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Article

"MasterChemist": A Novel Strategy for Reviewing Stoichiometry and Introducing Molecular Gastronomy to Chemistry Students

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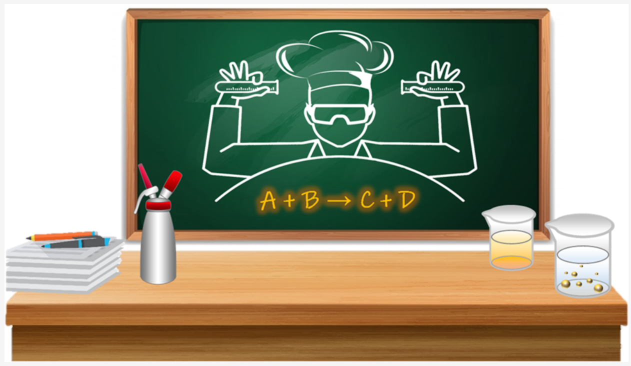
ABSTRACT: This article presents and discusses the results of an educational innovation that seeks to introduce the world of molecular gastronomy in chemistry lessons as a means to review stoichiometry and offer an alternative way to learn. In the literature to date, there is no evidence of haute cuisine having been employed to contextualize stoichiometry problem statements with its everyday applications. The proposed novel strategy, called "MasterChemist", involved the participation of Spanish first-year university students taking the subject General Chemistry in the Bachelor's Degree in Chemical Engineering. A Game-Based Learning (GBL) approach was used to solve the exercises and make the activity more appealing and interesting by adding fun to the learning process. The problems were contextualized in the use of siphons, isomalt sugar, and the spherification technique. Furthermore, dividing students into groups also boosted their cooperative skills. The students' answers to a final survey revealed that the general opinion regarding the activity was highly positive. The undergraduates reviewed some stoichiometry concepts which we had previously observed that they had problems understanding. In addition, the attractive theme of haute cuisine made the activity dynamic and enjoyable both for students and for the teacher.



KEYWORDS: *Chemistry, Stoichiometry, Applied Science, Molecular Cuisine, Motivation*

■ INTRODUCTION

In this paper, we evaluated the influence of novel stoichiometric exercises contextualized in haute cuisine and developed for chemistry students who are in their first year of the Bachelor's Degree in Chemical Engineering.

Students' Motivation through Contextualization

In the conventional teaching−learning process of sciences, such as chemistry, one of the main goals is to ensure students assimilate scientific facts, laws, and theories to form a body of scientific knowledge. Unfortunately, on many occasions in this process, no attention is given to aspects of scientific activity that have a direct relationship with student motivation, that is, for example, the relationship between academic contents and everyday life situations and real problems where scientific knowledge is used to solve them.[1] As a consequence, students cannot perceive the application of the academic contents in everyday life and this fact could lead to students losing interest in a subject because their attention was not attracted.

Another important aspect related to chemistry students' motivation is that many of them do not understand concepts where equations are needed and, hence, they solve, for example, stoichiometric problems mechanically, without truly understanding what they are doing. This is often accentuated by the fact that they have not fully assimilated some basic concepts of mathematics,[2] which are essential for all the scientific disciplines. The ability to apply mathematics in chemistry is fundamental to solve many problems, such as the use of logarithms to determine the pH value of a solution, or how to properly express the equilibrium constants of a chemical process, i.e., the relationship between pK and K values. Nevertheless, many students struggle with their mathematical skills and knowledge.[3] Besides, when they are asked the same question in a different way, they usually do not know how to solve the problem, which makes the subject difficult and boring for them. As a result, from that moment on, they lose interest in the subject.

It is also fundamental to improve the teaching−learning process where concepts learned in other subjects, such as mathematics, are connected with the concepts of mole and stoichiometry.[4] Hence, a good level in mathematics is essential to understand these or other chemical concepts more easily.[5] Likewise, the contents of subjects are interlinked.[6] Nevertheless, even though students often view the Chemistry

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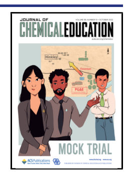

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curriculum as a disjointed set of topics and efforts made to enable them to connect concepts are usually further hampered,[7] a great deal of improvement is still needed in this respect.

It is common knowledge that chemistry is present in our lives, for example in medical drugs, energy drinks, fuels, detergents, fashion, climate change, sports, communication, health issues, nanotechnology, or food.[8−10] However, when concepts studied in the classroom are related to everyday life in our society, as in the present case with the contextualization of stoichiometry exercises with haute cuisine, students pay more attention and they are more interested.[11] Thus, they must not see the contents of chemistry as concepts that they only have to understand or memorize for the final exam.[12−14]

In addition, in the traditional teaching methodology, where the students work on exercises at home or alone in the classroom, they do not participate actively, and consequently, their attention in a session could also decrease.[15] Hence, in order to play a more active role in the classroom, students could work cooperatively. As a result, the students boost their coworking strategies, and they not only maximize their own learning capabilities but also play an important role in the learning process of their group mates.[16−18]

Educational Use of Cuisine in Science

To date, there is no evidence of haute cuisine having been employed to contextualize problem-solving activities of stoichiometry. Notwithstanding, the kitchen has been used for years in certain activities as a chemical laboratory at the primary and secondary education levels. As there is a rich history of using kitchen science to teach fundamental chemical concepts, some examples of it are indicated below.

In particular, in her book, Sánchez Guadix[19] gave scientific explanations for different experiences that students can investigate in the classroom and observe every day in their home when they or their family are cooking or cleaning.

For high school levels, Jones[20] proposed an activity so that students could experience for themselves in their kitchen at home what the scientific method is and how a term paper should be elaborated. For this purpose, students at home devised a hypothesis about the dish they would choose to make, and then they prepared it modifying a variable such as the type of spices, the amount of salt, the type of oil, or the cooking temperature. Afterward, the pupils observed the results, reformulated the recipe, indicated their conclusions based on the data collected, and finally, reported their work to the scientific community, which in this case comprised their classmates and the teacher. This activity enables students to expand their knowledge of the scientific method, learn to elaborate a scientific manuscript with their results, and gain confidence in their scientific skills.

Furthermore, García-Martínez et al.[21] offered three activities to do in the kitchen at home based on preparing muffins, spherifications, and cooking meat using different energy sources to tackle contents associated with energy and the changes undergone by matter addressed in the subject Physics and Chemistry in the third year of Compulsory Secondary Education.

The use of the kitchen as a chemistry laboratory has come to the fore in 2020 due to the COVID-19 pandemic. The two kitchen chemistry activities developed by Schultz et al.[22] improved students' observation skills and emphasized the importance of measurement and significant figures. The first of the activities included experimental measurement, solubility, heat capacity, combustion calculations for gas heating, and colligative properties. The second consisted in adding a constant amount of sodium bicarbonate and different amounts of vinegar in order to know the stoichiometry, connecting this to the gas law and the extraction of red cabbage as an indicator of the pH.

During 2020, Nguyen et al.[23] also suggested activities for higher education where different dishes could be prepared to introduce topics such as mixtures, colloids, concentration, energy, chemical reactions, and kinetics.

Besides, a food laboratory for a chemistry course had been developed by Cheng et al. in 2020.[24] The food preparations were designed based on chemical concepts that students had learned (accuracy and precision of measurements, stoichiometry and limiting reagents, acids, bases and pH, thermochemistry, melting points, and kinetics). Furthermore, the exams confirmed that this activity helped students to learn effectively new chemistry concepts.

With regard to haute cuisine, in the past few years there have been novel laboratory activities that linked chemical concepts with this type of cuisine. As an example, Radzikowski et al.[25] in 2021 developed the "Chemical Kitchen" project, which teaches the scientific method through gastronomy. The students, who worked in groups of three in a laboratory, cooked curd cheese, an egg yolk, and a freely creative dish based on haute cuisine. The students created using modern techniques faux caviar, foam, tea sphere, chocolate pebbles, chocolate bonbon, or meringue, to name but a few.

Finally, Corcoran et al.[26] in 2022 offered an experimental activity around the synthesis of biodegradable calcium alginate capsules and the study of their physical properties. Thus, different topics such as green chemistry or polymer science have been introduced as well.

Haute Cuisine

Haute cuisine has long been used to describe a style of cooking. It was born from the hands of French chefs who made cooking an art. French haute cuisine originated in the kitchens of the aristocracy during the 17th century, and it spread to the kitchens of wealthy households across the European continent in the next century.[27] At the same time, in the second half of the 18th century, haute cuisine reached the public domain in the restaurants of Paris, but this phenomenon was intensified during the French Revolution, when the number of restaurants increased dramatically.[28] Nowadays, haute cuisine restaurants can be found all over the world.

This type of cooking is constantly innovating in order to provide the best possible experience for its consumers, both in the taste and in the appearance of the dishes.[29,30] Due to the haute cuisine boom, in the early days of their career, some chef-owners, such as Ferran Adrià, changed the way they cooked from classical and nouvelle cuisine recipes toward haute cuisine, where creative methods, techniques, and concepts are used.[31] Moreover, in the present century, haute cuisine has come closer to the general population with television shows such as MasterChef, Hell's Kitchen, or Top Chef. When the modern techniques used for cooking are observed by scientists, it is easy to recognize that physical and chemical concepts are undoubtedly related to innovative culinary techniques.

Taking into account the success of these television shows and the fact that cooking is continually innovating,[32] as well as

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the scientific research involved, contextualizing chemistry exercises with haute cuisine may be of great interest. It appears to be an excellent way to allow students to perceive that science is present in everyday life and that it is necessary for any daily activity to progress. Hence, based on the above remarks, in this study we evaluate how stoichiometric exercises contextualized in cooking can be useful to review chemical concepts.

DESCRIPTION OF THE DIDACTIC PROPOSAL

General Objectives

The purpose of this study is to analyze the usefulness of reviewing stoichiometry exercises by introducing students in their first semester at university to the chemical concepts underlying molecular gastronomy. We aim to offer students new creative exercises based on supposed daily life experiences of haute cuisine. Our goal is also to offer an alternative way to avoid memorization techniques where students do not meaningfully incorporate new concepts.

The aforementioned objectives emerge as a response to the general lack of knowledge and misconceptions about stoichiometric problems of chemistry students and are based on Novak's theory of Meaningful Learning, which describes the process by which students incorporate new knowledge into their existing mental framework.[33,34]

Participants

This activity, which we have called "MasterChemist", involved the participation of 44 first-year university students who were enrolled in the subject General Chemistry programmed for the first semester of the Bachelor's Degree in Chemical Engineering at the Universitat Jaume I (Spain). The sample consisted of 23 males and 21 females, with an average age of 18 years. The students were previously informed about the objectives of this educational innovation along with a description of the methodology to be followed and the time it would take to complete the whole activity. All of them participated and answered the problems and the final questionnaire voluntarily.

Most of the participants had previously studied chemistry at high school for several years. Therefore, it was supposed that they had the required knowledge to properly solve stoichiometry problems. Nonetheless, a clear lack of knowledge about stoichiometry was noted over the two preceding months in which they had attended theoretical and problem-solving sessions. Thus, although the "MasterChemist" activity was conducted with undergraduate students at university, it could well be applied in problem-solving sessions at lower educational stages, such as high school. By doing so, students with different levels of education can review or delve into the basics of stoichiometry while they are introduced to the magnificent world of molecular gastronomy.

Methodology

The time required to develop the activity was estimated to be 2 h (the time of a problem-solving session of the General Chemistry subject). It must also be noted that some extra time may be needed depending on the stage in which the activity is applied. In addition, although it was not implemented in our case, teachers can also combine the problem-solving strategy (discussed herein) with some experimental demonstrations in the classroom concerning the topics discussed in the different exercises. With this in mind, the total time of the activity could be altered for larger classroom settings combining both the exercises and the practical part.

A Game-Based Learning (GBL) approach was used to solve the problems and make the activity more appealing and interesting by adding fun to the learning process. The GBL technique has been used for a long time and has stood out for having a positive effect on cognitive development.[35,36] GBL is unceasingly devoting attention so as to add some fun to the lessons and make them more dynamic, especially for areas of learning where the material often tends to be boring and students lose interest.[37,38] Hence, the use of GBL is a very adequate approach for solving stoichiometry problems.

To carry out the activity, students were divided into groups of 6 or 7 people to foster cooperation and group tasking, two aspects in which first-year undergraduates often fall short.[39] Once the groups had been established, students were given a short presentation about molecular gastronomy and the chemistry underlying it, together with an explanation of the main features of the problems that were going to be solved. After that, each group received a sheet of paper with a set of problems printed on it. As will be further discussed below, the exercises were divided into three different problems corresponding to the three main blocks of stoichiometry that were to be reviewed, namely gases, reactions, and dilutions. With the aim of both bringing molecular gastronomy closer to students and offering a real application of chemistry to stimulate their cognitive and reflexive abilities, each problem contained a set of successive exercises framed in a short and instructive story. Bearing in mind the GBL approach, the different groups could gain points if they gave the correct answer to the exercise. To motivate them, they were given some extra marks on the subject as a reward, according to the number of points the group achieved.

Before students could solve the problems in their respective groups, the teacher read the question and gave any required explanations, if necessary. Then, in a cooperative mode, the undergraduates started to solve the exercise. Once a group considered they could have a right answer, they raised their hands, and the rest of the students stopped working. If the answer given was correct, the group gained a point, and then the teacher explained the solution to the problem to ensure everyone got the right concept. If the answer proposed by the students was incorrect, the groups could continue to work again until the right response was achieved. At the end of the activity, all students answered an online questionnaire about their satisfaction with the strategy implemented in the problem-solving session.

As will be discussed further below in the Results and Discussion section, the time of the activity could also be extended if groups work at their own pace and the competitiveness character of the activity is decreased.

PROPOSED ACTIVITIES AND MOLECULAR GASTRONOMY BACKGROUND

The different activities proposed to students were divided into three different problems in accordance with the scope covered by the exercise (gases, reactions, and dilutions). Each problem was also linked to a different concept/technique employed in molecular gastronomy: the use of siphons, isomalt sugar, and spherification, respectively. The following subsections contain a brief introduction to the haute cuisine background of each problem, since it can be useful for chemistry teachers who want to implement this or similar activities in their classrooms. We

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also include a description of the chemical concepts involved, and we provide helpful comments to implement additional exercises or modifications in the classroom. The problems proposed and step-by-step solutions can be found in the Supporting Information.

Problem 1: Use of Siphons (Exercises about Gases)

Siphons are very common utensils used in haute cuisine to obtain foams, creams, and bubbles. Originally, they were designed to make whipped cream, although in 1994 the Spanish chef Ferran Adrià started using siphons to produce mousses and foams with unusual ingredients, such as vegetables, fruits, fish, or meat, something that was considered a milestone in the culinary world.[40] Siphons are canisters (commonly made of aluminum) with a metal cap that includes the whipping mechanism. The screw-top contains a nozzle attachment that allows dispersion of the solution, and a hole to introduce the gas charger holder.[41] A schematic representation of a siphon and its main components is depicted in Figure 1.

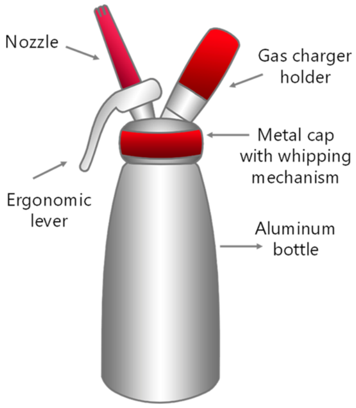

Figure 1. Schematic representation of a siphon and its main components.

Common siphons have a capacity of 0.5 L and are usually filled with the liquid of interest up to 80% of their volume. The solution is poured into the canister, then the lid is screwed on, and a gas is introduced into the chamber to increase the internal pressure. Subsequently, the siphon is shaken to spread the gas and allow it to mix with the liquid. The siphon can then be cooled or partially heated depending on the desired result. When the lever is pressed, the solubilized gas expands due to the difference in pressure, and the nozzle guides the foamed liquid out of the canister.

The gas (N_2O or CO_2) is usually sold in individual 8 g disposable charges. Carbon dioxide (CO_2) is used to give the food a carbonated effect, while nitrous oxide (N_2O) is used to produce foams, generally called "espumas" in reference to the original term coined by Ferran Adrià. N_2O can dissolve quickly in animal fat or proteins. Therefore, it is sometimes necessary to add an additive (fatty matter, lecithin, gelatin, etc.) to the liquid if it does not contain enough of it naturally.[42]

From a chemical and educational point of view, the use of a siphon opens up new avenues in the design of exercises about gases. In order to review the general concepts, students must take into account and be familiar with different magnitudes and parameters: temperature, pressure, molar mass, number of moles, units of the constants, and so forth.

Furthermore, it is also a good strategy to review the different gas state equations, that is, assuming an ideal (eq 1) or real (eq 2) behavior:

$$PV = nRT \tag{1}$$

$$\left(P + a\frac{n^2}{V^2}\right)(V - bn) = nRT \tag{2}$$

where P is the pressure of the gas, V is the volume occupied by the gas, T is the temperature, n is the number of moles, R is the ideal gas constant, and a and b are parameters that are determined empirically for each gas, although they can also be estimated from their critical temperature (T_C) and critical pressure (P_C).[43] We must note that, for the sake of simplicity, we have used the van der Waals equation to describe the real gas behavior, although other more sophisticated models such as the Dieterici, Clausius, or Virial equations could also be explained and employed.

The thematic thread of this first problem was a contestant in a famous cooking competition who attempted to prepare a lemon foam with a siphon (see more details in Section S1 of the Supporting Information). We gave students three exercises that included the calculation of pressures under different conditions using both ideal and real gas behaviors. Moreover, the last two exercises are intended to stimulate cognitive thinking and avoid repetitive and boring calculations. The students can solve the problem rationally, step-by-step, and finally calculate the percentage of nitrous oxide that has been solubilized in the liquid mixture prepared by the contestant.

Problem 2: Isomalt Sugar (Exercises about Reactions)

Isomalt is a type of sugar that is highly appreciated in baking for artistic elaborations with caramel due to its physicochemical properties. It is a sweet, low-calorie, odorless, crystalline, bulking agent with a pure sweet taste similar to sucrose (table sugar).[44] Industrially, isomalt is obtained from isomaltulose (6-*O*-α-D-glucopyranosyl-fructofuranose), a sweetener that is absorbed far more slowly in the body than sucrose. For this reason, isomaltulose is used in the elaboration of sugar-free baked goods for diabetic people.[45]

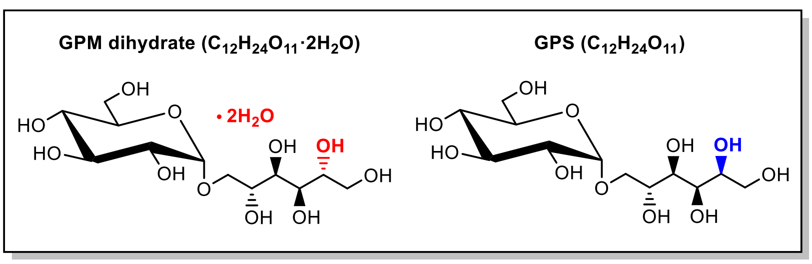

Figure 2. Chemical structures of GPM dihydrate and GPS highlighting the different stereochemical configurations of the hydroxyl group.

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From a chemical point of view, isomalt is made up of an equimolar (1:1) mixture of two disaccharides: glucomannitol dihydrate (1,1-GPM: 1-*O*-*α*-D-glucopyranosyl-D-mannitol dihydrate) and glucosorbitol (1,6-GPS: 6-*O*-*α*-D-glucopyranosyl-D-sorbitol), whose chemical structures and molecular formulas are indicated in Figure 2.

Sugars (composed of carbon, hydrogen, and oxygen) are good candidates for implementation in stoichiometric problems about chemical reactions such as combustion or decomposition (dehydration). Bearing this in mind, a vast gamut of exercises can be designed depending on the concepts needing revision: reagent purity, yield, amount of a product obtained after a reaction takes place, and so forth. The second problem in the "MasterChemist" activity considered different approaches to the reaction concepts (see more details in Section S2 of the Supporting Information).

On the one hand, the second problem started with an exercise focused on reviewing the decomposition reactions. As an experience based on reality, we proposed the case of a chef who intends to prepare a caramel dome suitable for diabetics using isomaltulose. She puts isomaltulose to heat in a saucepan but starts with the rest of the preparations and forgets the sugar on the stove. When she comes back to it, the chef notices that only a blackish dry residue remains. Thus, students have to write and balance the dehydration reaction of isomaltulose as well as identify the dry residue as carbon.

The other exercises in this problem were about isomalt. First, the participants had to calculate its molar mass taking into account the corresponding disaccharides and their concentration. A series of exercises about combustion reactions were then proposed, where the participants had to write and balance different reactions and use the concept of yield to calculate the amount of a product obtained.

Problem 3: Spherification (Exercises about Solutions)

The spherification technique consists in creating spheres with a liquid consistency encapsulated by a thin, hydrocolloid gel-like membrane. These spheres can be constructed in many sizes and from many different foods.[46] In haute cuisine, spherification makes it possible to obtain faux caviar (pearls), eggs, gnocchi, or ravioli. These spherical elements range from having a thin membrane (filled with a nongelled liquid) to elements that are gelled throughout.[47] Depending on the food used and the type of sphere to be obtained, there are two main spherification strategies: direct and reverse. The products commonly used are calcium chloride ($CaCl_2$) and sodium alginate ($NaC_6H_7O_6$), which is a polysaccharide obtained by extraction from seaweed.

For the "MasterChemist" activity, we used direct spherification as an educational tool because it is easier to work with in dilution exercises. The following steps are usually carried out for direct spherification:

(1) The liquid of interest and sodium alginate are mixed at a ratio of 5 g/L and cooled in the refrigerator.
(2) An aqueous solution of calcium chloride with a concentration of 5 g/L is prepared in another container.
(3) The alginate mixture is slowly added (with a syringe or other utensil) over the calcium bath, and the spheres obtained are rinsed.

When the two substances come into contact, the alginate reacts with the calcium to form calcium alginate ($CaC_{12}H_{14}O_{12}$), a gelatinous substance that coats the spheres, as can be appreciated in Figure 3.

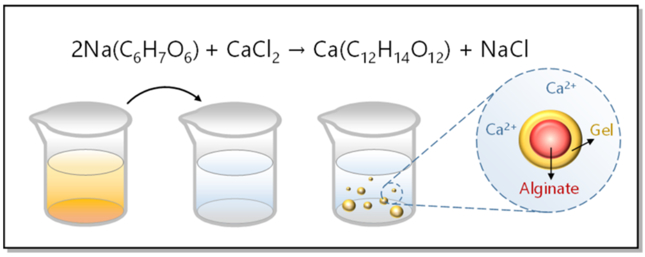

Figure 3. Schematic representation of the direct spherification procedure.

The thematic thread of the third problem was the preparation of melon pearls that are part of a dish on the tasting menu of a restaurant with two Michelin stars (further details in Section S3 of the Supporting Information).

We gave students several exercises about the basics of solutions as well as more complex problems. First, the participants had to calculate the amounts of sodium alginate and calcium chloride needed to prepare the melon pearls using the above-mentioned reagent/volume ratios. Then, in the following exercise, we introduced the concept of aliquot and the ppm units so that students had to take into account the effect of dilution. There were also some exercises about the calculation of moles, especially of the implied ions, and molarity, since we had previously noted that students tend to confuse these topics.

It must be highlighted that teachers could modify and/or implement a wide range of problems based on the previous exercises so that they can be adapted to increase or decrease the level of difficulty, depending on the academic level.

■ RESULTS AND DISCUSSION

The activity was successfully completed during the problem-solving session and in good time. All the students participated actively and worked together in teams with satisfactory results. When they finished solving the problems, they were asked to answer a questionnaire in order to evaluate different points of the "MasterChemist" activity and determine whether it could be implemented on future occasions or not. The questionnaire (indicated in Figure 4) was administered and answered online. The survey consisted of seven questions, the last two being optional. Figure 4 also shows the students' answers to questions 1−5 in different graphs, while responses to questions 6 and 7 are addressed in Tables 1 and 2, respectively.

The first result that stands out is that 73% of the participants had previously heard about Molecular Gastronomy (Q1), although, curiously, the same percentage of students did not know the chemical fundamentals underlying it (Q2). Question 3 asked students to choose which problem they had considered the most interesting/instructive. The results highlighted that all the problems were equal in terms of interest or instruction since almost the same percentage was obtained in their answers for each one (approximately 33%). This also indicates that all the problems were well designed and they were all considered attractive by students. It is worth highlighting that, in Question 4, 95% of the participants answered that they considered the activity a good way to review stoichiometry concepts while introducing molecular cuisine: 85% answered "Yes", 11% answered "Maybe", and only 5% (2 people) marked "No". Moreover, in Question 5 the participants had to evaluate the activity on a 5-point Likert scale from 1 (very low) to 5 (very

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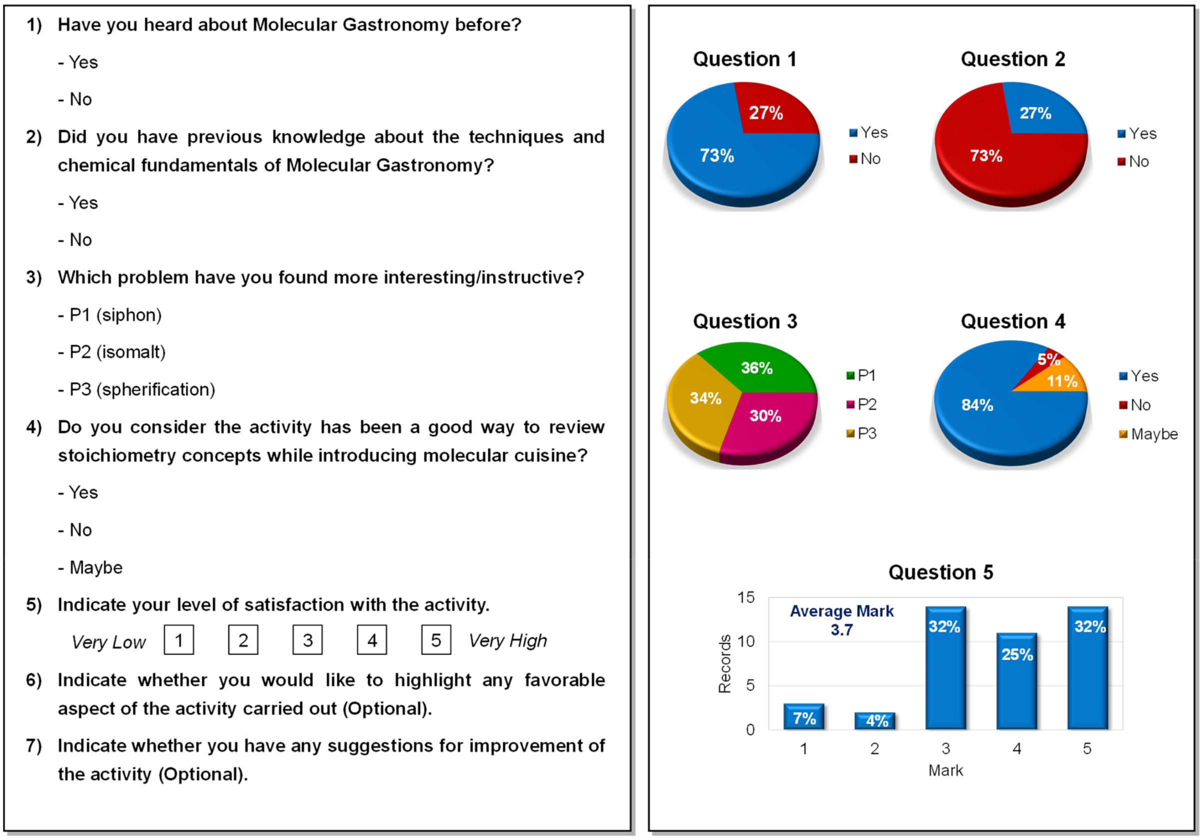

Figure 4. Proposed questionnaire and students' answers. Results are presented as pie charts for Questions 1−4 and as a bar chart for Question 5. All the graphs include the corresponding percentages. For answers to Questions 6 and 7, see Tables 1 and 2, respectively.

Table 1. Students' Responses to Question 6 of the Questionnaire (Points Worthy of Praise)[a]

Student's answer
"It has been a very good and entertaining activity for reviewing stoichiometry."
"I am delighted with the activity."
"Working in teams and the cooperation."
"It has been a very dynamic activity."
"I like cuisine, so it is cool to include it in a chemistry class."
"Very original."
"We can boost our competitive faculties."
"It has been a different way to learn chemistry and link it with cuisine."
"The attractive theme is a good way to learn and retain concepts."

[a]Total number of answers: 21. Similar answers are grouped.

Table 2. Students' Responses to Question 7 of the Questionnaire (Suggestions for the Activity)[a]

Student's answer
"To take better steps to ensure that when the exercises are being explained everyone is only paying attention and not trying to start doing the exercises before the others."
"More time for some exercises or doubts."
"For future occasions, I would use Kahoot (online platform) to carry out the activity."
"Sometimes it has been too competitive."
"The answers could be corrected at the same time for all the groups and not only when the first one gives the correct answer."

[a]Total number of answers: 10. Similar answers are grouped.

high). An average score of 3.7 out of 5 was obtained, indicating that, in general terms, the implementation of this educative innovation achieved a good level of satisfaction among the undergraduates and was helpful for them.

Responses to Questions 6 and 7 are summarized in Tables 1 and 2, respectively. When similar answers were given by the students, they were grouped. Twenty-one participants answered Question 6, in which they had to state any favorable aspects of the activity. At first glance, it can be extracted that the "MasterChemist" activity was dynamic, original, entertaining, and a good way to review and retain stoichiometry concepts. Furthermore, many people stressed the fact they had worked in teams and the degree of cooperation that they achieved. Hence, we feel that this educative proposal can really boost the interpersonal faculties of students and allow them to work as a team. This fact, along with the attractive theme of molecular cuisine, underscores the suitability of this activity for departing from the traditional way in which stoichiometry is usually taught in chemistry sessions.

Regarding Question 7, not so many participants suggested any improvements to be implemented in the activity (only 10 students). Notwithstanding, we must consider all of them for future occasions. One of the improvements that was called for the most was to develop the whole activity online with electronic platforms such as *Kahoot*. We feel that this might be a good idea to take into account for some of the exercises proposed. Nevertheless, in some of them the electronic version may be not so appropriate, as is the case, for example, of the exercises in which students have to write and balance equations. Another suggestion was to ensure that when the exercises are being explained by the teacher, everyone is only paying attention and not trying to start doing the exercises before their companions. We did our best to avoid these

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problems, but there were some situations in which, in the students' opinion, it was not achieved. For future implementations of the activity, further attention should be paid to this fact. On the other hand, some students claimed that the activity was too competitive sometimes. We feel that this competitiveness ought to be reduced for future occasions since it could discourage slower groups and avoid full assimilation of the chemical concepts. Thereby, the "MasterChemist" activity could be adapted to workshop-type classes where the spirit of coworking is maintained but students are not under such high pressure. We suggest to allow all the groups to solve the exercises at their own pace and correct the answers once they have finished. In order to maintain the GBL approach, a ranking of the time spent by each team could be established without prejudice to the educational aspect of the whole activity.

Be that as it may, the general balance of the educative innovation is highly positive. The undergraduates reviewed some stoichiometry concepts which we had previously observed they had problems understanding. In addition, the attractive theme of haute cuisine made the activity dynamic and enjoyable both for students and for the teacher.

Apart from that, one of our main goals was to observe some improvement in problems relying on stoichiometry. In order to check that, after this activity, students had to complete different assignments related to theory lessons in which stoichiometry calculations were involved in the exercises. In comparison to the three previous assignments, a remarkable improvement was noted, and students obtained higher marks in those kinds of problems. Approximately 65% of the 44 students obtained better marks, while the remaining 35% of the cohort did not improve their marks. The average mark for the exercises including stoichiometry problems of the previous assignments was 6.2 ± 1.6, while, for the corresponding assignments made after the "MasterChemist" activity, it was 8.1 ± 1.4, thus highlighting the improvement.

Another interesting point worthy of praise is that the "MasterChemist" activity helped students to boost their capabilities in thinking out of the box. Indeed, the final exam of the subject included different exercises (about pH, solubility, redox, etc.) contextualized in real situations that required a rational thinking approach and pretended to avoid solving the problems by heart. In all the cases, stoichiometry was somehow required to properly solve the exercise, and most of the students solved correctly this part of the exam. In particular, considering the students' performance on the final exams of previous academic years, we detected that there were some special stoichiometric exercises in which students had more difficulty solving properly. Some of them were related to dilution factors, reactivity, and unit conversion. Nonetheless, after the "MasterChemist" activity almost all the students (approximately 88%) that made the final exam (41 students) got a mark of 80−100 out of 100 in these exercises. As an example, they had to calculate and express the water hardness in g/L, molarity, ppm (mg/L), ppm of calcium/magnesium, and ppm of $CaCO_3$, to name but a few.

■ CONCLUSIONS AND IMPLICATIONS

In order to improve the learning−teaching process, a cooperative activity called "MasterChemist" was carried out and subsequently analyzed. This educative innovation involved novel stoichiometric exercises contextualized in haute cuisine for students taking the subject Chemistry in their first year of the Bachelor's Degree in Chemical Engineering.

In a problems class of the subject (2 h) and implementing a GBL approach, groups of 6 or 7 students solved the proposed exercises, which were focused on the three main blocks of stoichiometry: gases, reactions, and dilutions. In addition, following real-life experiences and the topic of molecular gastronomy, the problems were contextualized in the use of siphons, isomalt sugar, and the spherification technique, respectively.

The replies to the students' questionnaire confirmed that they were highly satisfied with the methodology implemented owing to its motivational character and the possibility of learning the chemical fundamentals of molecular gastronomy introduced in the exercises they had to solve. Based on its good acceptance, the "MasterChemist" strategy not only could be applied in general chemistry subjects in other Bachelor's Degrees but may also be introduced at lower educational levels, such as high school, as a way to encourage students to pursue a Bachelor's Degree in chemistry or a similar field.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.2c00250.

Collection of three problems with multiple sections aimed at reviewing some key concepts of stoichiometry that can be useful throughout a course of General Chemistry. The problems are based on molecular gastronomy, so that they bring us closer to the chemistry involved in the elaboration of avant-garde dishes. All the proposed exercises include the solution. The problems are presented as they were given to students (PDF)

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Notes

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