Chapter 1

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Context and Inquiry-Based Chemistry Teaching and Learning for Engineering Students

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Abstract

The central idea of this chapter is to show some applications carried out in recent years with first-year Industrial and Chemical Engineering students who study Chemistry. The aim of these kinds of experiences is that students solve, as a team, a series of problems and cases contextualized in their day-to-day life. To do that, they must understand a given problem, search for the underlying data set, analyse different information sources (in Spanish and English) for the data search, discriminate between the contents of the subject (and others) that they must apply, carry out experiments (in some cases), proceed according to an accurate data processing, make approximations, analyse the results (whose outcome is open) and propose future inquiries and applications. In detail, the cases included in this publication, chosen among dozens of others that have been adopted and implemented, are an experimental study of the ice melting rate in various liquids, calculations, and analysis of the relationships between vehicle fuel consumption and carbon dioxide emissions, discussion about self-heating beverage containers, chemical and thermodynamic fundamentals of domestic condensing boilers, and critical analysis of pseudoscientific deceptive information. These examples, suitable for other studies and stages of education, show that students are more interested in the subject and they acquire skills in a more appropriate way than with the use of more traditional problems, which are of a closed nature regarding the baseline data and with unique findings. Therefore, there is a clear contribution to the education of more responsible citizens with better knowledge of some products and technologies that they use in their daily lives. On the other hand, these experiences and other similar ones, have been made available for secondary teacher training courses to promote its use in pre-college educational stages.

Keywords: Inquiry-based learning, Contextualized Teaching, Consumer Chemistry, Chemistry for the Citizen, Competency-based learning.

Introduction

Students are often insufficiently interested in chemistry because they perceive science education as “irrelevant” both for themselves and for society (Dillon, 2009). This is a very worrying situation for students of the different engineering fields who usually perceive chemistry as a subject that is more remote from their interests than others, such as those related to math and physics. This work is part of a research program intended to help teachers include connections between students' daily experiences and chemical topics. The idea is that by bringing tangible examples we provide opportunities for students to apply science to familiar contexts with the hope that they will appreciate chemistry more and will be motivated to study concepts in greater detail.

We summarize here the results about contextualized open-ended and real-world problems and cases carried out with first-year engineering students, applicable to other educational stages and fields. There are only five examples, among several dozens of others, which have been developed in the last three decades and a half, which are easily accessible through the papers collected on the website https://bit.ly/33UdyYD.

The goals and challenges were:

- To improve students' (and also teachers') motivation.
- To encourage critical thinking skills in students.
- To promote science literacy and social responsibility for the education of students as citizens.
- To facilitate the acquisition of concepts (stoichiometry, thermochemistry, combustion, fuels composition, conversion factors...).
- To collaborate on the development of competencies (problem-solving, data analysis, teamwork…).
- To promote science literacy, social responsibility, and the understanding of Science-Technology-Society (S-T-S) relationships.

To address these goals, it has been considered appropriate to use updated educational tools (such as inquiry-based learning, active learning, and team participation). Besides, during the development of the cases, it has been observed that they are very useful to detect alternative conceptions and misconceptions in students, a fundamental aspect to bear in mind in the teaching and learning process. These aspects are summarized in *Figure 1.1.*

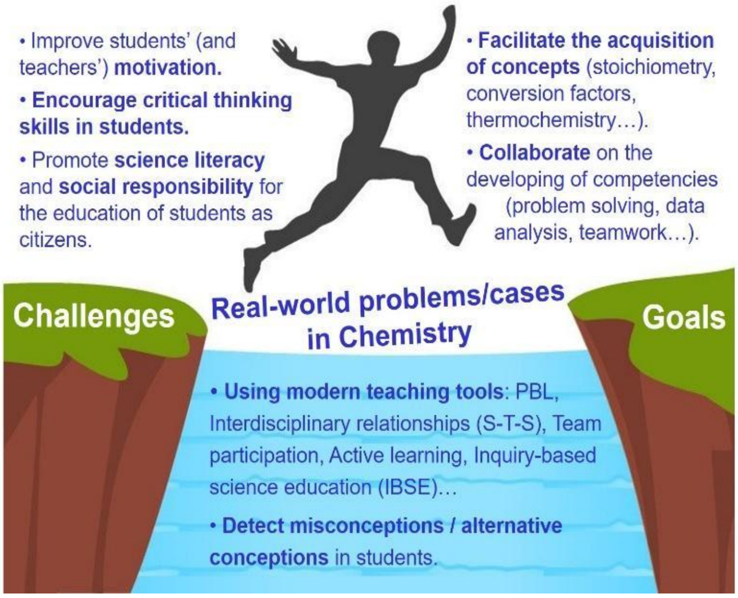

Figure 1.1. Outline of the challenges, goals, and teaching tools used in the methodology described in this paper, based on the use of real-world problems and cases in the learning of chemistry.

Some general characteristics of the activities suggested to the students were the following: use of short class time (usually less than 5 minutes in an hour-long class), and around 3 weeks to solve each one as homework; groups of 3 students; account for 10% of the grade; open results and the need of data mining. Also, the general rules indicated for students were, in short: the reports must be written (including, where appropriate, the preparation of tables, drawings, and graphics); results must be indicated (with appropriate units and care taken in the significant digits); proper citation of references and sites visited; and recommendation of discussion of the activity with the teacher before the delivery of the final project.

The stages and characteristics of the methodology of problem-solving followed for these cases were similar to those discussed by Rodríguez-Arteche and Martínez Aznar (2016).

To solve each case, the students must understand the problem posed, search for the initial data, analyse the different sources of information (in English and Spanish) for the search of the data, select the knowledge of the subject (and others) that they must apply, experiment (in their case), proceed according to an appropriate data processing, make approximations, analyse the results (whose outcome is open within reasonable margins) and propose future inquiries and applications.

Case 1: Rate of melting ice cubes in different aqueous solutions.

As an example of a simple but useful experimental experience, students research at home about the variation of the rate of melting ice cubes in different aqueous solutions. This case serves to discuss physicochemical concepts (Pinto & Lahuerta, 2015) but, mainly, it is an experience that is usually done the first day of class to introduce students to the scientific method, underline the importance of critical thinking and highlight the advantages of teamwork.

Thus, students are asked: “Where will it melt an ice cube before: in water or in water saturated with table salt?” After letting them think about it for a few minutes, the results are written down on the blackboard providing the opportunity to give 4 possible answers: “it melts before in water with salt”, “it melts before in water without salt”, “it is practically equal”, or “I don’t know”. As soon as the answers are gathered, the students are told to discuss the question in groups of three, asking the same questions next. The number of answers given to the 4 possible options changes, after the discussion as a group, which is a good occasion for the teacher to introduce the importance of teamwork. Also, during the time for discussion as a team, the teacher pays attention to the explanations given among the students. Typical examples are usually detected, for example, the fact that salt is added to prevent ice from roadways on very cold days because it lowers the melting point of water. Finally, students are suggested to recommend how it could be solved, as they have given different answers. Although sometimes they offer other alternatives (searching on the internet, enquiring experts on the topic, researching textbooks…), it is common, as a way of taking time to reflect, to find the option of doing it at their homes, using simple means, for example, a pair of glasses, water, table salt and two pieces of ice. Therefore, the teacher invites students to carry out experiences related to it, recommending them to study some other variable in detail too. Some of the results obtained during measurements are specified in Figure *2*, in which it is observed that, opposite to what is normally considered a priori (not only by students but also by teachers too), the time of melting ice is faster with pure water.

The phenomenon observed is due, mainly, to the different densities in liquid water at different temperatures and in salted water. Thus, I the case of ice in pure water, the water recently formed by the fusion descends, because it has a bigger density (at 0ºC approximately) than the liquid water at the beginning (at room temperature), forming convection currents that can be visualized easily adding some drops of food colouring (see *Figure 1.2.*). On the contrary, in the case of the ice added to the salt solutions, the water of fusion remains on top, because it has a lower density than the solution, without observing convection currents, so the ice is surrounded by colder water than in the previous case and the process is slower.

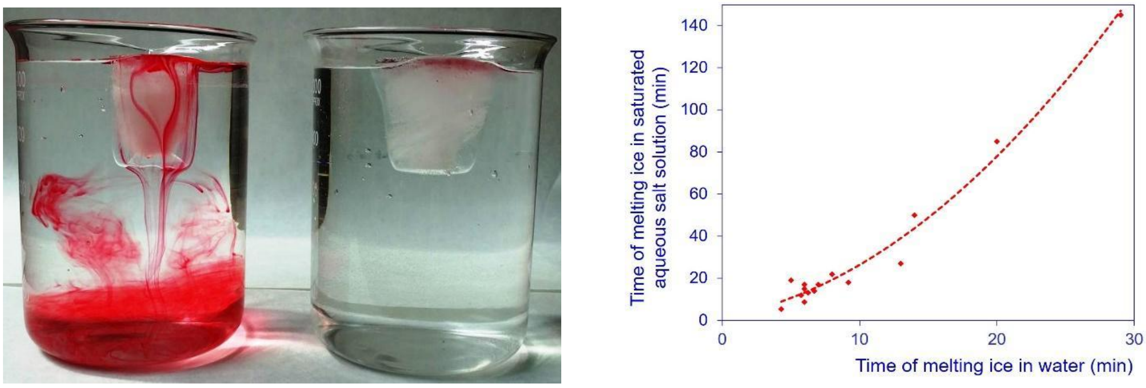

Figure 1.2. Detail of the experiment: melting ice in water (left) and in saturated water of table salt (right) with some drops of food colouring. Experimental data were obtained by students from the time of melting ice (blocks of different sizes) in both liquids.

Other questions the different groups of students can investigate, by their initiative and/or guided by the teacher, are: force the ice with a rod to be underwater, use of different concentrations of table salt, use of sugar instead of salt, use of constant agitation or fluid at rest, the measure of temperature to different heights of the liquid, and others. From their observations and a discussion of everybody´s results, the teacher can ask the students questions such as: “Why does one of the ice cubes move?”, “Why are water droplets produced in some cases on the outer wall of the vessel?” Surprisingly, some students suggest as an answer to this question that it is liquid water that oozes the “pores” of the glass, instead of suggesting that it is condensed water from the water vapour in the air. There are always further inquiries too, such as: “Is it possible to get a transparent (and not translucent) ice cube in the freezer at home?”, “What happens if we add an ice cube on cooking oil?”, “Why?” … They are experiences that can be studied thanks to simple practices that can be done, for example, in the kitchen at home. For instance, when you put an ice block in cooking oil, the ice stays on top, but the liquid water (of a higher density than the oil) produced by the melting of the ice sinks. Some of the results of these observations are shown in *Figure 1.3.*

As an example, a group of students tried to work with ice blocks made up of different beverages in the freezer of their homes, and they found it weird that vodka did not freeze: that is the way they discovered, thanks to the experiment and own their own, what freezing-point depression is since this alcoholic drink has a 40 % vol. of ethanol. This was a starting point for the teacher to explain it and to comment on the example of the regular use of the automobile antifreeze.

Figure 1.3. On the left, surfaces of the experiment described in the text with the ice (on the left in pure water and on the right in water saturated with salt); it can be observed the formation of condensation water droplets, on the outside of glass cans, in the second case. On the right, ice in cooking oil at room temperature.

This example is useful for motivating and also as a starting point to observe how properties of simple substances (water and sodium chloride) influence complex phenomena, such as thermohaline convection currents in oceans, caused by density gradients, as well as involved current topics, such as the circulation of microplastics at the bottom of the seas, a topic which is even discussed in the media.

Case 2: Emission of CO_2 by cars.

The contribution of CO_2 emissions to climate change is also frequently mentioned in the media. Through different questions and problems, students can discuss quantitative aspects related to the emissions, such as its relationship with vehicles fuel consumption, as it is posed in this activity. For this case, students must utilize basic chemical principles such as stoichiometry, density of liquids, and combustion reactions to calculate theoretical emission rates of CO_2 which are then compared to actual consumer product information (Oliver-Hoyo & Pinto, 2008). Representing graphically the emission of CO_2 versus consumption of fuel, it provides a tangible way of connecting concepts studied in chemistry classes to everyday life. Students are instructed to gather car CO_2 emission and fuel consumption data from a specific source. In fact, different sources are available for the kind of information required in this exercise. For example, students can gather this data from auto supplements that appear in papers (auto advertisements), popular auto magazines, car manufacturer data information online, car sales labels, or websites, which provide the information required in this activity for a variety of carmakers and models and which is freely accessible. As the students collect this data, the link between chemistry and everyday life becomes stronger.

The data are reported in units of grams per kilometre for emission of CO_2 and litres/100 km for fuel consumption. Students must graph emission of CO_2 (in g/km) versus fuel consumption (in L/100 km), which results in a line equation (see *Figure 1.4.*) whose slope is comparable to the theoretical stoichiometric calculations for CO_2 production in a combustion reaction for a particular fuel component. Since two major types of fuel are used (at least until now) in the automobile industry, gasoline and diesel, doing this exercise for the two types of fuels show differences between them in terms of CO_2 emission levels and fuel consumption.

Two assumptions for the theoretical calculations must be explicitly stated to the students: only the major component of the fuel is taken into account and all driving or climatic conditions are disregarded. For gasoline, octane, C_8H_{18}, is considered as the primary ingredient, and dodecane, $C_{12}H_{26}$, for diesel. The strength of this exercise is that even after such simplification in its treatment, theoretical values are comparable to released consumer data.

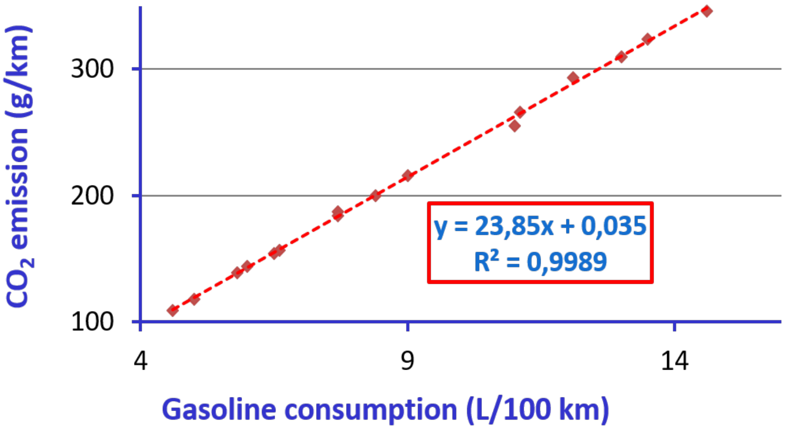

Figure 1.4. Example of CO_2 emission representation versus fuel consumption according to a group of students.

Stoichiometric relationships and the density of the fuel provide the necessary conversion factors to calculate the theoretical amount of CO_2 produced. An example calculation considering the density of gasoline as 0.75kg/L (each group of students must choose the density value, either consulting a data table or measuring it in the lab, with the teacher´s help) is shown below.

For octane: $C_8H_{18} + 12.5\ O_2 \rightarrow 8\ CO_2 + 9\ H_2O$

$$\mathrm{CO_2\ emission} = \frac{\text{Octane consumption (L/100 km)}}{\text{100 km}} \cdot 0.75\,\frac{\text{kg}}{\text{L}} \cdot \frac{\text{1 kmol octane}}{\text{114.22 kg}} \cdot \frac{\text{8 kmol CO}_2}{\text{kmol octane}} \cdot$$

$$\cdot \frac{\text{44.01 kg}}{\text{kmol CO}_2} \cdot 10^3\,\frac{\text{g CO}_2}{\text{kg}} = 23.1\ (\text{g CO}_2 / \text{L}\cdot\text{km})\ \text{x Octane consumption (L in 100 km)}$$

For gasoline the range falls between 21.6g CO_2/L and 24.1g CO_2/L (for 0.70-0.78kg/L density values) while for diesel the range is between 24.8g CO_2/L and 30.7gCO_2/L (for 0.80-0.99kg/L density values). When students graph the data from a specified source, regression analysis provides a slope that falls within the calculated range. Graphs by students use data from diverse car brands and models. These graphs show strong correlations to the theoretical values calculated and provide a quick visual account of the differences in emission and fuel consumption of gasoline versus diesel engines. Even though diesel engines consume less fuel, CO_2 emissions reach higher levels per litre of diesel consumed. Despite this, when comparable engines are reviewed, diesel engines consume less fuel and subsequently have lower CO_2 emissions per distance travelled.

This activity can be extended to calculate the annual average CO_2 emission per vehicle type. The magnitude of these numbers may be used to promote awareness of environmental issues in the classroom as well as an opportunity to discuss other current related topics such as the Paris Agreement and the Kyoto Protocol.

This activity may also be used to leap into discussions regarding environmental issues, hybrid engines, and the efficiency of gasoline versus diesel vehicles which may be of interest to students majoring in areas as diverse as public policy or engineering. This activity is an instructional resource that utilizes consumer product information to compare theoretical stoichiometric calculations to available car emission and fuel consumption data. Considerable simplification of an otherwise very complex chemistry problem still provides comparable theoretical and actual data that links chemistry principles to everyday life. Practice with unit conversion and graphing skills enhance this activity in a very practical way promoting skills used by professionals to perform emission measurements.

Case 3: Thermochemistry of self-heating beverages.

There are food commercial products that claim to heat their contents based on the dissolution process of a salt or a chemical reaction (Oliver-Hoyo, Pinto & Llorens-Molina, 2009; Pinto, Llorens-Molina & Oliver-Hoyo, 2009; Prolongo & Pinto, 2010). This is an example of inquiry-based/discovery learning, encouraged through an example of a commercialized device in Spain (https://the42degreescompany.com/) about the heating of commercially available self-heating beverages that takes place thanks to the hydration reaction of the calcium oxide. In *Figure 5*, it can be seen one of these kinds of drinks and the manufacturer's information specified on the label together with the different components used for its manufacture.

The questions posed to the students to be solved in teams are the following:

1. Describe the container and the chemical reaction that takes place in the self-heating beverage.

2. Determine the excess and limiting reactants and calculate the mass of the product that can be formed.

3. Search (through different sources) the values of standard heat of formation, $\Delta_f H^o$, at 25 ºC, for the substances involved in the reaction and present them in a table. Calculate the heat (kJ/mol) evolved.

4. Prepare a table with end temperatures (experimental, according to the manufacturer, and calculated theoretically) and compare them.

5. Identify and discuss the assumptions made.

6. Comment on the advantages and disadvantages of these containers for beverages and suggest ways to improve these cans.

7. Comment on any interesting aspect of this activity (possibility to cool beverages, instructions given by the manufacturer, additional information…).

To answer the first question, the students must observe the information given by the manufacturer on the label and the website. It is the following reaction:

$CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s)$

To solve question 2, the teacher offers, as data, the masses of the two reactants which have been previously determined by him or her in the lab; the can is opened carefully (see *Figure 1.5.*) using a cutter and the substances are weighed on a scale, or the procedure can be carried out in the lab with the students (a more effective method from a pedagogical point of view). A specific case of masses of substances used and more details of the problem can be found in a previous paper (Prolongo & Pinto, 2010). The search of thermodynamic data needed in question 3 shows the students that there are different sources of data, and not all share the same rigor. Taking into account the quantity of $Ca(OH)_2$ that can be formed and the heat of the reaction (calculated from the data obtained in question 2), it is estimated the variation of temperature, ΔT, that the beverage would reach with the expression $Q = \Delta T \cdot \Sigma (m_i \cdot C_i)$, in which Q is the heat released in the reaction, m_i is the mass for each component, *i.e.* the different materials and substances involved (beverage, container and substances associated with the device) and C_i is the specific heat for the corresponding component (for the beverage, it can be considered as water). It is observed that the calculated final temperature theoretically is higher than the one measured with a thermometer and the one given by the manufacturer; among other reasons, it is due to the fact that, in all the thermodynamic processes, there is heat loss (ambient transfer, reaction yield …).

Figure 1.5. Can, label and different components for the commercially available self-heating beverage described in the text.

When students discuss this case, they consider, among the possible advantages, the benefit of drinking a warm beverage in places where it is difficult to heat it, for example, during an excursion to the mountain or when people go skiing. They take into account some disadvantages too, such as the increase in the price or the higher environmental impact compared to conventional beverages. Finally, students can go deeper into aspects related to other applications and designs of beverages, as is shown in *Figure 1.6.* With the new designs, the students put into practice what they have learned in other subjects during the year and they develop their creativity. Therefore, this activity can be considered an example of a STEAM (science, technology, engineering, arts and mathematics) educational case.

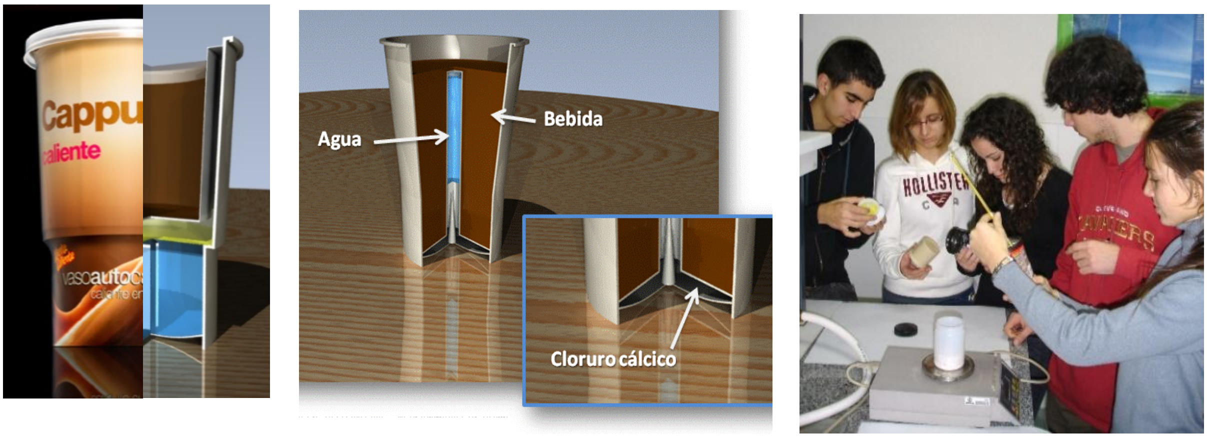

Figure 1.6. Self-heating beverages containers designed by students and a photo of students discussing the case.

Case 4: Why should we use domestic condensing boilers?

Among other examples posed to students, related to the quantitative evaluation of the reduction of CO_2 emissions through several methods, such as the use of solar power (Pinto, 2009), it can be highlighted the use of domestic condensing boilers (Pinto, 2013). Here is a brief description of the questions posed to students to inquire about aspects related to this kind of boilers (they get liquid water instead of steam). The specific goals are to facilitate the learning concepts (enthalpy change, combustion, natural gas…) and at the same time, it promotes critical thinking and "consumer chemistry", because of the discussion of aspects such as the causes of public support for the installation of condensing boilers and the use of household bills as an information source.

For example, there is a known "*Plan Renove*" for domestic boilers in Spain that is part of the "*Action Plan for Energy Saving and Efficiency*" developed for promoting the use of "condensing boilers". Taking into account that natural gas is the most used combustible in cities like Madrid, and after introducing the questions (for example, through a commercial advertisement, as the one in *Figure 1.7.*) in the classroom, the type of questions posed to students to be solved as a team are the following:

Figure 1.7. Commercial advertisement published in Madrid, in 2010, where citizens are invited to change a domestic conventional boiler by a condensing boiler.

1. Through suitable sources, collect in a table a typical composition of natural gas expressed as % vol. and mole fraction.

2. Create a table with the composition of a “model” natural gas, considering only the two major hydrocarbons.

3. Consulting adequate sources, provide a table with data of standard heat of formation, $\Delta_f H^o$ (kJ/mol), at 25ºC, for gases selected in the previous section and of CO_2(g), H_2O(g) and H_2O(l).

4. Calculate the standard enthalpy of combustion, ΔH^o_{comb} (kJ/mol), of natural gas, at 25ºC, assuming that the water is obtained as gas.

5. Repeat calculation by assuming that the water is obtained as a liquid.

6. Determine the quantity of natural gas that should be used, in a condensing boiler, per each mole of natural gas that should be used in the other kind of boiler (the conventional one), to obtain the same energy. Discuss economic and social implications.

7. Discuss if the condensate water in the condensing boiler is acid or alkaline.

8. Itemize the assumptions made in your calculations.

9. Discuss any aspect of interest (additional data, sustainability, environment, need to subsidize the condensing boilers, obtaining natural gas ...).

An example of a table in which it is described a typical composition of natural gas is shown in *Table 1.1*. Each group of students can give a different table, as the natural gas is a raw material of varying composition. Therefore, the students discover that the composition of natural products that consist of mixtures of multiple substances, such as natural gas, does not have only one composition. This seems weird to some students, who prefer to give compositions that look more exact and accurate. In question 1, it is also discovered that students do not usually have the habit of elaborating their tables, that sometimes the total composition exceeds 100% and that, frequently, they confuse the concepts of substance, chemical element, and compound.

Table 1.1. Example of the composition of natural gas.

Substance	**Formula**	**Composition**	
		% vol.	**Molar fraction**
Methane	CH_4	87.0-96.0	0.870-0.960
Ethane	C_2H_6	1.5-5.1	0.015-0.051
Propane	C_3H_8	0.1-1.5	0.001-0.015
Isobutane	C_4H_{10}	0.01-0.3	0.0001-0.003
Butane	C_4H_{10}	0.01-0.3	0.0001-0.003
Isopentane	C_5H_{12}	Traza-0.14	Traza-0.0014
Pentane	C_5H_{12}	Traza-0.14	Traza-0.0014
Nitrogen	N_2	0.7-5.6	0.007-0.056
Carbon dioxide	CO_2	0.1-1.0	0.001-0.010
Oxygen	O_2	0.01-0.1	0.0001-0.001
Hydrogen	H_2	Trace-0.02	Trace-0.0002

Question 2, although apparently simple, is usually a topic for discussion among students, because they find it difficult to understand that a simplification can offer an accurate result. One more time, it is expected that each group would offer a different composition for its "model" of natural gas, due to the fact that there are very different possibilities (always within certain limits). For example, one composition to simplify this kind of thermochemical calculations for the natural gas, is the one described in *Table 1.2*. A typical mistake in some groups of students consists in preparing a table in which the total amount of the two selected gases is not 100%.

Table 1.2. Example of the composition of a "model" natural gas, considering only the two major hydrocarbons.

Substance	**Composition**	
	Molar fraction	**% wt.**
Methane	0.850	75.1
Ethane	0.150	24.9

In question 3, similar to case 3 analysed previously, students discover that there are different ways of obtaining thermodynamic data, so they must choose the ones that are accurate, not always the same as those in other teams. Thus, the results obtained for question 4 could be as follows:

$$CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g) \qquad \Delta H^o = -803 kJ/mol$$

$$C_2H_6(g) + 7/2\ O_2(g) \rightarrow 2\ CO_2(g) + 3\ H_2O(g) \qquad \Delta H^o = -1429 kJ/mol$$

Taking into account the example in *Table 1.2.*, it is obtained:

$$\Delta H^o_{comb} = 0.85\cdot(-803 kJ/mol) + 0.15\cdot(-1429 kJ/mol) = -897 kJ/mol$$

Students solve question 4 with some difficulty, especially because of mistakes committed in the stoichiometry of the chemical reactions. When the previous calculation is repeated by assuming that the water is obtained as liquid (question 5), and, therefore, enthalpy of condensation of water at 25ºC (-44kJ/mol) is taken into account, the result is:

$$\Delta H^o_{comb} = 0.85\cdot(-891 kJ/mol) + 0.15\cdot(-1561 kJ/mol) = -992 kJ/mol$$

In question 6, which is the key aspect in the case, using the data at the two previous sections, the calculation is:

$$\frac{897\ kJ / mol\ gas\ conventional\ boiler}{992\ kJ / mol\ gas\ conden.boiler} = \\ = 0.904\ mol\ gas\ conden.boiler / mol\ gas\ conventional\ boiler$$

That is to say, the use of the condensing boiler guarantees a saving in the order of 10% of fuel (which Spain, as other countries, must import), and, also, that same percentage of CO_2 emission decreases caused by the combustion. This way, students observe how aspects related to chemistry allow explaining a question of great interest that has an impact not only on the user but also in the country: facilitates the use of gas for future generations. In any case, there are not only advantages: condensing boilers are more expensive than the conventional ones and they imply more maintenance cost, that is the reason why the State Administration offers grants to consumers to encourage the change.

Besides this key issue, the case can have other applications, as suggested in question 7. The answer is that the condensate water in the condensing boiler is acid, due to the dissolution of the CO_2 gas in that water, which produces the equilibrium:

$$CO_2(g) + H_2O(aq) \rightleftarrows HCO_3^-(aq) + H^+(aq)$$

In fact, the pH in the condensate water caused by condensing boilers is between 3 and 5, which causes certain technical problems in drainage.

Question 8 allows students to think about the approximations in calculations, for example in the use of a model of natural gas. Finally, in question 9 they go deeper and discuss topics that arise during the handle of the case, for instance, which countries are Spain's main natural gas suppliers, what are the technical specifications of a condensing boiler, or even that they participate in the supervision of a boiler at their homes to take a closer look at the main components that make it up.

As can be seen, apart from the practical development of physical and chemical knowledge and calculations, this type of problem raises classroom discussion of current issues, such as the importance of science for the achievement by 2030 of the Sustainable Development Goals (SDG), a call by United Nations for action by all countries – poor, rich and middle-income – to promote prosperity while protecting the planet.

Case 5: Critical analysis of pseudoscientific deceptive information.

Another case puts into practice the critical analysis of pseudoscientific deceptive information about some products. Among other examples, we have introduced students to the case of a certain salt contained in a glass ampoule that, according to the supplier, “changes” the bond angle of molecules of water and thus other properties of this liquid, with “healing effects” because it removes kidney stones. Another example is the case of a “special” bottle made with a glass “containing silica” that changes certain physicochemical properties of the water it contains, making it useful to heal certain diseases. In both cases, the students are provided with websites in which they will find the information (https://www.slackstone.com/en/ and https://www.flaska.eu/, respectively) to analyse in teams and then write a short report and discuss it in class.

Surprisingly, a lot of students think that they are scientific indications, with beneficial health effects. Others consider, on the contrary, that an apparently scientific language is used, but it is not well-founded. The teacher helps in the discussion by convincing students of the fact that although it uses scientific jargon, it deals with impossible aspects (“can the bond angle of the water molecule be modified?”) or simply indifferent (“any common glass used in the manufacturing of bottles contains silica!”). Also, he/she helps them analyse how apart from the use of a pseudoscientific language, the information is based only apparently on relevant bibliographic references.

This is a hot topic because of the proliferation of this kind of pseudoscientific information that, sometimes, is not banned by authorities because, despite not offering advantages, it does not have any harmful effects. It is also a topical issue of pseudoscientific information that defends the opposition to getting the Covid-19 vaccine, among other examples.

Outcomes

Intending to supplement the traditional content of introductory chemistry for engineering students, with training in critical and creative thinking, we have suggested a few examples of solving open-ended problems. These examples clearly link different chemistry principles (phase changes, stoichiometry, chemical formulation, chemical thermodynamics, production of energy…) to real life and social issues. Other topics and skills were included, such as comprehension of information given in English, preparation of scientific data tables and graphs, rounding off in calculations, and searching of data. For example, students need to search for data such as atomic masses, enthalpies, composition of common products..., to solve the problems.

By bringing tangible chemistry examples we provide an opportunity for students to apply chemistry to familiar products with the hope that they will be motivated to study concepts in greater detail, and will connect the relevance of chemistry to their everyday lives.

First-year undergraduate engineering students appreciated the question-answer approach and were motivated and interested. They liked the activities and most of them gained an appreciation for the necessity to study chemistry as an introductory science for their specializations.

Students' responses are not always positive: some of them complain that "these topics are not part of the course syllabus" and prefer more conventional problems. But most of them express keen interest in this type of "tangible" chemistry where concrete examples of everyday life put textbook chemistry in context. Further, such cases promote training in "consumer chemistry", and enable students to realize the relevance of chemistry outside the classroom, which is especially relevant for engineering students.

By the other hand, the implications and environmental issues related to proposed chemistry studies make this science more relevant, real-life reflection, and practical to students.

According to our experience, this kind of instructional tool is an effective way to help improve the students' engagement, motivation, and interest in chemistry. Some of the opinions given by students were the following:

- This kind of exercise helps us better understand the world around us.

- Makes chemistry a tangible experience so that it is not only solving problems on a piece of paper.

- It shows chemistry is not only a set of formulas and is valuable for something.

- Chemistry is very boring, any tool to make it more interesting is worth the try.

- My chemistry teacher in high school said that "chemistry is everything", and this helped me to see why.

- It serves to relate concepts of chemistry with products we can easily find.

- It can be observed the passion for the subject in the teacher when he/she poses practical examples

In short, in this way, there is a contribution to the education of more responsible citizens and a better knowledge of some products and technologies used in their everyday lives. These experiences, and other similar ones, have been taught by us in secondary teacher training courses too, at our same University, to encourage its use in undergraduate stages. With this kind of student (future teachers), the results are similar, and they show a great interest in applying them to their future students.

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