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The Concept of Electronegativity: Approximations and Separations in Chemistry Textbooks

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Abstract In this work we seek to identify approximations and separations in relation to the Reference Sciences tothe concept of Electronegativity in Chemistry Textbooks using the Cone Model. We identify that there is a strong standardization of the Electronegativity concept at High School and Higher Education textbooks, as well as ahistorical and decontextualized treatment from the original source. The textbooks analyzed showed a strong standardization of characteristics that, from our point of view, is configured as a horizontal separation in relation to knowledge of reference that can lead students to conceptual errors.

Keywords Electronegativity, Chemistry Textbooks, Didactic Transposition

1. Introduction

According to Lopes[1], the passing of the scientific knowledge to the scholarly context is a process of transformation; after all, if science is a collective production that is socially contextualized, the removal of scientific knowledge from this context implies in its transformation. Further, according to Lopes[2], even before the "arrival" at schools, this transformation begins with epistemological and social purposes.

Chevallard[3]states that the teaching of a determined element of knowledge will only be possible if it undergoes some type of "transformation or deformation". In this sense, he indicates elements that characterize didactic functioning based on the concept of didactic transposition, andthe knowledge taught assumes processes of decontemporization, naturalization, decontextualization (to bring something significant from wisdom knowledge, decontextualizing and then recontextualizingit in a different discourse) and depersonalization. Chevallard[3]statesthat didactic transposition is "the work of fabricating an object of teaching, that is, to make an injection of knowledge produced by wisdom to be an object of scholarly knowledge."

Pinho-Alves[4] points out that the transformations accomplished by means ofdidactic transposition make scientific knowledge accessible, and that these transformations are made by different actors belongingto the diverse social instances related to education – official education agencies, universities, researchers, textbook authors, and teachers, among others.

For this author, a transformative process requires the determination or adoption of a starting point or reference point.

The reference point or "reference knowledge" adopted is the knowledge produced by scientists according to the statute rules of the community towhich it pertains, submitted to rules and specific language. On the other hand, the knowledge to be taught (scholarly knowledge) also has its own rules during the process of didactic transposition. According to Chevallard[3] these rules will undergo a process of degradation, in which the loss of the original context considering its source occurs through decontextualization and reconstruction. The didactic transposition process, by removing scientific concepts from the historical context of their production and their limiting to restricted definitions, may generate obstacles to the understanding of these same concepts.

According to Forquin[5], the scholarly culture (scholarly knowledge) is considered as a "secondary culture" in relation to the "culture of creation or invention." For this author, scholarly culture is derived and transposed from knowledge, and can be identified through teaching materials, because before arriving at school (high school, higher education) the reference knowledge suffers processes of approximations or separations with the objective of becoming knowledge to be taught. Therefore, such

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approximations and separations are part of the didactic transposition process, which do not mean that there are easy tasks to be accomplished, because the act of transforming scientific knowledge into didactic content - conserving its complex theories and without losing its properties and characteristics - may be considered the largestchallenge for textbook authors, teachers and the school. Thus, it is necessary to consider not only the characteristics of the knowledge themselves, but also the characteristics of the student, and his or her capacity for reasoning and previous knowledge.

In order to be able to differentiate the types of separations found, we use a tool developed by Franzolin[6], by means of which the separations are classified into two categories, both derived from didactic transposition: vertical distancing, which originates from the transposition of the scientific knowledge to each level of teaching, being necessary to facilitate the learning for students of different age groups. This is represented by a central axis, and all knowledge that is inserted within the cone that surrounds it would originate from a separation from this category (Figure 1).The knowledge that has a greater rigorousness in relation to the referenceis inserted on the axis represented in Figure 1 by the straight *V* line. The knowledge that is located within this cone (exemplified by the dotsin Figure 1) is also found there due to its rigorousness, or accuracy, in relation to the reference; however, its rigor varies according to the academic age component; the other type of separation would be the horizontal one, referring to the separation in relation to the determined axis by the rigorousness, and, therefore, generates knowledge that is found outside the cone that surrounds it. This skill is used by those who teach to facilitate the learning, but it is not related to the academic age group. This separation would arise from the flexibility of the knowledge taught in relation to the rigorousness related to the reference science. However, it is important to clarify that the knowledge originating from this separation is not reduced to conceptual errors, even though it can also be in this category, but it is knowledge that can have different natures.

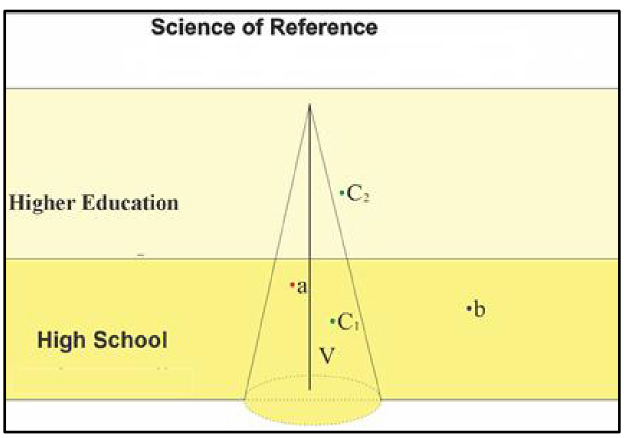

Figure 1. Representation of the possible types of separation found among knowledge taught at the different school levels and those presented by the reference (adapted by [**6**])

In Figure 1, the ***V*** axle refers to the academic age component, where the vertical separations that have greater rigorousness in relation to the reference are located. The cone which surrounds it encompasses the other knowledge, which is vertically separatedfrom the reference at the different teaching levels. It may be verified that two distinct lines of knowledge are represented, with High School corresponding to the base of the cone, by having a greater diameter originating from the ample need for didactic transposition necessary at this cognitive level. Soon the cone straightens in the sense of increasing scholarization, in this case from High School to Higher Education, byvirtue of the lesser use of didactic transposition. The cone model makes it possible to evaluate the rigorousness of the content; that is, content will be more rigorous when it is found within and closer to the top of the cone. Each highlighted point represents one of the "many knowledge" taught at High Schools and Higher Education institutions. Point ***a*** refers to the electronegativity concept taught at High School and which is vertically separated from the reference and, therefore, is located within the cone. Point ***b*** refers to the electronegativity concept also taught at High School, but which is found horizontally separated from the reference located outside the cone. While point ***C1*** represents the electronegativity concept which, when taught at High School, is characterized as originating from vertical separation (however less rigorous than point ***a***), because it originates froma didactic transposition necessary to the corresponding level of education. Point ***C2*** is found horizontally separated when taught at this education level, being characterized as a laxity in relation to the reference[**6**].

In this work we analyze High School chemistry textbooks and textbooks for General Chemistry and Inorganic Chemistry used in Higher Education, verifying the distance that they maintain in relation to the reference knowledge. The research does not intend to evaluate the books in a traditional style, grading themas "wrong" and "correct," but to estimate the concepts which separate or approximate them to the reference knowledge, requiring the teacher's identification and active intervention. It was possible to analyze this process through the textbook, which investigates the relation of proximity and separation between the knowledge taught through such teachingmaterials and the reference knowledge. This research is also characterized as an epistemological study. Therefore, the judgments involved in the analysis and their results are related to the view of the investigators, which is inserted into a sphere of individual knowledge.

2. Methodology

In order to perform the comparison between knowledge of electronegativity found at High School and Higher Education textbooks in relation to the reference knowledge and its approximations and separations, a table was created with the frequencies of the separations found in the diverse contents or areas, which were then confronted with the reference knowledge. In this research, reference knowledge is considered as the knowledge of the scientists and which is found in periodicals. The textbooks used in the analysis are represented in Table 1.

Table 1. List of the textbooks analyzed

Reference Code	Textbook
TB1-HS	EDUARDO LEITE DO CANTO, E. L.; PERUZZO, F. M. Química na abordagem do cotidiano. São Paulo: E. Moderna, 2011.
TB2-HS	REIS, MARTHA. Química: meio ambiente, cidadania e tecnologia. São Paulo: Ed. FTD, 2011.
TB3-HS	MACHADO, A. H.; MORTIMER, E. F. Química. São Paulo: Ed. Scipione, 2011.
TB4-HS	LISBOA, J. C. Ser protagonista químico. São Paulo: SM edições, 2011.
TB5-HS	CASTRO, E. N. F.;SILVA, G.S.; MÓL, G. S.; MATSUNAGA, R. S.; FARIAS, S. B.; SANTOS, M. O.; DIB, S.M.F.; SANTOS, W.L.P. Química cidadã. São Paulo: Ed. Nova Geração, 2011.
TB1-HE	MAHAN, B. H; MYERS, R. J. Química: Um Curso Universitário. Trad. Henrique E. Toma, et al. 2. ed. São Paulo: Edgard Blücher, 1993.
TB2-HE	ATKINS, P.; LORETA, J. Princípios de Química, questionando a vida moderna e o meio ambiente. Trad. RicardiBicca de Alencastro. 3 ed. Porto Alegre: Bookman, 2006.
TB3-HE	RUSSEL, J. B. Química Geral. trad.MárciaGuekezian et al. 2. ed. v. 1. São Paulo: Makron Books, 1994.
TB4-HE	BROWN, T. L., LEMAY, H.E., BURSTEN, B.E. Química: a ciência central. 9. ed. São Paulo: Pearson, 2007.
TB5-HE	KOTZ, J. C.; TREICHEL, P. M. Jr. Química Geral e Reações Químicas. São Paulo: Thomson, v. 1, 2005.
TB6-HE	LEE, J. D. Química inorgânica não tão concisa. trad. Henrique E. Toma et al. 5. ed. São Paulo: Edgard Blücher, 2000.
TB7-HE	SHRIVER, D. F; ATKINS, P. Química Inorgânica. trad. Maria Aparecida Gomes. 4. ed. Porto Alegre: Bookman, 2008

The criteria for the choice of the textbooks were based on two factors: for the High School textbooks (TB-HS) the books approved by the 2012 National Textbook Program for High School were selected [7]; the Higher Education textbooks (TB-HE) are indicated as basic bibliography in training courses for chemistry teachers.

3. Results

In this analysis we analyzethe concept of electronegativity proposed by J.J. Berzelius in 1811, when developing the electrochemical theory of bonding (also known as dualistic theory). Berzelius organized the simple bodies in decreasing order of electronegativity, this series being defined due to the manner in which the elements bond in the compounds which defined it as being the capacity that an atom has to attract electrons to it[8]. In 1931, Linus Pauling reformulated and amplified the concept of electronegativity, proposing a scale of electronegativity. Pauling sought to determine differences between the energies of homonuclear bonds and heteronuclear bonds (between different atoms), assuming that if two homonuclear diatomic molecules interact to form diatomic heteronuclear molecules, the bond energy of the latter would be an average of two homonuclear bond energies in the original molecule (Postulating from the addition of normal, covalent bonds). However, Pauling observed that the real heteronuclear bond energy was greater than the average expected, and that this energy increased as the atoms became different in relation to a property, which chemists called electronegativity. Such a property was defined as the power of an atom in a molecule to attract electrons to it, and as the bond energies refer to molecules in a gaseous state, electronegativity also refers to isolated molecules [9].

As a consequence of the work realized by Pauling, only differences of electronegativity were defined. According to Santos, Silva and,Wartha [10], after the work of Pauling, severalstudies on electronegativity were carried out, and other scales of electronegativity were proposed based on different atomic parameters and physical properties. Among these are the scales of Mülliken in 1934, Allred-Rochow in 1958 and Sanderson in 1951[10].

Mülliken proposed a scale of absolute electronegativity, in which he suggested that this absolute electronegativity would be the mathematical average of the energy necessary to remove an electron from an atom in the gaseous phase (ionization energy) and energy releasedwhen an electron is added to an atom in the gaseous phase (electron affinity). Mülliken suggested that these values should correspond to a state of appropriate valence; that is, the electronegativity would depend on the oxidation state of the element [11]. Allred and Rochow considered that electronegativity was related to the electrostatic force experienced by an electron on the valence layer of the atom caused by its effective nuclear charge. They considered electronegativity as a measurement of the effectiveness of the nuclear charges on the outermost empty orbitals and that, therefore, an intimate relationship would exist between atomic structure and this property. Thus, this property cannot be interpreted solely as a number, but also as a consequence of the atomic structure. The fact that it becomes more distinct when the blinding effect of the nuclear charge from an atom is analyzed and it is perceived that the outermost electrons are not as effective as the innermost, thereby allowingthe effective nuclear charge to interfere in the number of valence electrons from a given atom[12]. Sanderson pointed outthe relation between electronegativity and atomic size. He considered electronegativity as a function of the relative density of the electron cloud around the nucleus of the atom, recognizing that the natural tendency of some atoms with high electronegativity is to acquire partial negative charge, causing expansion of the electrosphere to a less compact condition (less electronic density). The natural result of the partial loss of electrons by an atom of low electronegativity is the contraction of the electrosphere to a more compact condition (greater electronic density)[13].

Pearson suggested that the different scales of electronegativity have distinct applications and that each one is correct within their own areas of application. A scale of electronegativity should adequately reflect the particularity of the elements, and explain in a satisfactory manner various physical and chemical properties of the compounds. Pauling' scale is the most extensively used, because it has been effectively used to predict the polarity of a bond, solubility and the fusion point of compounds. The reliability of the other scales is generally verified by means of the comparison with the original scale. Thus, when working with atomic electronegativity, the values proposed by Pauling in 1932 and revised by Allred and Rochov in 1958 are recommended [13].

The concepts of electronegativity found in the textbooks are listed in Table 2.

Table 2. Concepts of electronegativity found in high school and higher education textbooks

Reference code	Definitions for the concept of electronegativity
TB1-HS	"Electronegativity is the capacity that atoms of a determined element have to attract electrons." P.203
TB2-HS	"Electronegativity is the tendency that an atom has to attract electrons close to it, when it is found bonded to another atom of a different chemical element in a compound substance." P.155
TB3-HS	"Electronegative is the intensity with which a bonded atom attracts the electrons of the chemical bond." P. 259
TB4-HS	"Electronegativity is the measurement, based on a series of parameters, of the tendency of an element to attract the electrons which participate in a chemical bond." P.195
TB5-HS	"Electronegativity is different intensities of attraction of the electrons, responsible for diverse chemical and physical properties of the substances." P.244
TB1-HE	"The tendency of an atom to gain, instead of lose, electrons in a bond is called electronegativity." P.355
TB2-HE	"The power of attraction of electrons exercised by an atom which participates in a bond is called electronegativity." P.182
TB3-HE	"It is defined as the relative tendency shown by a bonded atom to attract the pair of electrons." P.370
TB4-HE	"Electronegativity is the capacity of an atom in a molecule to attract the electrons of a bond to its surroundings." P.170
TB5-HE	"Electronegativity, X, of an atom is defined as a measurement of the ability of an atom in a molecule to attract electrons to it." P.275
TB6-HE	"In 1931, Pauling defined the electronegativity of an atom as a tendency to electron attract in its direction when combined, forming a compound." P.80
TB7-HE	"The electronegativity of an element is the capacity that an atom of an element has to attract electrons when it is part of a compound." P.52

The concepts of electronegativity found in High School and Higher Education textbooks are very similar. If we only consider the manner how electronegativity was originally defined by Pauling, i.e., "the power of an atom in a molecule to attract electrons to itself", as in[8], without making any reference to the context of its production, it would be possible to consider the positions of the majority of the definitions found in the textbooks coherent. However, analyzing the context in which this concept emerged (from the energy values of simple molecule bonds), it becomes clear that it only makes sense to speak of electronegativity when an atom is bonded to another atom of a different chemical element.

High School textbooks (TB-HS) present definitions very similar to the original definitions provided by Pauling and Berzelius. We could state that there is no separation in relation to the reference knowledge. However, if we take the context of construction of the concept proposed by Pauling into account, the definitions presented in these textbooks may be considered as equivocal, because by showing electronegativity outside of its context, they give the idea that electronegativity has unit of force (Newton) in its capacity or intensity to attract electrons. Electronegativity is not shown as relative greatness and this property does not have unit. In these books we do not verify vertical separation in relation to the reference knowledge, seeing that they are very similar to the definitions found in the textbooks with the reference concept. On the other hand, we verify a horizontal separation by not considering the context of construction of the concept of electronegativity, and also by not clarifying that electronegativity is a parameter that is only applied to atoms in molecules. Generally, the definition is presented in the unit in which the Periodic Table is studied, showing it as a periodical property. As application, it generally appears to explain the formation condition of a polar covalent bond. The values of the elements' electronegativity are presented in an arbitrary manner, without any explanation as to their origins, serving only to define the polarity of the covalent bonds. Generally, electronegativity is confused with the definition of electronic affinity. Only TB2-HS mentions that this property only makes sense when the atom is bonded to another atom of a different chemical element in a compound substance. TB4-HS says that it is a measurement based on a series of parameters; however, it does not indicate which elements these are, and why certain parameters over others.

On the other hand, it was possible to verify that Chemistry textbooks used at Higher Education (TB-HE) make it clear, in the construction of the electronegativity concept, that it refers to a parameter that only applies to atoms in molecules. However, the majority of these books do not mention that this property only arises when atoms of different chemical elements are joined by a bond. Similar to books destined to High School, the Higher Education books do not exhibit vertical separation in relation to the reference knowledge. The definitions are very similar in the majority of the Higher Education textbooks in that they define electronegativity as a tendency, capacity or measurement that one atom has to attract electrons to it.

In regard to horizontal separation, we identify that three books mentionthat the first scale of electronegativity was proposed by Pauling and that different scales of electronegativity have been proposed based on distinct experimental parameters. However, only two of these (TB1-HE and TB2-HE) present the development of the original scale and show that this is a relative scale. Additionally, these same teaching materials were the only ones to mentionMülliken as another researcher who also studied electronegativity.

In regard to relations with other properties, electronegativity has been related with: the atomic ray (TB1-HE and TB3-HE), the effective nuclear charge (TB3-HE), ionization energy and electronic affinity (TB2-HE). In the first case, TB1-HE only informs that smaller atoms are more electronegative than larger ones. In the second, TB3-HE mentions that electronegativity tends to increase from left to right, through a period of the periodic table, due to the increase of the effective nuclear charge and that going down a group of the periodic table electronegativity diminishes as the valence layer becomes more removed from the nucleus, that is, increases as the radius of the atoms becomes larger. In TB2-HE electronegativity is related as ionization energy and with electronic affinity, and explains that highly electronegative atoms lose electrons with difficulty and tend to gain them, as they have high ionization energy values and electronic affinity. TB4-HE and TB5-HE only relate electronegativity with the dipolar moment and possibility to predict tendencies of polarities.

The organization in relation the electronegativity concept found in the High School and Higher Education textbooks, even verifying a very large approximation in relation to the reference knowledge, showed a horizontal separation in regard to the historical construction of the electronegativity concept, indicating a limited vision of the concept of electronegativity. There are few textbooks that indicate that the values of the relative electronegativity of the atoms on the Pauling scale were obtained from experimental data of the standard formation heat of simple molecules, and consequently, of the values of bond energy. The question of electronegativity of the rare gases is treated, when it occurs and without much depth, in texts destined for Higher Education as is the case with TB2-HE.

4. Conclusions

We identified that the majority textbooks, both for High Schooland Higher Education, show the concept of electronegativity in an ahistorical and decontextualized manner. The knowledge taught appears as knowledge without producers, without origin, without place, transcendent of time, teaching only the result, isolating them from the history of construction of the concept, removing them from the group of problems and questions from which they originated. In this perspective of teaching, the concept of electronegativity becomes inadequate to the reality into which it is inserted, because the information present in the textbooks, generally speaking, does not seek to explain the relation between electronegativity and other periodical properties. We also verify that the textbooks useonlyLinus Pauling's definition of electronegativity of, not taking into account the contributions made by Mülliken, Allred-Rochow and Sanderson.

One can conclude that both High School Textbooks andHigher Education Textbooks show a strong standardization of characteristics that, from our point of view, is a horizontal separation in relation to knowledge of reference that can lead students to conceptual errors.Thus, it is proposed that the treatment of the concept of electronegativity be performed within a historical context establishing connections between electronegativity and the concepts with which this is constituted in an inter-relational base.

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