NEW TRENDS IN LEARNING STRUCTURES IN EUROPEAN HIGHER EDUCATION: AN OPPORTUNITY FOR ENCOURAGING CRITICAL THINKING IN CHEMISTRY STUDENTS

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ABSTRACT

In June 1999, in Bologna (Italy), 29 ministers of higher education signed the known as “Bologna Declaration.” Forty five European countries are now involved in the “Bologna Process,” which has the ultimate goal of establishing, by 2010, an open *European Higher Education Area* in which students and staff can move with ease and have fair recognition of their qualifications. In this context, the priority is the quality assurance and the harmonization of degree system throughout the participating countries. New degrees will have a credit structure based on ECTS, the *European Credit Transfer System* . Among other considerations, the ECTS involves a student-centered teaching. In the first part of this discussion, I will explain the goals and steps involved in the Bologna Process and, in the second part, I will give a short view of how analogies, questions, experiments and exercises, developed from real-world applications, can be used for motivating students' interest in Chemistry learning within the philosophy of the new trends in University European Education.

1. TOWARD A EUROPEAN HIGHER EDUCATION SPACE: THE BOLOGNA PROCESS

It was on May 25, 1998 that the Ministers in charge of higher education of France, Italy, United Kingdom and Germany signed the Sorbonne Declaration, on the occasion of the 800 th anniversary of the Sorbonne University, proposing the harmonization of the architecture of the European Higher Education System. With the Bologna Declaration in June 1999, the number of signatory countries increased to 29 countries (not only from European Union members' states but also from non-members' states as well as from Norway and Switzerland). The Bologna Declaration (1) has a clearly defined common goal, which is the creation of a coherent European higher education space by the year 2010. There is an action programme in the Bologna Declaration, which is defined by six specific objectives:

• Adoption of a system of easily understable and comparable degrees through the implementation of a Diploma Supplement, in order to promote European citizens employability and the international competitiveness and the attractiveness of the European higher education system throughout the world.

• Articulation of studies in a system essentially based on two main cycles, undergraduate and postgraduate levels. Access to the second cycle shall require successful completion of first cycle studies, lasting a minimum of three years. The degree awarded after the first cycle shall also be relevant to the European labor market as an appropriate level of qualification. The second cycle should lead to the masters and/or doctorate degree as in many European countries.

• Generalization of a system of credits - such as in the ECTS (European Credit Transfer System) system - as a proper means of promoting the most widespread student mobility. It must be noted that the credit system was unknown to most of the continental European countries ten years ago.

• Elimination of remaining obstacles to the mobility of students, teachers and graduates, with particular attention to students (access to study and training opportunities and to related services) and to teachers, researchers and administrative staff (recognition and validation of periods spent in a European context researching, teaching and training, without prejudicing their statutory rights).

• Promotion of a European dimension in quality assurance and accreditation with a view to developing comparable criteria and methodologies.

• Promotion of the necessary European dimensions in higher education, through an organized follow-up and implementation structure, based mainly on intergovernmental cooperation conducted in collaboration with education institutions and associations. The Declaration also states that ministers would meet again in Prague in 2001 to review progress and plan for the next stages. In fact, after signing the Bologna Declaration, the ministers in charge of higher education of European signatory countries met every two years in different cities (Prague 2001, Berlin 2003, Bergen (Norway) 2005, and the next conference to be held in the city of London, in 2007) to follow up the Bologna Process and to set directions and priorities for the coming years.

In many countries, legislative changes introduced after the adoption of the Bologna Declaration have contributed to accelerate the movement toward convergent reforms. Spain, for example, has already announced the replacement of all old degrees by new ones, the newly created accreditation councils are now operational and the introduction of credit-based studies is reaching the operational phase at all universities. In a number of countries, there is an animated debate about the respective role of universities and colleges/polytechnics concerning the award of masters degrees.

The change toward more convergence and compatibility is a complex process in which political and educational aspects need to be coordinated in a dynamic way; stimulation for change do not always come from the same side, and contacts at the European level between ministers, governmental officers/agencies, heads of institutions, teachers, administrators and students are the main means to overcome resistance. Static and bureaucratic ways of thinking and acting among a number of education decision- makers, university governors and administrators, as well as university staff, can present severe obstacles in the substantial restructuring of higher education.

Fig. 1. Map of countries involved in the Bologna Process .

2. A NEW CREDIT SYSTEM STUDENT CENTERED: E.C.T.S.

Given the aims of this work, among other aspects of the Bologna process, it may be more useful to introduce a brief explanation about the t he European Credit Transfer and Accumulation System (ECTS).

A credit system is a systematic way of describing an educational program by attaching credits to its components. The definition of credits in higher education systems may be based on different parameters, such as student workload, learning outcomes and contact hours.

The ECTS is a student-centered system based on the student workload required to achieve the objectives of a program, specified in terms of the learning outcomes and competences to be acquired. ECTS was introduced in 1989 within the framework of the Erasmus program. It is the only credit system which has been successfully tested and used across Europe. ECTS was set up initially for credit transfer, and it facilitated the recognition of periods of study abroad and thus enhanced the quality and volume of student mobility in Europe. Recently ECTS is developing into an accumulation system to be implemented at institutional, national and European level. This is one of the key objectives of the Bologna Declaration of June 1999, as pointed out before.

The key features of ECTS are:

- It is based on the principle that 60 credits measure the workload of a full-time student during one academic year. The student workload of a full-time study programme in Europe amounts in most cases to around 1500-1800 hours per year and in those cases one credit stands for around 25 to 30 working hours.

- Credits in ECTS can only be obtained after successful completion of the work required and appropriate assessment of the learning outcomes achieved.

- Student workload in ECTS consists of the time required to complete all planned learning activities such as attending lectures, seminars, independent and private study, preparation of projects, examinations, and so forth.

- Credits are allocated to all educational components of a study programme (such as modules, courses, placements, dissertation work, etc.) and reflect the quantity of work each component requires to achieve its specific objectives or learning outcomes in relation to the total quantity of work necessary to complete a full year of study successfully.

- The performance of the student is documented by a local/national grade. It is good practice to add an ECTS grade, in particular in case of credit transfer. The ECTS grading scale ranks the students on a statistical basis.

ECTS makes study programs easy to read and compare for all students (local and foreign), facilitates mobility and academic recognition, and helps universities to organize and revise their study programs. But ECTS is not reduced to the issue “workload of students“; it has enormous potential for reforming and improving higher education curricula, cultures of learning, and structures.

The coherent and meaningful implementation of ECTS implies that it is possible to successfully complete study programs and their modules within a specific timeframe defined by the work load of students. This would mean for a number of European higher education study programmes enormous re-orientation.

Coherent introduction of ECTS (instead of rather ambivalent units of measurement such as weekly hours of tuition, meaning actual classroom instruction) implies far-reaching changes in the professional responsibilities and working contracts of higher education staff, as well as changes of learning cultures (compulsory attendance of students in seminars vs. orientation on pre-defined learning outcomes with students as autonomous learners responsible for their learning processes).

3. REAL-WORLD APPLICATIONS FOR ENCOURAGING CRITICAL THINKING IN STUDENTS

For a good number of Chemistry educators in Spain, the Bologna process is a threat for the present way of teaching, but I see it as an opportunity for a positive change. A lthough some changes have been introduced in recent years to University Chemistry courses, the main method of teaching in countries such as Spain is still the lecture. Students do not spend much time studying independently, but rather spend their time listening to lectures and taking notes. There are seldom tutorials. Outside the lectures, students are only required to complete assignments. At the end of the semester, they have to pass the final examination.

According to the aim of ECTS, the most important aspect is making students more active learners. In this context, it is necessary to significantly reform the structure and teaching style of chemistry courses. There are many things that can be done to improve the traditional teaching strategies in general Chemistry:

- Redesign the contents by using interesting examples related to real life. Examples based on everyday life should be used as often as possible. This is one of the best ways to promote the interest of learner. From the examples, the student will find that the difficult concepts become easier to understand.

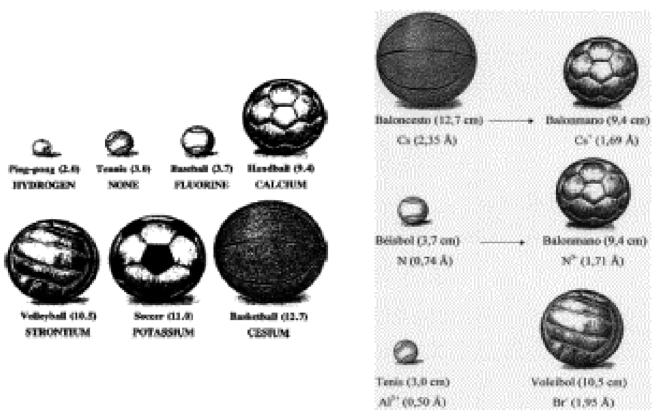
- Using contemporary teaching approaches. Using correctly the different theories about teaching and learning has its advantages. Several useful strategies are: the use of concept mapping, problem-based learning (by means of challenging tasks for students), case studies, interdisciplinary approaches, team participation, and develop online learning.

In the last few years I have developed a program intended to help chemistry teachers include connections between students' everyday experience and chemical principles taught in the classroom. The idea is that students have a greater appreciation of the principles of chemistry if they can see the relevance to their own lives. This idea of using a familiar context with chemistry is common but not found usually in textbooks. Discussing these kinds of examples may encourage students to explore topics in more depth. Real-world applications (apart from lectures and laboratory work) serve to favor students-centered approaches. Apart from other works, such as the experimentation about an ancient method for cooling water explained by mass and heat transfer (2), or the use of news from media for the learning of Chemistry (3,4), I summarize here several works I have developed related to analogies, exercises and experiments. More details about them can be found in the corresponding references.

3.1. Using Balls from Different Sports to Model the Variation of Atomic and Ionic Sizes (5).

Teachers have found that analogies that relate to real-life examples and students' daily experiences usually help students to understand certain science concepts. Such analogies help students develop non-observable pictures by comparing them to something observable with which they are familiar.

Periodic variation of atomic sizes, normally evaluated by atomic radii, is an important topic in introductory chemistry courses; but the order of magnitude of this variation, involving submicroscopic scales, is difficult for students to imagine. The radii of official balls of seven well-known sports are given in Figure 2. Students are involved in the activity of finding atoms that correspond to the various sports balls because, for homework or for a classroom activity, they must assign an atom for each ball, by using tabulated single-bond covalent radii and by considering that the smallest ball (the ping-pong ball) is assigned to the smallest atom (the hydrogen). They must find the most similar atom in proportion to the ball of each radius, accepting a deviation of, for example, 5%.



With this analogy the following effects can be debated in the classroom: Comparison of the order of magnitude of variation between the extreme tabulated covalent radii—those of hydrogen and cesium; Typical trend for atomic size within a family in the periodic table: IA (H, K, and Cs) or IIA (Ca and Sr); AND Typical trend for atomic size for a row in the periodic table: K and Ca.

Fig. 2. Left: Balls of several sports and corresponding atoms, by analogy in terms of relative size. The radius of typical official balls, in centimeters, is given in parentheses. Right: relationship between ion sizes and balls, in accordance to the analogy.

3.2. The effect of temperature on the rate of dissolution of a fizzy tablet (6).

This work presents an experiment illustrating the effect of temperature on a reaction rate, and the determination of the activation energy, E_a . The explanation of E_a is common, but it is relatively unusual to find a simple experimental demonstration for Freshman Chemistry Laboratory. Effervescence is a popular delivery system for oral dosage of some medications such as aspirin, vitamin C or antacid. The reaction of a solid organic acid such as citric acid with a bicarbonate or carbonate source in water produces carbon dioxide (effervescence) and a salt of the acid. This reaction provides rapid dissolutions of the active ingredients and improves palatability and solubilizing actions for several drugs.

There are a number of multicomponent formulations for effervescent products. Effervescent tablets normally contain at least citric acid or other similar acids, and sodium bicarbonate (baking soda), as the effervescent excipient agent, so that when it is added to water, the bubbling of the CO_2 causes the drug to dissolve. The solid acid does not react with $NaHCO_3$ in the tablet form (dry), but when the tablet is added to water a vigorous change occurs.

Experimentally it has been found that the rate constant, k, of a reaction can usually be related to the temperature by eq. 1, the Arrhenius equation:

$k = A \cdot \exp(-E_a / RT)$ [1]

where R is the gas constant and T is the absolute temperature. The equation contains two parameters: A is called the preexponential or frequency factor and E_a is the experimental activation energy. E_a is commonly expressed in kJ per mole. Reactions typically have E_a in the range 8-200 kJ/mol. Using the previous equation including the time taken, t, to complete a certain fraction of a reaction is inversely proportional to the rate constant, we can say that:

$\ln t = C + E_a / RT$ [2]

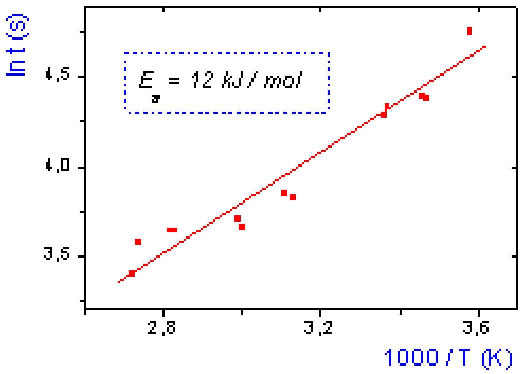
where C is a constant incorporating *-ln A* and the proportionality constant.

The time is measured at different temperatures, T, by introducing a fizzy tablet into a known volume of water. The effervescence starts immediately, the carbon dioxide bubbles out of solution with the familiar fizz, and students can easily determine the time until the tablet is exhausted, t. A plot of ln t *vs.* 1/T then permits the calculation of E_a .

Figure 3 shows a typical example based on a set of 14 data points for dissolving a fizzy tablet, named *Couldina* , in 200 mL of water. Temperatures from 5 - 95 ºC give times in the range 30 - 120 s. The observed decrease in the value of reaction time with an increase of temperature is consistent with the observation that the rates of almost all chemical reactions increase as the temperature goes up. The linear relationship that exists between ln t and 1/T, obtained by means of the least-squares method, shows a good correlation. Thus, the reaction has “Arrhenius behavior” in the temperature range studied and follows the equation:

$\ln t = (-0.4 \pm 0.3) + (1.4 \pm 0.1) \cdot 10^{-3} / T$ [3]

with a correlation coefficient of 0.98.



The slope of this graph results in an apparent value of the activation energy for the range 5 - 95ºC of $E_a = 12 \pm 1$ kJ/mol.

Fig. 3. A plot of ln t vs. 1/T for the dissolution of a fizzy tablet immersed in water, where t is the time taken and T is the absolute temperature.

3.3. Kinetics of the osmotic hydration of chickpeas (7).

This work describes a straight-forward activity to introduce students to several concepts, normally discussed in the university level freshmen and sophomore chemistry class, and other topics introduced in other subjects such as Physics, Calculus or Biology, in order to allow the quantitative explanation of a process familiar to students.

The main purpose of this activity is to present a simple and novel kinetics laboratory or home assignment covering miscellaneous topics. In this experiment students measure the rate at which water is absorbed by dried chickpeas. Measurements are made at several temperatures and using water and salt solutions. By calculating the initial hydration rate at different temperatures, the Arrhenius-type activation energy may be estimated. Under isothermal conditions, the kinetics of moisture sorption by foods, such as cereal grains or legumes, can be modeled by application of the Peleg equation. This model may be represented by the following equation:

$$M(t) = M_0 + t / (k_1 + k_2 \cdot t) \quad [4]$$

where $M(t)$ and M_0 are the moisture content of the solid (w/w) at times $t>0$ and $t=0$ respectively, and k_1 and k_2 are rate constants. According to this model, the equilibrium moisture, M_E, is asymptotically attained, i.e., when t ® ¥ :

$$M_E = M_0 + (1 / k_2) \quad [5]$$

Similarly, the momentary sorption rate, $dM(t) / dt$, is given by:

$$dM(t) / dt = k_1 / (k_1 + k_2 \cdot t)^2 \quad [6]$$

and the initial rate, i.e., at $t=0$, by $1 / k_1$. A general feature of mathematical relations such as Eq. 4 is that they can be transformed to a linear relationship in the form:

$$t / [M(t) - M_0] = k_1 + k_2 \cdot t \quad [7]$$

In our case, due to the negligible initial equilibrium moisture content of the chickpeas at room conditions, we will suppose $M_0 = 0$ and Equations 4 to 7 may be simplified. Figure 4 illustrates the variation of moisture content with the immersion time during osmotic hydration at the range of temperatures studied. As expected, the hydration rate increases with temperature, due primarily to the combined effect of increasing diffusivity and decreasing viscosity. According to an Arrhenius-type behavior the semi-log plot in Fig. 5 predicts the temperature dependence of the initial hydration rate as:

Initial hydration rate (g water / (g initial wt.·min)) =

$$= (24.8 \pm 7.0) \cdot \exp [(-2.35 \pm 0.11) \cdot 10^3 / T) \quad [8]$$

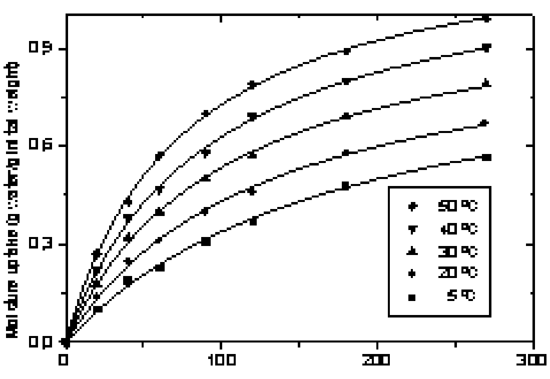


Fig. 4. Graph of the moisture uptake (g water/g initial wt.) for chickpeas immersed in water at different temperatures. Curves show the Peleg model.

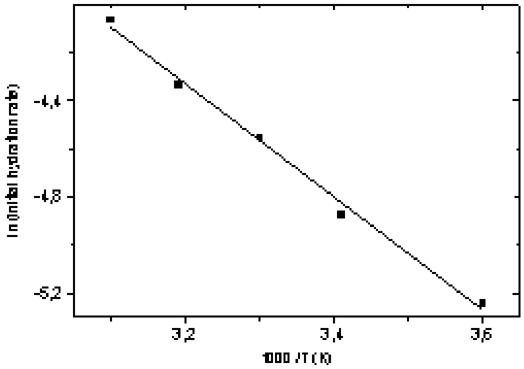


Fig. 5. Graph of natural logarithm of the initial rate of hydration (g water / (g initial wt.·min)) as a function of reciprocal Kelvin temperature.

From the slope of this plot, ($-E_a/R$), the apparent energy of activation (E_a) was calculated as 19.5 ± 0.9 kJ/mol.

3.4. Stoichimetry of medicines.

Here are several motivating exercises pertaining to the study of stoichiometry and other topics, to encourage critical thinking in students, which should be a primary purpose in general chemistry.

3.4.1. Stoichiometry applied to an iron medicine (8).

As an introduction to the problem, students could be told that iron(II) sulphate sesquihydrate is used in pharmaceutical products, recommended for pregnant women and high-risk infants being screened for iron-deficiency anemia. Iron is essential for the production of hemoglobin, the red oxygencarrying pigment in red blood cells.

Problem: The current information leaflet for a medicine indicates that each tablet contains 256.30 mg of ferrous sulphate sesquihydrate, equal to 80 mg of iron. In a previous version of the leaflet, the same manufacturer indicated that the amount of this salt per tablet is 270 mg and that it is also equivalent to 80 mg of iron. According to stoichiometric considerations, which of the two leaflets gives the correct amount?

Answer: First we must know that the formula for iron (II) sulphate sesquihydrate is $FeSO_4 \cdot 1.5H_2O$ to calculate its molar mass. The molar mass of iron (II) sulphate sesquihydrate is 178.93 g/mol. Considering the current leaflet, and assuming from the salt's formula that the molar ratio is one mole Fe to one mole salt, the stoichiometric equivalent of iron present in each tablet is 80 mg Fe, as shown in Eq. 9. So the current leaflet's claim is correct. For completeness, following the same stoichiometric procedure, the value of 270 mg of salt, given in the other instructions, corresponds to 84.3 mg of Fe.

$$\frac{0.25630\ g\ salt}{178.93\ g/mol\ salt} \times \frac{1\ mol\ Fe}{1\ mol\ salt} \times \frac{55.85\ g}{1\ mol\ Fe} \times \frac{10^3\ mg}{1\ g} = 80.00\ mg\ Fe$$

[9]

3.4.2. Determination of the degree of hydration of iron (II) sulphate in a medicine (9).

Students could be informed that iron (II) sulphate, as other salts, can be presented with different degrees of hydration. In that case, the most common are: mono, sesqui, penta and heptahydrate. The iron (II) sulphate is a component of pharmaceutical products, recommended for the prevention and treatment of iron deficiency. *Problem:* The current information leaflet for a medicine indicates that "each tablet contains 525 mg of ferrous sulphate, equal to 105 mg of iron element". According to stoichiometric considerations, and by supposing that the ferrous sulphate has a certain degree of hydration, determine the chemical formula of the corresponding salt.

3.4.3. Stoichiometry of calcium medicines (10).

Here I use the topic of calcium supplements to provide a context in which to review much of the core content of general chemistry, including: stoichiometry; concentration units; hydration of salts; inorganic and organic salts; physiological importance of elements; resonance in ions; geometry of polyatomic ions and isomerism.

Question No. 1. The information leaflet for several medicines and medicinal sourcebooks indicate that a quantity (per tablet, per envelope or per spoonful) of different compounds is equivalent to a certain quantity of elemental calcium, as indicated in the third column of the Table 2. Check by stoichiometry the values of equivalences given.

Question No. 2. In the information about a medicine the manufacturer indicates that there are 800 mg of calcium phosphate, 200 mg of calcium carbonate and 5 mg of calcium fluoride per tablet. According to the information, these quantities are equivalent to 393 mg of calcium ion and 2.43 mg of fluoride ion. Check these equivalences.

Question No. 3. According to the prospectus of a medicine, recommended for deficiency of vitamins and mineral salts, each tablet has, among other substances, 90 mg of calcium as calcium phosphate and 70 mg of phosphorus, also as calcium phosphate. By considering these data, check that the indicated “calcium phosphate” is not $Ca_3(PO_4)_2$.

Question No. 4. Based on the information supplied on the packaging, the composition of each effervescent tablet of a supplement (medicine F in Table 1) for the treatment of decalcification shows that, among other compounds, it contains 2.94 g of calcium lactategluconate and 0.30 g of calcium carbonate, both altogether equivalent to 500 mg of calcium ions. Deduce from these data a composition of calcium lactategluconate provided the gluconate forms usually monohydrate.

Table 1. Calcium equivalences data for selected medicines.

Medicine Ca compound Equivalence in Ca element a Equivalence in Ca element b

A 1250 mg calcium carbonate 500 mg 500.5 mg

B 1260 mg calcium carbonate 500 mg 505 mg

C 2500 mg calcium carbonate 1000 mg or 25 mmol 1001 mg or 25 mmol

D A spoonful (=15 mL) of solution with

1671 mg calcium phosphate per 100 mL 100 mg 97 mg

E 3750 mg calcium pidolate 500 mg 508 mg

F 2.94 g calcium lactategluconate and

0.30 g of calcium carbonate 500 mg 500 mg

a data given by the manufacturer as shown in prospectus and medicine handbooks.

b data obtained by considerations of stoichiometry.

Question No. 5. Following from the previous question, determine the number of stereoisomers of the lactate and gluconate anions.

Question No. 6. Identify in which of the calcium salts mentioned above the bonding of the anions can be explained in terms of resonance structures.

Answers for these questions can be found in Ref. 10.

3.5. Stoichiometric determination of the boron content of a fertilizer (11).

As an introduction to the problem, students could be informed about the use of fertilizers. In this sense, plants require several nutrients for formal growth. They draw C, H and O from the air and water. They absorb N, K, Mg, Ca, P and S from the soil.

Problem: Several months ago, I was going for a walk in the country and I found, near a field of cherry trees, a white plastic sack printed with information about the substance contained in it. According to stoichiometric considerations determine, by using two digits after the decimal point in the atomic weights, if the bore percent content indicated in the sack is correct.

3.6. Chemical composition of mineral waters (11).

Mineral waters contain, as suggests the name, various minerals (inorganic compounds) and trace elements although they are indicated in the label of bottles. These minerals have various effects on the health. Many people drink mineral water each day without giving any thought to the components. As an introduction to the problem, students could be informed about the importance of chemical analysis for the characterization of beverages.

Problem: Look for information about the chemical composition of a mineral water in the label of a bottle or in the Internet. According to stoichiometric considerations determine if the value of dry residue or total dissolved solids is in accordance with the chemical composition. Further, calculate the total positive and the total negative charges and discuss the results. To answer the questions, take into account that hydrogen carbonate anion decomposes in carbon dioxide and carbonate anion at high temperature.Discussing this kind of example may encourage students to explore topics such as water hardness, characterization of beverages, chemical analysis, rounding off in calculations, and so on, in more depth. The activity may be used to introduce a more quantitative experiment or to suggest ideas for additional experimentation. For example, it is easy to measure in the laboratory several ion concentrations or the dry residue contained in bottles of mineral water and to compare data with such provided by the manufacturer.

3.7. Use of chloroisocyanurates for disinfection of water (12).

This work describes a motivating and holistic approach to the study of the chlorination of water produced by "mysterious" (at first for the students) compounds, allowing students to focus on the versatility of the general chemistry concepts. After an introduction to the subject a series of questions is proposed in order to address many topics, including: formulation; molar mass; stoichiometry; chemical equations; balanced equations; oxidation states; acid-base reactions; tautomerism; resonance; chlorinating products; and the use of chlorine as a disinfectant.

3.8 Chemistry of moth repellents (13).

In this work, I suggest a set of questions about a household product, very well known by students, such as moth repellents, to motivate students to understand everyday phenomena through their underlying chemistry.

4. CONCLUDING REMARKS

As is always the case with respect to educative tools, there is no one best teaching strategy to teach students in all courses. Teachers should use different teaching strategies according to different situations of teaching content. More information about topics covered in the work and other analogous examples can be found (in Spanish) in http://quim.iqi.etsii.upm.es/vidacotidiana/Inicio.htm .

ACKNOWLEDGMENT

The author would like to express this sincere appreciation to Prof. Paul Kelter, for his valuable suggestions, which helped to improve the manuscript. I would also like to thank Universidad Politécnica de Madrid, for the funding support (*Ayudas a la Innovación Educativa en el marco del proceso de implantación del EES y la mejora de la*

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Note the comparison to the U.S. 9-month academia year, in which a full-time load is considered 32 credits, with each credit representing 15 hours of in-class instruction (more, with a laboratory course) or about 480 total hours of in-class instruction. It is often said in U.S. that students should study for 3 hours for each credit, meaning a total study time of 1440 hours in addition to the 480 in-class hours.
