Episode of Group should not be viewed as a lower constituent rank of the Episode of metals or that of nonmetals, because there is no hierarchical exhaustiveness (Halliday 1994 [1985]: 12) between them. On the contrary, the Episodes of metals and nonmetals coexist with the Episodes of Group at the same level in the periodic table. They share a co-equal structural status but contribute to different meaning.

As for visual Modality (O'Toole 1994), the periodic table construes a high degree of scientific truth. Like mathematical visual images (O'Halloran 2005: 141), the truth-value of scientific tables does not rest on the correspondence between the representation and the perceptible reality but is culturally and historically determined. Given that submicroscopic meaning (e.g., the atomic number) is dominant in the periodic system, a maximal truth-value is accorded at the rank of Table.

4.2.2. *Analysis of the rank of Episode.* Individual Episodes gain Relative Prominence through Modal systems. As discussed earlier, the Color red and its largest Size highlight the Episode of metals while the Episodes of Group attract the viewers' attention via Framing and Labeling. However, all the Episodes in the periodic table share similar internal organization of Cells, which are aligned together, yet remain distinct components of the whole. In other words, while the compounding of different Cells in an Episode shows their close relationship, the Line between the neighbor Cells highlights their separate identities.

The relations between chemical elements remain a crucial issue in the periodic system, which was intensely debated between its two most renowned co-discoverers. Mendeleev emphasized the separateness of individual elements; conversely, Meyer strongly believed in the existence of primary matter among all the elements (Scerri 2007: 183). In fact, Meyer once arranged chemical elements in the form of a cylindrical helix to represent his idea of chemical periodicity (Stewart 2007: 237). From the perspective of visual grammar, the curves in Meyer's helical image compositionally constitute vectors (Kress and van Leeuwen 2006 [1996]: 70–71), which symbolize directionality and movement, and thus suggest the possible transmutation between the elements. However, no vectors exist between the elements of each Group in Figure 1, where Cells of equal size are welded together to form different Episodes of Group in a "mechanical, technological order" (Kress and van Leeuwen 2006 [1996]: 54). Through the system of Alignment between Cells, Figure 1 makes significant Compositional meaning to support Mendeleev's belief in the individuality of the elements.

Another important Inter-Cell relation is the construal of Taxonomy at the rank of Episode. Martin and Rose (2007 [2003]: 81–82) formulate four main types of Taxonomic Relations in linguistic texts. However, it seems that neither repetition nor synonymy occurs in the periodic table. Although chemical elements such as lithium and sodium share similar chemical properties, they are not considered synonyms because they do not possess the same electronic configuration, which determines the significant Representational meaning in chemical discourse (Darányi 2000: 229). Contracted Taxonomic Relations at the rank of Episode are useful to reduce semantic redundancy in chemistry and thus construe scientific realities in an economical and unambiguous manner.

The only Taxonomic Relation prevalent at the rank of Episode is the relation of class to member, which exists in both the Episodes of Group and those of metals and nonmetals. For instance, fluorine and iodine are subordinate members of Group VII as halogens. Likewise, sodium and iron are subordinate members of metals. Apart from the co-class relation, Cells in each Episode of Group also have the taxonomic relation of contrast, which is, however, not available in the Episode of metals or that of nonmetals.

As Cells in the Episodes of Group are organized into seven Periods, then the elements with similar chemical properties are arranged subsequently in cycles. It might be argued that there is no prototypical sense of periodicity in each Episode of Group considering that the neighbor Cells do not share regular intervals in terms of the atomic number. For instance, the inter-Cell interval of noble gas is 8, 8, 18, 18, and 32 in the Episode of Group 0. However, such irregularity could be dissolved if the intervals are conceived according to the number of Periods or that of electron shells. In this way, there is a regular interval of one Period or one electron shell between the neighbor Cells in each Episode of Group.

4.2.3. *Analysis of the ranks of Cell and Part.* Despite being a powerful meaning-making resource, visuals are far from the sole modality to construe chemical periodicity. On the contrary, the periodic table is a multi-semiotic ensemble, especially at the rank of Cell, which consists of linguistic names for the element, visual squares, chemical symbols as well as mathematical symbols (i.e., the atomic mass and the atomic number). Through the mechanism of Inter-semiotic Adoption,[6] different semiotic resources operate with each other and are integrated as a single textual phenomenon.

Cheong formulates the nature of experiential construal across language and images in multi-semiotic print advertisements as "bidirectional investment of meaning" (Cheong 2004: 176), which is useful to investigate the process of cross-modal interaction at the rank of Cell. For example, a visual square may have various connotations such as one geographic region in a map. However, when it is juxtaposed with a chemical symbol, the mechanism of Inter-semiotic Adoption invests specific Representational meaning (i.e., a chemical element) from the symbol to the visual square, and thus symbolism acts as a stabilizer to elucidate the meaning of visuals. On the other hand, Inter-semiotic Adoption invests Compositional meaning (i.e., Period and Group, see Section 4.2.1) from the visual square to the symbol. In this way, the grammatical strategy of Spatial Position unique to visual displays can now be exploited by symbolism, thereby giving rise to semantic expansions.

Modally, the viewer's attention is directed to certain individual Cells due to their prominence. The most prominent Cell might be the element of hydrogen, which is positioned in the middle of Period 1 and keeps a more or less equal distance from the nearest metal element of beryllium on the left and the nonmetal element of boron on the right. The Color blue (in the original) indicates that hydrogen is one member of the Episode of nonmetals. However, its separation from other nonmetal Cells compositionally suggests hydrogen's ambiguous identity. On the one hand, hydrogen shares the same number of valency electrons with the elements of alkali metals in Group I and is electropositive in terms of chemical behaviors (Onn et al. 2006: 242). On the other hand, this element has many physical properties similar to nonmetals. To take an example, hydrogen is in the gaseous state at room temperature, which is not possible with alkali metals.

Hydrogen's prominent Spatial Position at the rank of Cell further proves that there exist different criteria to classify Episodes in the periodic table. As alluded to in Section 4.2.1, the distinction between the Episode of metals and that of nonmetals is made on the basis of their construal of both macroscopic meaning and submicroscopic meaning. However, if the two types of meaning come into conflict such as in the case of hydrogen, it might be rather problematic to use an either-or approach to classify the elements.

At the rank of Part, the atomic symbol gains prominence through Font and Boldness. Additionally, two numbers are positioned in different regions of the Cell and they make different Representational meaning. As explained in the Key of Figure 1, the number above the chemical symbol represents the relative atomic mass while the other on the left bottom corner indicates the atomic number. Both of them make submicroscopic meaning and the former laid the foundations for Mendeleev's construal of periodicity. In contemporary scientific research and practice, the atomic number is identified as the more reliable attribute of an element given that relative atomic weights could become unstable due to the existence of isotopes (i.e., atoms of the same chemical element with a different number of neutrons) (Scerri 2007: 58). However, the designers of Figure 1 do not emphasize the significance of the atomic number with Modal meaning-making resources (e.g., Color, Font, Size), and might cause problems when young pupils learn the periodic system.

Similar to mathematical visual displays (O'Halloran 2005: 140), the periodic table is characterized by standardized Stylization and Conventionalization through the means of production at the rank of Part. Accordingly, little marginal or peripheral information is construed in the tabular representation where the generalized participants and abstracted values are directly presented, which tends to maximize the Modality value.

5. The limitations of periodic tables

As may be clear from the preceding social semiotic examination, the periodic table is far from the mirror image of a matter of fact about the natural world.

Rather, tabular modes develop powerful grammatical resources at four ranks to make specialized Representational, Modal, and Compositional meaning, which in turn construe the scientific knowledge of chemical periodicity.

While periodic tables have been widely applied in scientific research and practice, it is important to note that as multi-semiotic artifacts they do not have omnipotent modal affordances and might only provide a partial account of chemical periodicity. For example, the elements of the lanthanides series not only possess exceedingly similar properties but also could be subsequently arranged at regular intervals of one atomic number (Scerri 2007). However, since the vertical grouping of elements is identified as the significant Compositional device to model chemical homogeneity, periodic tables are limited in their ability to demonstrate periodicity in the properties of lanthanides, which belong to the same Period and are arranged horizontally. In fact, the placement of lanthanides was regarded by Mendeleev as one of the most difficult problems confronting the periodic law (Laing 2005: 203; Scerri 2007: 172). The social semiotic account indicates that this challenge might be caused by the limited Compositional affordances of tables.

Apart from the lanthanides series, periodicity in the properties of some other metallic elements also outstrips the meaning potential of tabular modes. For instance, the elements of zinc and tin show extraordinary parallels in melting points, solubilities, toxicity, and compound structures (Rayner-Canham and Oldford 2007: 120–121). However, in the periodic table the element of tin is positioned one Period down and two Groups to the right of zinc, and their spatial relationship is described as “Knight’s Move” by comparison to the chess move in the same manner (Laing 1999). So it will be very difficult to model the periodic pattern between zinc and tin with tabular representations where Verticals and Horizontals dominate the meaningful organization of the elements.

Last but not least, the geometrical shape of square and the Inter-Cell Alignment exemplified in Figure 1 are powerful meaning-making resources to defend Mendeleev’s assumption that chemical elements were indestructible and there was no potential transmutation between them (Scerri 2007: 119–120). However, such an assumption has been falsified by the scientific discovery of radioactivity, which provides convincing evidence that an element can be transformed into another in certain circumstances (Scerri 2007: 258).

As Jacob (2001) notes, operations with chemical symbols, though once established on an empirical basis, need to be distinguished from operations with substances because the former is neither a sufficient nor a necessary condition for the latter. In a similar vein, although the periodic table was originally designed on the basis of empirical evidence including relative atomic weights and helped scientists to test and explain chemical phenomena, its interpretations are not always accurate or trustworthy. In fact, Mendeleev failed in half of his predictions of unknown elements (Scerri 2007: 143), which reveals that the period table cannot replace empirical research although it is a useful semiotic tool to shape scientists' research topics.

6. Conclusions

Despite the thorough and in-depth philosophical account of chemical periodicity, Scerri concludes that "there is one ideal periodic classification, regardless of whether or not this may have been discovered" (Scerri 2007: 280). The present study, however, has shown that there might not exist one single periodic table "that most closely approximates the truth about the elements" as Scerri (2007: 278) suggested. Our argument is that the scientific truth of chemical periodicity does not pre-exist in the material world, but is socially shaped and constructed through the combination of different semiotic resources in periodic tables. With the development of computer graphics, tabular representations might immensely expand their functional specialization to account for more subtle and complex meaning of chemical periodicity. Yet they can never gain unlimited modal affordances. Different forms of periodic tables highlight some aspects of chemical periodicity, but at the same time background other aspects, thereby shaping different potentials for pedagogical practice.

Given that the design of periodic tables is dominated by submicroscopic meaning at the atomic level, science teachers need to develop explicit instructions on the periodic system. It is argued that the SF framework in Table 1 provides a preliminary reference for teaching and learning multiliteracies in tabular modes. Through the lens of social semiotics, young learners might be aware that chemical periodicity is modeled through a wide range of grammatical options from different semiotic resources, and even the choices of Color, Font, and Size, which seem trivial, can produce significant meaning.

The semiotic systems in Table 1 also provide a meta-language for teacher and students to evaluate the multimodal design of curriculum materials. For example, they might agree that the key notion of Periods in Figure 1 will draw more attention from pupils if the Modal resource of Labeling is exploited, and they might suggest that the atomic number in Figure 1 should be printed with more salient Color or Font in order to emphasize that the atomic number rather than the atomic mass determines the ordering of chemical elements in modern periodic tables. When science education is informed by multimodal social semiotics, young learners will no longer view chemical periodicity as plain facts immune to revision, but learn to critically examine its multisemiotic construction, thereby achieving a deeper understanding of science as inquiry.

Notes

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1. Lexicogrammar includes both grammar and vocabulary. They are treated in SFG as different ends of the same continuum where lexis provides a more delicate perspective on grammar (Halliday 1994 [1985]: 15).
2. The term "meta-function" is used to emphasize that language (as well as other modalities) is by nature functional and thus function is the intrinsic component of language (as well as other semiotic resources; Halliday 1994 [1985]: 31).
3. From a social semiotic perspective, human experience can be modeled in the grammar of language and other modalities. For example, the experience of "doing" can be linguistically realized with a linguistic clause "John hit Jerry," in which the two nouns "John" and "Jerry" play the semantic role of participants while the verb "hit" realizes the semantic role of process (Halliday 1994 [1985]). Likewise, similar experience can also be realized in the grammar of an image where two visual volumes representing "John" and "Jerry" function as participants, and a vector (usually a diagonal line) sets up the interaction between the two volumes and plays the semantic role of process (Kress and van Leeuwen 2006 [1996]).
4. Halliday (1994 [1985]: 23) proposes a scale of rank for making constituent analysis of English grammar including clause complex, clause, word group, word, and morpheme (listed from the largest grammatical unit to the smallest one). For example, the clause "The periodic table is multimodal" consists of a word group at a lower rank "the periodic table," which in turn consists of three words: "the," "periodic," and "table."
5. Following Liu (2009), macroscopic meaning is the resource to describe visible and tangible phenomena and submicroscopic meaning is the resource to highlight the particulate nature of chemicals and construe scientific reality beyond the reach of natural human senses. For instance, a photograph of a lump of cooking salt realizes macroscopic meaning and construes ordinary experience whereas micrographs of the ions of sodium chloride formulate submicroscopic meaning and construe scientific knowledge.
6. Semiotic Adoption is an inter-semiotic semantic mechanism where system choices from one modality are incorporated as system choices within another semiotic system (O'Halloran 2005: 169).

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Yu Liu is an associate professor at Sichuan International Studies University ⟨liuyunus@gmail.com⟩. His research interests include Systemic functional multimodal discourse analysis and scientific literacy. His publications include "Intersemiotic Texture: Analyzing cohesive devices between language and images" (with K. O'Halloran, 2009) and "Metaphor, multiplicative meaning and the semiotic construction of scientific knowledge" (with Y.S.M. Owyong, 2011).

Aylanda Dwi-Nugroho is a lecturer at Petra Christian University ⟨aylanda@peter.petra.ac.id⟩. Her research interests include Critical discourse analysis and multimodal discourse analysis. Her publications include "Generic structure of Elizabeth Arden's Intervene advertisement" (2009).