AC 2007-1680: TEACHING CHEMISTRY AS A CROSS-CULTURAL SUBJECT : IT & LINGUISTICS

Margherita Landucci, Liceo Artistico Statale
Fabio Garganego, Municipality of Venice
Teaching Chemistry as a Cross-cultural Subject IT & Linguistics

Abstract

The main theme of this paper is the language of chemical formulae rather than the language that explains chemistry; the focus of our interest is the code used in writing chemical formulae.

The paper describes the nature and scope of a research project started by an out-of-school multidisciplinary team who set up in 1993 and concluded their research in 2003. The research was conducted in Italy in technical as well as classical secondary schools with students 14-16 and 16-18 y.o. respectively; different socio-cultural contexts were also part of the parameters.

This work discusses how communication about chemical topics has been improved by getting the student to master the world language of chemistry. This task was accomplished following a procedure divided in three different stages.

The first stage involved the use of a computer card-game based on the chemistry code. The software CHICKA (Code Helping In Chemical Knowledge Acquisition, © 1999) was built on the entire set of chemistry rules for composing inorganic chemical formulae; the chemistry rules were translated into game rules.

Throughout the game one inadvertently learns to build chemical formulae and concepts such as valency, electronegativity and stereochemistry.

The second stage identifies links between Chemistry and Linguistics by applying to the chemistry known natural language concepts such as morphemes and lexemes in order to make students understand the concept of chemical formulae long before the explanation of chemical bonds and molecular structures is carried out, and by giving teachers some guidelines on practical application to chemistry through such concepts as context, actants and student’s encyclopaedia.

The third stage gives to some familiar processes a scientific interpretation to be used as a vehicle towards theories of physical-chemistry. A drastically diminished time gap between teaching and learning was the result that demonstrated the effectiveness of this approach. The shorter time necessary for the student to learn and command chemical formulae allowed the teacher to increase the time spent in introducing and explaining chemical concepts; it also allowed for an increased participation of the students to the class.

It is at this level that the main difference and results of the method proposed in this study could be appreciated. By keeping all real life examples and situations closely within the correct context, and by ensuring that the story was always closely related to the story of real life known to the student, it was possible to transmit to students how pervasive to real life Chemistry is by simply ensuring to use the students’ encyclopaedia. By ensuring that students could always link the concept of actants as they knew from linguistics with the new actants as they were discovering in chemical processes, a good interdisciplinary bridge was built. The fact that the full process was transparent to the students (interdisciplinary links were outlined and explained) contributed greatly to the students involvement.
This paper introduces a new method to teach Chemistry. The proposal is to use this methodology in the first two years of the subject, followed by the application of the traditional methods. Through this combined approach the students should achieve a comprehensive knowledge of the subject.

The question this study attempts to address is the following: would the student be assisted in the understanding of chemical concepts and processes by a method that develops a good familiarity with the language of chemistry?

This study therefore postulates the hypothesis that the chemical formulae system is a language in its own right, and thus in order to achieve an effective learning of the subject, it is necessary to link the chemistry language to the real and daily experience of the students. In this way students understand how the chemical formulae system is actually a language.

This links back to the initial key point of contact between the process of teaching and the process of learning chemistry, when students begin to “speak” the Language of Chemistry effortlessly for the first time.

Teachers experience had highlighted how the adoption of modern techniques such as links to real, daily experiences, off site visits, or case studies achieved less significant results – in terms of measuring students’ interests and active classroom participation – when applied to the subject of chemistry in comparison with other subjects[1].

The aim of the work was to investigate as whether or not the teaching-learning process speeds up when students are provided with a previous mnemonic knowledge of chemical formulae and to test the feasibility of associating old and well known natural language concepts with chemical concepts. The focus of our interest is the code which governs the writing of chemical formulae in their capacity as the language of chemistry since by studying a language we may discover abstract principles that govern its structure and use (Chomsky 1975)\(^5\).

In 1993 began the discussions among teachers of different subjects and comparison of different results achieved using different methods, while the experimental phase of the project in the classrooms ended in 2003. The research was conducted in Italy in different socio-cultural contexts in technical as well as humanistic secondary schools; students were 14–15 and 16-17 y.o. respectively.

This study stems from discussions among some chemistry teachers in secondary schools that were trying to reach an increased effectiveness of the method to teach chemistry at their local level and with the assistance of two consultants, a pure linguistic teacher and a teacher specialized in linguistics didactics. This team was not integrated within a specific institute of research. The idea of presenting the results of this study at an International Conference was born after a subsequent research where the team was trying to find the best venue to present the results. This research (Landucci 2005)\(^12\) was conducted between 2004 and 2005 and showed that the majority of text books were following the traditional method.
The genesis

This work has its genesis in the following consideration: in the contemporary world of technology, the active knowledge of chemistry is of fundamental value. Nevertheless, Chemistry is an unknown science to the general population, and while people are interested in subjects such as environment, food, diet, health, etc., they don’t know that all of these stem from chemical processes.

The underlining idea of this work is that these shortcomings can be overcome by associating known concepts of natural language with the chemical concepts of the processes through which they are presented.

Starting from the idea that every micro-language defines patterns and values for reality just as any human language does, the development of students’ scientific language is better achieved by emphasizing and developing structures which already exist in specialized fields of the language. Thanks to the memorization of chemical formulae, students are now ready to consider the formula as a word and to apply to it some of the concepts they have assimilated when studying linguistics.

In order to enable students to understand the concept of chemical formulae long before the chemical bond theory and molecular structures are introduced, we have identified in the language some features that can link Chemistry and Linguistics. A computer card game has been developed – CHICKA – so to speed up the language acquisition process, the Language of Chemistry and the chemical symbols and formulae.

The proposed method does not seek to undermine the traditional way of teaching chemistry but rather constitutes an important background towards mastering of the chemical terminology in a systematic manner.

The Methodology

This work is structured in two parts.

The first part is a theoretical analysis of the subject, subdivided in three stages:

- Stage 1 - the links between the Language of Chemistry and Linguistics are identified;
- Stage 2 - an innovative way of presenting common chemical process through macro-linguistics principles is proposed;
- Stage 3 - the introduction to the software game CHICKA.

The second part consists of the empirical research, subdivided in two stages.

- Stage 1 – CHICKA has been used in the classroom to test the speed of Language Acquisition.
- Stage 2 – Macro-linguistic concepts were used to teach chemistry and a potential increase in the interest of the subject was measured.

Part 1, Stage 1 - Identifying links between Chemistry and Linguistics

In this part some analogies between Chemistry and Language have been explored in order to highlight the existing links. These pertain to 6 specific characteristics: Word formation; Inflectional and derivative morphemes; Compounds and compounding; Graphemes, morphemes, lexemes; Open and Closed-Class Words; and Word order.
**Word formation**

The Chemistry language, as every language, has strict rules on word formation: it gives morphological information about the internal structure of formulae. For example, our intuition tells us that the words *tree* or *eat* can not be broken down into any meaningful parts. In contrast, the words *trees* and *eating* seem to be made up of two parts: the word *tree*, *eat* plus an additional element, -s (the ‘plural’) or –ing (the ‘past or present participle’). In the same way, our intuition tells us that the chemical word *Fe* can not be broken down into any meaningful parts. In contrast, the word *Fe(s)* seems to be made up of two parts: the word *Fe* plus an additional element (s), which indicates the solid state of aggregation.

**Inflectional versus derivative morphemes**

‘*Tree*’, ‘*eat*’ and ‘*Fe*’ are called *free morphemes*; while ‘–s’, ‘–ing’ and ‘(s)’ are called *bound morphemes*. Two or more morphemes in combination give a *complex morpheme* (a complex word). Bound morphemes can be inflectional morphemes as in the above case where they do not change the category of words, or derivative morphemes, as –ize in modernize and –O in FeO that change the category of the words which they are attached to: *modern* is an adjective and *modernize* is a verb, *Fe* is a metal and *FeO* is a compound. Inflectional morphemes are used to mean particular aspects of the grammatical function of a word or particular states of a compound: in English –er gives smaller, -ing gives singing; in Chemistry *H2O* followed by (s) means ice (solid water) and *NaCl* followed by (aq) means a solution of table salt in water.

**Compounds and compounding**

In English new words can be formed from already existing words to form a compound word. A compound word has semantic and often grammatical characteristics quite different from the two words taken separately. The part of speech of the whole compound is the same as the part of speech of the rightmost member of the compound: the rightmost member of the compound *overdo* is a verb (the verb *do*), therefore the whole compound is also a verb. In Chemistry the compound word *FeO* has both *semantic* and *grammatical* characteristics quite different from the two words taken separately. And considering that the rightmost member of the compound *FeO* is the ion oxide, the whole compound must also be an oxide, as it actually is. *FeO(s)* is a compound word in its own right, as its properties are not connected to the properties of the single elements *Fe* or *O*.

**Graphemes, morphemes, lexemes**

In the following reaction: \( CO(g) + Fe_3O_4(s) \rightarrow CO_2(g) + 3FeO(s) \) the formula \( 3FeO(s) \) contains six *graphemes* 3 Fe O s ( ), one *free morpheme* 3, one *compound lexeme* (compound word) *FeO* and one *bound morpheme* (s). In order to distinguish between different compound words having the same graphemes such as *FeO* and *Fe3O4*, the chemistry code uses special signs. These signs are *subscript numbers*. If we were to spell the same formulae using the English code, they would be *FeO* and *FeFeFeOOOO*. Conversely, if we were to spell the English words *to*, *too* and *feed*, *fed* using the Chemistry code, they would be written as *to*, *to2* and *fe2d*, *fed.*
Open versus Closed-Class Words

Examples of open-class words include the English words brother, run, tall, quickly (noun, verbs, adjectives, adverbs) which tend to be quite large and open-ended. That is, an unlimited number of new words can be created and added to these classes. In the same way, we have in Chemistry examples of open-class words that include the words Fe, HNO₃, FeO, CaSO₄ (metals, acids, oxides, salts) which tend to be quite large and open-ended. That is, an unlimited number of new words can be created and added to these classes (see Ca(SO₄)₂H₂O for gypsum or FeO(OH) for rust).

Conversely, closed-class words are those belonging to functional classes (such as articles, conjunctions and prepositions). In English the word ‘and’ has the grammatical function to join noun phrases. In Chemistry the word ‘+’ has the grammatical function to join chemical words under the label of reagents in the context of a chemical reaction; the word ‘→’ corresponds to the English word towards, and has the function to signal the direction the chemical reaction points to.

Perhaps a better way of observing the linguistic forms of different languages in order to find the wanted analogies would be to look at the use of the notion of ‘message elements’, the morphemes, without having to depend on identifying ‘words’. One can for example disassemble the following English and chemical sentences and list the elements as shown in figure 1.

Readying and studying though broadened the minds of all
Na(s) + H₂O(l) → NaOH(aq) + H₂(g) + J

| ready-ing and study-ing though broad-en- ed the mind-s of all Na (s) + H₂O (l) → Na -OH (aq) + H₂ (g) + J |
| lex.    | infl. | funct. | lex. | infl. | funct. | lex. | deriv. | infl. | funct. | lex. | infl. | funct. | lex |

LEGENDA
deriv. derivative
fuct. functional
infl. inflectional
lex. lexical

Figure 1 The message elements in English and in Chemistry

Word order

In English the grammatical functions are indicated by the position of each word. In Chemistry, if we consider the formula as a sentence, the character of the constituents of the formula is also indicated by word order: the element (or the group of elements) with acidic character typically precedes the element (or group of elements) with base character, e.g. (NH₄)₂S.

Part 1, Stage 2 - Giving familiar processes a scientific interpretation

Once the analogies between chemistry and micro-linguistics have been identified, it’s possible to proceed to the second stage: a structured exploration of the subject giving familiar
processes a scientific interpretation strictly linked to reality. The fundamental concept is the identification of the main concepts that govern macro-linguistics in order to apply them to the classroom explanation of many chemical processes. While bringing these examples to the classroom, it is essential to adhere to the linguistics theory concepts that follow.

The Message

In order to work, the message must refer to a context that can be easily understood by the receiver, it requires a code common to sender and receiver and then a contact, a physical channel and a psychological link to establish and maintain the communication (figure 2).

Figure 2 The Communication

The Students' Encyclopaedia is the understanding about a subject which students have in their mind when approaching anything new - a scientific subject or a material situation in reality. If this encyclopaedia is constantly used by the teacher as a key factor, students will get used to constantly use the reality they observe as their point of reference. The specific textual competence acquired in this way will enhance their encyclopaedia so that when approaching other specific realities they will be able to develop other skills that in the long run will combine in the general textual competence in science (figure 3).

Figure 3 Enhancing the Students' Encyclopaedia

The Context

The context is something that must be known by the receiver of the message in order to allow for message transmission. For example, for iron ore to be transformed into iron we must put it into a context: the creation of this context is the blast furnace. Let’s now consider the facts that happen into the blast furnace as a story (tale).
Into the blast furnace, Iron Ore (The Subject) must pass certain tests to be able to become Iron (The Object). The Cold (The Opponent) is beaten thanks to the action of Coal (The Helper) and eventually the Hero reaches his goal dictated by a certain Need (The Designator) to the benefit of Man (The Recipient). This view mirrors the six semantic categories, actants, used in literature to describe the roles of the characters in a story: the helper assists the subject in the trials where he must succeed to obtain the coveted object. This action is rendered difficult by the opponent. The designator establishes the object as the end of desire and communication, while the recipient is the one who benefits from it (figure 4).

**Figure 4** Actants, the six semantic Categories in Literature

*The Story and the Plot*

We all know that the story (tale) is accessible to everyone, as it uses a type of approach which is temporal and the receiver is in possession of the temporal code. The use of the plot, on the other hand, is allowed only to those who also have textual competence. Therefore, when we introduce a subject concerning chemistry or technology with a plot that doesn’t fit perfectly the story, the only attainable thing is a loss of information due to the noise caused by the unknown code (figure 5).

**Figure 5** The Noise preventing Communication

Physical reality can be perceived from various points of view: the very same blast furnace story can be told with different plots depending on the teaching objectives. However, when we present a chemical phenomenon with a plot close to the story, we will be able to easily locate and use those ellipses concerning the way the plot is arranged over time, in order to develop all the wanted sub-stories. These sub-stories allow for the parallel development of the truly scientific plot, the knowledge of particular codes and the resulting application of textual competence (figure 6).

**Figure 6** The Story and the Plot
Describing a process

A chemical sentence should be ‘built’ as far as possible based on the students’ background knowledge about how the world is made so that they can make sense of what the text deals with, grounded on what they would normally expect to happen (consistency between theory and reality). A chemical sentence that describes the students’ experience in the picnic context should be the following:

(1) Coal or wood + match + air → heat

which, using chemical language, becomes:

(2) C(s) or (CH$_2$O)$_n$ + $J_1$ + O$_2$(g) + N$_2$(g) → $J_2$ (J$_2$ >> J$_1$)

However, the reaction found in textbooks to describe the burning of coal is

(3) C + O$_2$ → CO$_2$

This reaction, which in itself is correct, does not take into account students’ knowledge about their world - in which for coal or wood to burn there must be a source of ignition (a match), and the process happens in a normal environment where air is present. The textbook reaction contradicts what the student knows however, because it doesn’t mention the need for a match.

This is a clear example of how the gap between theory and reality can be misleading when the plot doesn’t match closely the story: the textbook reaction is perceived by the student as a writing strictly belonging to a chemistry course and not as something that describes a process encountered in real life. Chemistry – from the first approach – becomes in this way only a school subject, rather than an accurate description and often an explanation of the real world.

Allowing students to capitalize on their educational background, and build-up their knowledge on it, we obtain not only a keen interest in the subject (due to its connection to reality) but also a comprehensive study from the ground level upwards. The need to spell out every chemical reaction exhaustively from the very first time it’s introduced means that not only strict chemical formulae, as required by stoichiometric calculations, are learnt, but also that thermodynamics are introduced – as an additional and more descriptive layer of reality seen in chemistry language. You can see how the reaction (4) of figure 7 adds to the students’ background knowledge as expressed by reaction (5).

(4) C(s) or (CH$_2$O)$_n$ + $J_1$ + O$_2$(g) + N$_2$(g) → $J_2$ + N$_2$(g) + CO$_2$(g) + CO(g) + C(s) + H$_2$O(g)

(5) Coal or wood + match + O$_2$(g) → heat + CO$_2$(g) + CO(g) + C(s) + H$_2$O(g)

Wood       the Reactant
$J_2$ (Heat) the Product
CO$_2$(g)   the Waste (by-product)

Figure 7   Picnic reactions

Through this process, students will find the obvious links between the expression they already know and the content. It is essential to consider not just the students’ encyclopaedia but also the context within which the chemical reactions occur when determining the most appropriate presentation style. Consequently it is beneficial to examine some of the chief features of the teaching-learning process.
Using familiar processes as vehicle towards theories of physical-chemistry

Mundane daily processes can be used to introduce the specific chemical reactions we want to talk about. The ellipses shown in the diagrams suggest theoretical developments and certain basic notions that can be given according to the specific needs. The following process is only an example of the many that can be used.

- *Frying potatoes:* is the Story that allows the teacher to introduce osmosis, to demonstrate that oil never boils, to show the transformation of carbohydrates in coal a home-made reproduction of the process which thousand years ago led to the formation of the present coal-mines (figure 8).

**Figure 8** The experience of *Frying Potatoes* as General Story

**Part 1, Stage 3 - Mastering the world language of chemistry**

The third stage of the theoretical excursion consists in finding a valid tool that could enable students to use formulae and the Language of Chemistry with ease. The tool identified as best responding to the goal was a game. From here therefore was born the idea of a computer game built on the whole set of chemistry rules for composing inorganic chemistry formulae, that were then translated into game rules: CHICKA (Code Helping In Chemical Knowledge Acquisition, © 1999).

The use of CHICKA develops the students’ ability to work with symbols and pictures by taking advantage of other symbolic or pictorial activities, such as card games, which are already part of their cultural background. It creates a communicative situation between teaching sources and students; favours the interpretation of the chemical formulae while respecting the rules inherent to the chemistry code; and addresses and resolves the first problem common to any communication as it establishes the message.

It might appear that the game CHICKA has little to do with Linguistics. This could be true at a first level of analysis. However, CHICKA demonstrated to be an effective tool to provide students with such a command of chemical formulae that allows considering the system of formulae as a language, and therefore can be used to better follow explanations about chemical concepts and processes.
At a deeper level of analysis, the idea of developing this computer game stems from the hypothesized parallel between Chemistry and Linguistics because it tries to reproduce the same mechanism of learning that are shown in the learning of the mother tongue in a child.

The full program consists of two separate games: CHICKA-Basic and CHICKA-Advanced. Both games have many levels of difficulty, and both include sublevels of increasing complexity - conceived so as to add a different chemistry rule each time. Because the linguistical translation (between chemistry rules and game rules) is performed by the program, the chemistry rules are perceived by students as game rules.

Any formula, composed each time according to the cards dealt to players with each hand, appears on the monitor only if it is correct: it will be one of the hundreds formulae of inorganic compounds. If the player makes the wrong selection, the PT pops up and no score is assigned. Then the computer takes the hand the player has missed.

In learning mode, the software does not expect any previous knowledge in the players: the computer has the first hand and the player must reproduce the computer moves. In the final test of each sublevel, however, and in the tournaments, the computer stops being the tutor and becomes the opponent.

The code [2] of the game is as follows:

- **The color.** The main valences of the elements are associated with different colors, so that elements of the same valency have the same color. Elements that present a secondary valency have two colors: the color of the group and black. Transition elements are light-blue in their main valency and light-blue/black in one of their most common secondary valences.

- **The check-box.** The check-box position on the card (left, right or center) is associated with the relative electronegativity value (low (metals), higher (non metals), or mean) assigned to the element (or the Group). The check-box in the center is given to cards that represent elements that in a compound behave as metals or nonmetals depending on the electronegativity value of the other element.

Chemistry is taught here by using images and taking advantage of the natural talent of teenagers for keen observation: the colours of the cards and the position of the check-box on each card are the things to observe, see figure 9.
During the game, the player will also begin to realize that the sequence in which the computer clicks on the cards corresponds to the sequence of the Groups in the PT that pops up any time a wrong move is performed, see figure 10. The game is for any user the world over as no nomenclature is used.

In inorganic chemistry the empirical formula gives essential information, as it gives a fairly complete description of the compound it represents. There is actually a code hidden into the spelling of the formula. Thanks to this code the computer can teach electronegativity, valency, anfoteric behaviour[3] and stereochemistry. To briefly illustrate how the game teaches these concepts, an attempt has been made to summarise the relevant game-chemistry rules as follows:
Electronegativity

The condition imposed by the first game rule, together with the knowledge of the sign borne by each Group as indicated in the PT, reveals that elements sitting on the left of the formula bear positive combining-power. With this the player can infer the existence of a ‘certain’ characteristic (electronegativity) that governs the position of the elements in the formula, whose trend proceeds from left to right in the row and bottom up in the column (group) of the PT.

Valency / combining-power

The computer imposes the condition that the player selects as many cards of one group as the number of times the element appears in the formula. Thus the player understands that elements can combine one another with different ratios and, for example, to match one Group IV card a player needs two Group VI cards. Should the player’s selection be incorrect, the computer pops up the PT where it is shown that the combining power of the two groups are different: +4 for the Group IV and -2 for the Group VI.

Anfoteric behaviour

The game imposes as a first rule to click first on the card that has the check box on the left or more on the left, the central position of the check-box allows the player to make hydrogen sit on the left of the formula if the other card the player wants to select has the check-box on the right, and on the right of the formula if the other card has the check-box on the left. The possibility for a chemical entity to behave in different ways depending on the context (its position) is called anfoteric behaviour. The anfoteric behaviour of hydrogen is signalled in the formula by the spelling, while in the game its potential anfoteric behaviour as an element is signalled in the hydrogen-card by the central position of the check-box.

Stereochemistry

To compile formulae made out of more than two elements such as for example potassium, sulfur and oxygen in the salt $K_2SO_3$, the computer considers the group $SO_3$ as if it was a single element and puts it in brackets; it then gives it the appropriate combining-power. The group $SO_3$ (and all other similar groups) is represented graphically by a three-dimensional geometry; in this way students link their background knowledge of Geometry to Chemistry, understand the importance of the spatial distribution of the atoms in the molecules and therefore begin to get acquainted with Stereochemistry.

The students’ goal is to score as many points as possible; therefore students will spontaneously follow the game rules, thus applying without knowing concepts of valency, electronegativity, stereochemistry, etc. This initial phase is important, because by the time the teacher introduces and explains these concepts in the classroom, making also references to the game rules, the students link the explanation to their gaming experience and in the next game apply consciously these concepts to the game in order to maximize their score.

Part 2 – The empirical research: Participants

As previously described, the second part of the method followed for this research, consists of the empirical research, subdivided in two stages: 1 – CHICKA has been used in the
classroom to test the speed of Language Acquisition; 2 – Using macro-linguistics concepts to teach chemistry and testing whether the interest in the subject increased.

The subjects that volunteered for the empirical part were students whose socio-cultural background differed considerably among the various schools: a village (Mirano), two industrial towns (Pordenone and Mestre), and a university heritage city (Venice) (Figure 11).

Figure 11 Participants in relation to the socio-cultural context of participants

The types of secondary schools were also different: some had a humanistic focus, and some had a technical focus. Students’ ages were from 14 to 15 and from 16 to 17.

Part 2, Stage 1 had 250 participant students tested.

Part 2, Stage 2 had 220 participant students tested.

A Control-Test Group of students (that followed the traditional method and were tested in parallel) consisted of an additional two classes of students per school that participated in the project.

Stage 2 was introduced during the first year of chemistry studies and throughout the second year to the same students that participated to Stage 1. A research limitation consisted in the different syllabus that different schools have about chemistry studies: in some schools Chemistry is taught for one single year, while in other schools it is taught for two consecutive years.

It has therefore not been possible to bring all participants of Stage 1 into Stage 2, and the number of participants to the two Stages does not imply that some students could not be promoted to the second year, but simply reflects those classes that did have two years of chemistry studies in their syllabus.

Part 2, Stage 1 – Using CHICKA to learn the Language of Chemistry

The participants that followed the method described in this study are referred to as Group 1, while the other students that followed the traditional method are referred to as the Control-Test Group.

The computer game was introduced to Group 1 as a new tool of language acquisition to test if the time required to learn the elements of the PT, the basic formulae and concepts could be reduced when compared to the same ability achieved through traditional, text-book methods.
The traditional method of teaching chemical formulae followed by the Control-Test Group is based on classroom lectures of Atomic Orbital Theory. Once the lectures were delivered, the students were requested to memorize the Periodic Table. At this stage the teacher was coaching the class with exercises that demonstrate how the various elements combine and how chemical reactions occur.

The results of Stage 1 were measured in quantitative terms (length of time occurred to learn). The measurement had to vary according to the Group of student that was tested: in Group 1 students were given two tests. These were similar in concept to the tests usually given to students at the end of the first term (14 weeks), however in this case the tests were given after only 6 weeks. The first consisted in showing students a list of formulae, among which they had to choose the correct from the incorrect ones. This test was used to verify the ability to recognise a correct chemical formula.

The second test consisted in playing with CHICKA in “test mode” (as opposed to the “learning mode” of the game). This test was used to verify the ability to compose chemical formulae starting with the single elements.

In Group 2 students were also given two tests, however while the first test was the same that had been used by Group 1, the second test consisted in requesting the student to compose some formulae and chemistry reactions among those shown during classroom lectures.

**Part 2, Stage 2 - Using macro-linguistic concepts to teach chemistry**

Once the teacher is satisfied that the students are proficient in the Chemistry language, some lectures are given to recall the cross-disciplinary knowledge of the students about linguistical concepts, and to introduce and explain the chemical concepts from a linguistical standpoint.

The message, the context, the story and the ellipsis are all explained within the chemistry language context. This initial introduction allows the teacher to continuously reference the students’ encyclopedia when proceeding in the teaching method.

The teacher would introduce to the class a process to be analyzed, whenever possible bring the class to an on site visit (industries), and then conclude the circle by an open discussions with the students to translate the described process into chemical formulae.

The results were measured through constant monitoring of students’ interest and participation from both a quantitative and qualitative perspective. The number of students that was actively participating in class (e.g. questions) and the number of overall questions defined the quantitative parameter of the results.

The qualitative parameter to define students’ interest was defined by the pertinence of the questions themselves, how deeply were they geared in order to achieve a complete, detailed understanding of the process, and how closely connected were the questions to the flow of the class activities. It was shown that there was an increase of questions logically connected to concepts learned through a detailed answer just offered, thus showing that the ability to construct logical connections was increasingly applied to the subject.
The Results

Stage 1 Both Groups of students have 3 chemistry classes of one hour per week, reaching a total of 45 hours of chemistry class per quarter. The test is administered to both Groups halfway through the quarter, at the end of week 6. In Group 1, 80% of the students showed that the speed with which they could learn to read and write chemical formulae increased by 133% (the learning time reduced from c. 14 weeks to c. 6 weeks).

5% of students showed the same time reduction, but in relation to reading and recognising the formulae only, and not to composing them.

15% of students did not benefit of this method and reacted in the same way as they did to traditional methods.

In Group 2, only 40% pass the test administered at the end of week 6, and it is necessary to wait until the end of the quarter (week 14) in order to see 80% of the students being able to recognize and compose chemical formulae without errors (see fig. 12).

Figure 12 Learning time

Figure 13 Stage 1 Overall Results
Stage 2 results were measured in qualitative terms, as the focus was the very interest shown towards the subject, and the quality of learning (high marks versus low marks) compared to the same quality achieved with traditional methods.

Focus on interest and quality was deemed critical because it is essential to the concept of teaching itself, where teachers’ objectives are not only to have students proficient in the class syllabus, but also to have students engaged with the subject at hand, and certainly generally interested in the learning process per se, so that education becomes a life long commitment.

40% of students showed interest in the subject taught, compared to 15% that showed interest when taught in a traditional manner.

Interest was measured by looking at how closely they were following the classes, and how often they participated to class discussions without prompts. The students that showed interest were not (as it is often the case) always corresponding to the top students: in determining the level of interest shown, the marks achieved were not taken in consideration (Figure 15).

When analysing the results through focusing only on the good Chemistry students (marks 7 to 10 in a marking scale that measures from 0 to 10), 66% of the good Chemistry students were also proficient in Maths. This data can be compared with classes where the traditional method was taught. In those classes 98% of good Chemistry students were also good Maths students (Figure 16).
Figure 16 Stage 2 Results: “traditional” and “new method” comparison in relation to the percentage of students also good in Maths.

The research method therefore expanded the top student base by 33%. Of little statistical significance, but of some interest, is the case of a single student that did not achieve a sufficient level of results in ANY of their subjects and that had to repeat the year: this student did achieve the pass mark (6) in Chemistry.

It is difficult to understand whether the increased interest in the subject is a consequence of the CHICKA game and of the better familiarity to the use of formulae, or if it is a consequence of the students’ understanding that the system of formulae is a language, together with the teachers explanations of the link between Chemistry and Linguistics to introduce chemical concepts according to macro-linguistics principles.

The authors tend to believe that the increased interest into the subject is due to the second factor. This conclusion is based on the fact that through the use of CHICKA students acquire familiarity with formulae, but they are not yet able to identify with a correct name the compounds that they are building. For example, they would associate the symbol Fe with the word iron, the symbol O with the word oxygen, and would therefore call the formula FeO “iron-oxygen” instead of the correct “iron oxide”. For this reason it looked apparent that the students at the end of the first phase (week 6 of the teaching process) did not yet understand that FeO is a compound that has different characteristics from Fe and O (similar to a child that learns the word “overdo” but hasn’t understood exactly what the word means).

It is at this point that phase 2 begins. Here the teacher explains the difference between “iron oxygen” and the compound of “iron oxide”, using the comparison with micro-linguistics concepts.

In this way, the effort that students must go through is reduced, because to learn and memorize the new compound they only need to associate two pieces of information already known.

It was noted that right at the point in which the teacher explains the connection between the system of formulae and the characteristics of language, students show complete engagement, apparently fascinated and struck by this new perspective.
Conclusion

The creation of a conceptual framework by teaching through multi-faceted issues played a constructive role in developing awareness of the relationship between chemistry and other disciplines and resulted in a significant re-orientation of attitudes by demonstrating the role of chemistry in life with a valid influence on students’ judgment and attitude.

The effectiveness of this approach has been demonstrated by the dramatically diminished gap between teaching and learning. Long lasting learning was verified by using this approach on students who chose Chemistry at University level. The atmosphere in the classroom was pleasant and friendly. The knowledge of the language of Chemistry acquired before entering the study of chemistry improved the ability to comprehend the subject matter.

In conclusion, the teaching-learning process implemented on the knowledge of the language of chemical formulae to which the content of chemical processes adds, together with a close attention given to matching chemistry processes to the Story of real life, gives a proper understanding of how expression and content are linked in chemistry.

The theoretical and empirical research parts have highlighted the added value of a teaching methodology that closely links the learning of new concepts to the real life of the students, together with the importance of keeping the perspective of macro-linguistics concepts through the phase of this message transfer: the lecture.

If it was possible to achieve this in a subject such as Chemistry – usually considered by students as an abstract theory, far from real life – it is reasonable to hope that the same method applied to other subjects could lead to similar if not even better results. Specifically, what has been developed during Stage 2 of the theoretical part (the attention towards the message, the context, the noise, the Story and the Plot) can be considered generally applicable to all sciences. This certainly assumes a commitment from teachers to restructure the content of their lessons in order to match the described linguistics concepts to the real life of their own students.

As for Stage 3 of the theoretical part, the game CHICKA, it is necessary to explain that this is only one of the many methods that can be used so that students are encouraged into learning the language of chemistry. Within the scope of this study, we have seen that it is a particularly efficient method but, again, it is possible that other methods are available to achieve this linguistical fluency.

This study used CHICKA as one of the available methods for one of the phases, while the perspective of the macro and micro linguistical concepts within the context of real life examples and the students’ encyclopedia is the main focus.

The application of linguistic concepts to the teaching of Chemistry is not dependent, nor is a consequence of, the use of this specific game. It was simply shown how, once again, the play element and the physical movement of students enhance their ability to concentrate, memorize and understand a subject. This concept is valid generally: the “play” element has been included in most teaching methods for a long time, with obvious differences dependent on the age of students – for adult learning just consider role-playing and problem-solving activities.
The added value introduced with CHICKA is that – although not applicable to every subject – it is applicable to every language. It can be used in any country in the world as there are no references to a specific language: the only language taken in consideration is the universal Language of Chemistry.

Acknowledgements

For the evolution of this work I want to thank the many students I have taught and from whom I have learned. I would especially like to mention Hugo Edgardo Lombardini of the Centro Linguistico Interfacoltà, CLI, of Venice University and prof. Gianni Zanmarchi of the University Ca’ Foscari of Venice for their substantial support to the idea of giving chemical formulae the status as language.

Notes

[1] This was highlighted in the initial discussion among multidisciplinary teachers where they were asked to give their perception on the interest shown by students whenever these modern methods of real life experiences and on the field visits were used.

[2] Students need not be informed on the game code and rules. They will learn through playing.

[3] Gr. ἀμφότερος (amfòteros) = in two ways, the one and the other.

Bibliography