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A Preuniversity Initiative to Motivate Students to Pursue Chemistry Higher Education

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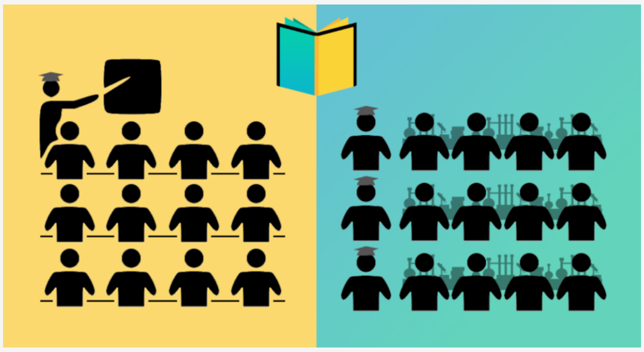

ABSTRACT: Molecular School (MS) is an extracurricular initiative intended to show relevant and complex concepts of chemical sciences to precollege students. The main goal is to motivate the participants to expand their awareness of chemical sciences and to acknowledge its relevance in everyday life, in order to stimulate the students to engage in chemistry undergraduate degrees. Here, we address the successful case of MS, implemented in Portugal, where recently, the universities have been facing significant difficulties in attracting new students to join chemistry-related courses. We report the first three editions of this free of cost preuniversity school, whose main subject is chemistry. All editions were held in the University of Coimbra, Portugal, and organized by PhD students of the department of chemistry of this institution. The three editions are discussed here, with particular focus on the last edition. Several participants ultimately chose chemistry BSc degrees to continue their education, which substantiates the positive outreach of this initiative. We believe MS can be replicated, adapted, and improved in other contexts and countries to increase the number of students enrolling chemistry university degrees.

KEYWORDS: *high school/introductory chemistry, interdisciplinary/multidisciplinary, laboratory instruction, collaborative/cooperative learning, hands-on learning/manipulatives*

■ INTRODUCTION

In this article, we describe and analyze a nonformal educational initiative developed to reinforce Portuguese secondary school students' interest in scientific fields, particularly in chemistry, and conceivably increase their motivation to pursue chemistry-related higher education degrees. This initiative was held in a university environment and was projected by PhD students from the University of Coimbra. The pilot edition occurred in 2019, with 36 10th grade students from Coimbra and surrounding cities.[1] In 2020, the second edition had distinct classes for the three years of secondary education in Portugal (10th, 11th, and 12th grades). Nonetheless, due to the COVID-19 pandemic, that deeply affected the educational system and related activities, the school was exclusively online, which was a profound drawback in the laboratorial component of this project. Finally, in 2021, it was possible to hold the initiative in person, with 56 secondary students from around the country.

The main reason to start this initiative was the significant lack of attractiveness of chemistry undergraduate degrees in Portugal in recent years. Indeed, in the last two years, in the main Portuguese National Higher Education Access Call, the number of candidates for chemistry BSc degrees was substantially low, with more than one-quarter of the vacancies being unfulfilled. This contrasts with the reality of two other bachelor's degrees with similar scientific backgrounds: biochemistry and chemical engineering. Biochemistry seems to be a more alluring degree, having no vacant positions in twice the number of university vacancies for new students compared to chemistry, which proves the high attractiveness level of this degree. Also, chemical engineering degrees have around 1.25 times more vacancies in the Portuguese universities compared to chemistry, and in the last two years, only 1.6% of the vacancies remained unfilled. In contrast, in the chemistry BSc degrees (including chemistry, medicinal chemistry, industrial chemistry, applied chemistry, technological chemistry, and educational physics and chemistry), 153 of the 557 vacancies (27.5%) remained open. The 557 vacancies are dispersed by nine different institutions, and the two universities of the Lisbon metropolitan region (which comprise 31% of the positions) had no vacant positions, being the

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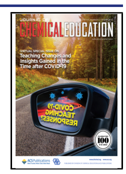

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exception to this general trend. Therefore, as university chemistry players (PhD and MSc students, with the help of university professors and researchers), we believe that it was imperative to contribute to a solution to overcome this problem. Hence, we developed the Molecular School (MS), a differentiated preuniversity school, based on hands-on approaches, in which the secondary students (from the Portuguese 10th, 11th, and 12th grade) visit the Department of Chemistry of the University of Coimbra and are introduced to the real world of research in chemistry at an academic level. The main focus of MS is to change the preuniversity students' attitude toward chemistry while, at the same time, offering an immersive contact with a university environment.

As the National Association for Research in Science Teaching describes, learning "derives from real-world experiences within a diversity of appropriate physical and social contexts".[2] Concepts in science are frequently abstract and complex.[3] Driver stated that teachers need to present new concepts through a range of ideas and across a range of experiences.[4] As King and Glackin put it, experiences outside the classroom comprise exceptional opportunities "for students to engage with different structures and different sort of social interaction than those that they are used at school" and also to "address some of their preconceptions regarding the nature of careers in science", concluding that "learning experiences outside the classroom offer students the possibility to develop across the cognitive, affective, physical and behavioural domains of learning".[3] These activities are also seen as unique opportunities for young students to interact with scientists and to better understand what a science career requires.[3] Furthermore, the possibility to build new types of relationships, as student−student, student−environments, and student−community, in no longer time-constrained initiatives, outside the physical space of the classroom, is also seen as very positive.[5]

MS differs from other typical science initiatives[6−27] offered to preuniversity students since it comprises both theoretic and laboratorial activities and it is held during the school year rather than during the holidays. Additionally, as will be discussed in detail, it nourishes the interaction of the participants with university professors, academic and industrial scientists, as well as PhD, MSc, and BSc chemistry students. Due to the positive results that will be described and discussed in this work, we believe that the Molecular School program might now be replicated, with the necessary adaptations, in other countries and scientific contexts.

STRUCTURE OF THE SCHOOL

It has been stated that students who attend science programs before joining college are more likely to choose a scientific career.[28,29] Moreover, precollege initiatives in partnership with schools that do not have the conditions to provide modern laboratory and technological equipment to their students have a major role in broadening their future professional options.[22,24] There are three important factors in the organization of precollege science programs, which were taken into consideration in the planning of MS: a hands-on experimental component; a close collaboration between university professors, researchers, and secondary school students, in an university environment; and the evaluation of the success of the project.[24,30] The MS program for 10th and 11th grade is based on the Portuguese physics and chemistry school program. By the end of the 11th grade, a national exam takes place to evaluate the students' knowledge on the subject of chemistry and physics of both the 10th and 11th grades. We decided to frame the MS program for these grades around the national curricula to increase the attractiveness of our initiative. In this way, the students are able to understand the applicability of chemistry as a science at the same time as they revise important concepts that can be used in the preparation for the future national exam. The approach for 12th grade, since these students are not involved in national exams, is rather different. In this case, we opted to show the interface between a chemical concept, developed in the university laboratories, and its translation and application into a spin-off or startup company or even into a multinational corporation.

The initiative had two types of activities: theoretical lessons and laboratorial practical lessons, which in total comprise approximately 3 h of activities per session. Each MS lesson took place out of the school timetable of the participants, on Saturday mornings, and both theoretical and laboratorial classes focused on the same scientific topic.

The organizing committee of this preuniversity initiative was composed of PhD students from the University of Coimbra that are also part of Molecular JE,[31] the first Portuguese Junior Enterprise that focuses on science outreach and whose headquarters are based in the Department of Chemistry of the University of Coimbra.

The theoretical lessons were given by University Professors or postdoc researchers, which were invited to prepare the different lessons considering their main scientific areas of expertise. The laboratorial practical lessons were developed and supervised by Molecular JE PhD student elements. The supervision of the lab work (2 supervisors per group) was provided by these PhD students together with volunteer MSc and BSc students, allowing them to interact with secondary school students to develop their skills to communicate and teach science on an early stage of their professional career.[14,16,32]

PARTICIPANTS

MS was designed to receive 50 high school students per year. The students came from different regions around Portugal (in the last edition the participants came, on average, from 64 km away from the venue of MS). The application process was completed online, one month before the first session of this initiative. The event was advertised in social networks, in regional media, and directly to the teachers of several secondary schools, who were invited to share the general information about MS and its application process with their students. At the end of the event, every participant received an attendance certificate.

THEORETICAL LESSONS

Molecular School has a different approach regarding the theoretical classes for the 10th and 11th grades, relative to the 12th grade. The subjects discussed during the five sessions of the 10th and 11th grades are based on the chemistry program taught in the Portuguese secondary schools.

For the 10th grade, the chemistry syllabus is currently divided into two main parts: the first concerns the chemical elements and their organization in the periodic table (atoms size, electron energy, and periodic table) and the second part involves matter properties and transformations (gases, dispersions, and introduction to chemical reactions). For the 11th grade, the chemistry syllabus includes chemical equilibrium (quantitative aspects of chemical reactions, the state of equilibrium, and the extension of chemical reactions) and reactions in aqueous systems (globally concerns the chemical equilibrium in acid–base, redox, and solubility systems). The main program topics addressed can be found in Scheme 1. Since the participants are already familiarized

Scheme 1. Summary of the Theoretical Lessons Present in the Program for 10th, 11th and 12th Grades in Molecular School

10th	11th	12th
Radiation, Energy and Spectra	Quantitative Aspects of Chemical Reactions	EcoXperience
Electron Energy in Atoms	Chemical Equilibrium and Chemical Reactions Extension	Science 351
Chemical Bond	Acid-Base Reactions	BSIM Therapeutics
Gases and Dispersion	Redox Reactions	Antibiotic Resistance
Chemical Transformations	Solutions and Solubility Equilibrium	LaserLeap Technologies

with the concepts explained in the theoretical classes, the lecturer focuses on their utility to the everyday life activities and to state-of-the-art scientific research. The purpose of the classes was mainly to stimulate the participants' interest and enthusiasm on the different themes and questions presented, using modern day interactive tools such as *Mentimeter* or *Kahoot!*.

For the 12th grade, we decided to show objective examples of chemical concepts and their relevance by putting the students in contact with distinct start-ups that were born in an academic environment. In fact, as Simon and Osborne state, "school science needs to appeal to young people by presenting itself as the means to solve the major problems facing humanity",[33] and this was the main motivation used to build the 12th grade program in MS. The start-ups chosen to present their work for the 12th grade were LaserLeap Technologies;[34] BSIM Therapeutics;[35] EcoXperience;[36] Science 351.[37] The representatives of these companies are all science entrepreneurs with PhD degrees in Chemistry and shared the scientific solutions to the distinct health, environmental, or industrial problems that their companies address. They were also encouraged to share the story of the creation of such business within the university and its subsequent expansion outside the academic environment. A class about antibiotics resistance and the strategies that are being developed in an organic chemistry/catalysis research group to overcome such problem was also integrated in the program.

A comprehensive description of all the classes is available in the Supporting Information.

■ LABORATORIAL ACTIVITIES

General Description

The process of learning a natural science like chemistry is highly connected with laboratorial training. In fact, science teaching is directly related to experimentation, and the theoretical approach is usually seen as insufficient.[38] Performing laboratorial experiments reduces the gap between theoretic concepts and their application, promoting the engagement of the students in the learning process.[38−40] Furthermore, the laboratorial practical methodology is also seen as the main key factor for catching and holding the students' interest in science and encouraging them to pursue this subject in further education stages.[41−43]

In MS, a series of simple and accessible experiments was chosen to stimulate the interest of the students toward chemistry, allowing them to perform the activities by themselves, in a hands-on approach. The aim of these activities is to motivate them to further understand the concepts explained in the theoretical classes, as well as general aspects of chemistry that are present in daily life. Hence, and due to the relatively short time for each lab session, we decided to design laboratorial sessions with multiple but simple experimental activities. Each of these activities were selected to be the most related as possible with one of the topics addressed in the theoretical session held in the first part of the school. These activities had an average duration of 90 min and were projected, organized, and supervised by PhD students. Before the first activity, an overview of the laboratory safety rules was explained to the participants and all the emergency equipment was demonstrated and discussed. The laboratorial work was done by the participants (except when explicitly said otherwise), with close supervision by one PhD student and one Master/Bachelor student. These supervisors acted as mentors during all the activities, helping the students with questions that might appear and ensuring that everything ran safely. The participants were initially divided in groups of 4 or 5 elements, and those groups remained the same throughout the five sessions of MS. All elements of the group took part in every step of the lab work, and the supervisors guaranteed that the interpretations of the observed scientific events, made by the participants, were correct. The relationship developed between the participants and the supervision staff was clearly mentioned as one of the strengths of the event by the participants at the end of MS. The experiments were established considering two different approaches, based on the educational level of the students.

The students in the 10th grade were given a set of instructions to perform the experiments independently (see Table 1), but under close supervision. With this strategy, they were able to understand the main aspects of a scientific protocol and interact with a significant range of laboratory material and equipment, which has been considered an important factor of the scientific learning process.[38] The development of the participant's laboratorial competences was quite remarkable throughout MS. In the first activities, the students tended to wait for the approval of the supervisor to execute each different task. Over time, they gained the confidence and, more importantly, the skills and reliability to perform the appropriate experimental procedures without having to ask, step by step, what was the best way to complete them.

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Table 1. Experiments Conducted in Each Session of the 10th grade[a]

Lessons	Experiments
Lesson 1—Radiation, Energy and Spectra	Light Source
	Turmeric and Colors
Lesson 2—Electron Energy in the Atoms	Flame Colors
	Shiny Water
Lesson 3—Chemical Bond	Dissolve Styrofoam
	Tie Strings of Water
	Hot Ice
Lesson 4—Gases and Dispersions	Coke Foam
	Fill Balloons without blowing
Lesson 5—Chemical Transformations	Firelighter Manufacture

[a]The description of each laboratorial experiment is presented in the Supporting Information.

To develop a more structured scientific mindset in older students, the laboratorial approach for the 11th grade students was planned differently. The students had access to key instructions about the aim of the experiment but not to a detailed protocol. With this methodology, the participants were supervised while executing the activities according to the initial rules but were encouraged to develop the protocol by themselves, in a "minds-on approach".[38,44] Additionally, the chosen experiments for the 11th grade level had, in general, higher complexity and applied more advanced analytical chemistry techniques. At the end of the activity, it was expected that the participants had developed a simple laboratorial strategy to obtain a specific outcome. They also had to analyze the results obtained and to identify the terms of correlation and/or causality and, finally, to suggest extrapolations to different experiments that may lead to similar or complementary results. In Table 2, we summarize the experiments developed with the students at this level.

Table 2. Experiments Conducted in Each Session of the 11th Grade[a]

Lessons	Experiments
Lesson 1—Quantitative Aspects of Chemical Reactions	M&M's Chromatography
	Turn Oil into Soap
Lesson 2—Chemical Equilibrium and Chemical Reactions Extension	The Speed of Chemical Reactions
Lesson 3—Acid–Base Reactions	Homemade pH Indicator
Lesson 4—Redox Reactions	Blue Bottle
	Sugar in Beverages
Lesson 5—Solutions and Solubility Equilibrium	Solution Mixtures
	Hot Ice

[a]The description of each laboratorial experiment is presented in the Supporting Information.

All laboratorial classes took place in the teaching laboratories of the Department of Chemistry of the University of Coimbra. The students were given lab coats and had access to common laboratorial glass material, to all the reagents required to perform the experiment, to distilled water, and to other common solvents to clean the material. When required, UV lights, heating plates, and additional equipment were also supplied.

For the students of the 12th grade, all the experience of Molecular School was designed focusing on a possible career path in the field of chemistry, giving them notions about the research that is currently being developed in the different fields. Hence, the practical part of the initiative for those students was also planned in a different way. To increase their interaction with state-of-the-art research, they were accompanied by PhD students to several research laboratories in the Department of Chemistry of the University of Coimbra. These visits were used to show the main research purposes of each laboratory and the type of equipment necessary to conduct the different research activities. In the Synthesis and Organic Chemistry laboratory, the students got familiar with the equipment and techniques necessary for the synthesis of new compounds. They were shown typical solvent evaporation and drying techniques, different conditions to perform a chemical reaction (lower or higher temperature, reflux, inert atmosphere), the function of a rotary evaporator, as well as the most common reaction-control and purification strategies (thin layer chromatography, column chromatography, crystallization). In the Photochemistry and Time-Resolved Spectroscopy laboratory, students were in contact with equipment that uses light to study compounds or chemical reactions, i.e., spectrophotometers, fluorimeters, LEDs, and nanosecond, picosecond, and femtosecond lasers. A brief and simple explanation of steady-state and time-resolved absorption and emission spectroscopy, as well as photoacoustic calorimetry, was addressed throughout the visit. In Theoretical and Computational Chemistry laboratory, the students used molecular representation software to design and optimize the geometry of molecules of interest and experienced the process of writing inputs to run electronic structure calculations. Finally, in the Photobiology laboratory, they were introduced to cell culture equipment. The students learned about the necessary conditions for the cells to successfully multiply to be used in complex *in vitro* studies. Additionally, the basic concepts of drug development and the role of medicinal chemistry, including *in silico*, *in vitro*, and preclinical and clinical studies were displayed.

Synopsis of the 10th Grade Experiments. Theoretical lesson 1 focused on electromagnetic radiation and related phenomena, and properties of the molecules. The experiments chosen in this subject were "Light Source" and "Turmeric and The Colors". In the first one, the concepts of refraction and total reflection of light are discussed based on the trajectory of a light beam in the path of a trickle of water. The participants assembled a simple recipient where it was possible to align a laser light to a falling water stream, where the total reflection of the light is evident. The direct analogy with the optic fiber, present in everyone's house, is addressed. The refraction phenomenon, that occurs when part of the radiation crosses two distinct media, was also discussed to acknowledge the differences between the two properties of light. With the second experiment, the students observed the different colors of turmeric in solutions at different pH values and correlated them with differences in the molecular structure. The reasons behind pH-induced colors were among the most intriguing questions for the students. The molecular structure of turmeric was shown to them, and the concept of electron delocalization between aromatic rings and double bonds was explained. They were able to see that different molecular structures can coexist in one same compound, generating different colors. Focusing on spectroscopy and quantization of energy, the Lesson 2 experiment, "Flame Colors", allowed students to deepen their understanding of the reason underlying the different colors exhibited by metal salts, when heated. The students were asked

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to speculate on the color of the flames of each salt before the experiment, based on the concepts addressed in the theoretical class, and their assumptions were tested and discussed. When heated, the valence electrons of the metal are excited to a nonstable molecular situation. Returning to the ground state, a characteristic wavelength radiation is released, with color dependent on the energy difference between the electronic levels. "Shiny Water" focused on the observation of fluorescence by UV light irradiation of an aqueous marker's ink aqueous solution. When the ink is irradiated, the electrons in some of its components are excited. By returning to the ground state, they emit light, through fluorescence. Polarity, intermolecular interactions, and solubility were the main topics addressed in Lesson 3, whose theoretical component covered chemical bonds. "Dissolve Styrofoam" consisted of acknowledging that "polar dissolves polar", by the solubilization of the polystyrene foam in acetone, due to the polar nature of both components. The students learned that polar molecules are more likely to interact with each other because of the attraction between opposite charges or dipoles. In "Tie Strings of Water" the students were expected to recognize the strong hydrogen bonds as the origin of the strong cohesion observed for liquid water, allowing the "tying" of two parallel water strings. With "Hot Ice" the students were challenged to relate solubility and temperature and identify crystallization processes with the addition of sodium acetate to a saturated aqueous solution of this salt. This last subject was extended in Lesson 4, focused on gases and dispersions. With "Coke Foam", the addition of sodium chloride to coke causes the solubility of carbon dioxide in water to decrease, and the gas escapes the liquid to form a foam. In "Fill Balloons Without Blowing" the goal was the identification of the products resulting from the addition of sodium bicarbonate to vinegar (acetic acid), which causes a balloon to inflate due to the formation of the gas carbon dioxide. The last experiment, "Firelighter Manufacturer", covered the colloidal field, with the formation of a gel composed by calcium acetate, water, and ethanol. The gel forms from the dispersion of a solid phase (calcium acetate) into a liquid one. The alcoholic nature of the dispersed phase allows the gel to ignite upon contact with a flame. The combustion reaction was the link to the respective theoretical lesson, that encompassed chemical transformations.

Synopsis of the 11th Grade Experiments. The first subject of the 11th grade theoretical lessons was related to the quantitative aspects of chemical reactions. The experiment "M&M" Chromatography" was chosen with the goal of introducing the chromatographic process, an important method for the evaluation of the progression of chemical reactions. In this experiment, the M&M's shell was dissolved and the resulting solution applied to a filter paper with the help of a small brush. The base of the filter paper was submerged in 50% ethanol, and the differences in the retention of pigments (or mixtures of them) were analyzed. The students observed that, with the climb of the solvent in the paper, some of the pigments were more retained than others, leading to a separation of the components. It was explained that this is due to the interactions between the pigment molecules with those of the solvent. Since ethanol is a polar molecule, the pigments that rise faster on the filter are the most polar ones. They were also told that this is a widely used technique to control organic reactions and purify organic compounds, based on the polarity-induced behavior of reactants and products with silica and different solvents. The second part of the class consisted of watching a demonstration made by a PhD student about turning used cooking oil into a surfactant, a reaction promoted in the presence of a base. Parameters such as saponification and acidity indexes (related to the amount of triglycerides in the oil capable of being converted into acids as well as the amount of free acids) were addressed, and concepts like the structure and function of a surfactant (hydrophobic tail and hydrophilic head that can interact with both water and grease, bridging them together) and the type of species formed after the hydrolysis of triglycerides in oil were discussed. The final acid molecules have long tails and can be converted into soap by the addition of, for instance, a base, to form a charged hydrophilic head. This experiment also covered several sustainability issues, including some of the topics mentioned in the correspondent theoretical lesson. Lesson 2 established a bridge between reaction kinetics theory and the visualization of clear examples. Therefore, in "The Speed of Chemical Reactions", the students were encouraged to understand some variations made when effervescent tablets were added to water. With this simple experiment it was possible to illustrate the influence of specific factors such as temperature and reagent concentrations. It was possible to macroscopically observe a more rapid dissolution of the effervescent tablets with higher kinetic energy (higher temperature), higher concentration (two tablets instead of one), and higher surface area (macerated tablets). The function of catalysts in enabling or accelerating a chemical reaction was demonstrated with the addition of hydrogen peroxide to sodium and potassium tartrate with and without the presence of a solution of cobalt chloride. Without cobalt chloride, the reaction between tartrate and hydrogen peroxide does not occur. By introducing cobalt chloride, an initial reaction with tartrate happens, allowing the hydrogen peroxide to react with this later species. The consumption of the tartrate regenerates cobalt chloride, with this being the catalyst that allows the reaction to occur. Related to the acid and base theme of Lesson 3, the students performed "Homemade pH Indicator", an experiment where red cabbage was boiled resulting in a pH indicator solution. This indicator was added to several solutions of chemicals and everyday life products. The main goal was to understand the structural and consequent color changes of anthocyanin with pH and conclude about the acidic or basic nature of the analyzed materials. Redox reactions were the topic of Lesson 4, and the "Blue Bottle" experiment was thought to recognize the successive oxidation of bottled glucose. The oxidation is mediated by a cyclic interconversion between methylene blue (blue) and its reduced form, leucomethylene (colorless). The second part of the laboratorial component of this lesson was designed to raise awareness for the nutritional problems currently observed. "Sugar in Beverages" reports to the evaporation of a set of chosen soda drinks or juices and the determination of their sugar content. The last lesson focused on solubility, and in the "Solution Mixtures" experiment the students mixed an aqueous solution of copper sulfate with one of sodium hydroxide, to identify the reaction products and acknowledge the low solubility of the formed precipitate. "Hot Ice", an experiment already discussed for the 10th grade, was also one of the activities of the 11th grade, with the difference that the students developed the protocol by themselves, verifying the dependence of solubility with temperature.

A further description of the laboratorial experiments of both 10th and 11th grades is presented in the Supporting Information.

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OUTCOME/PARTICIPANTS' GENERAL OPINION

To evaluate the outcomes of MS, a short standard survey instrument was developed. The aim of the survey was to evaluate the participants' satisfaction regarding the activities performed during MS. Together with the output from the constant communication throughout the five sessions, we concluded that the initiative had a very positive impact on the students, with most of the participants stating that their expectations were largely exceeded. For the 10th and 11th grade participants, the connection between the scientific concepts that were initially addressed in the theoretical lessons with the experiments performed in the lab environment was seen as a major benefit for their scientific comprehension. The 12th grade participants stated that the direct contact with scientific entrepreneurs increased their notion of the career possibilities a scientist has and, more importantly, the contribution of chemistry to make the world a better and more sustainable place to live.

Hence, the general impression of the participants on the importance of science to the society was increased as well as their willingness to pursue chemistry-related undergraduate degrees at the university level. In fact, from the 30 12th grade participants in the last two editions, ten ended up joining chemistry BSc degrees, which is rather significant, given the Portuguese higher education scenario mentioned in the Introduction. Moreover, these students stated that they were still uncertain about the BSc degree they wanted to apply to before participating in MS, which reinforces the impact that this initiative had in their decision process.

CHALLENGES AND HOW TO OVERCOME THEM

One of the main constraints raised during the MS organization was the difficulty of advertisement in some of the schools. Hence, the majority of MS advertisement was done online and via local printed media. Additionally, we have also asked the participants of previous editions to advertise MS to their colleagues, which turned out to be an effective alternative. In terms of the geographical distribution of the participants, despite having a considerable number of participants living at significant distances from the venue of the MS (several living more than 100 km away), it is obvious that the participation in this initiative is much easier for people living close to Coimbra. Students from farther distances need to consider their parents' availability to drive them to the venue or to use public transportation (sometimes more than one). Therefore, it would be interesting to consider the establishment of a partnership with the Social Services of the University of Coimbra to allow the participants from longer distances to spend one night in Coimbra and overcome this hassle. Finally, the overlapping of MS with other extracurricular activities occurring on Saturdays, namely sportive and cultural activities, was also one of the limitations identified, and in such cases, the participants were allowed to skip one of the lessons, so they could complete their participation in Molecular School and, at the same time, do not miss other important events of their sportive and cultural education.

CONCLUSIONS

Molecular School is a nonformal educational activity with encouraging results regarding the change of perception of students about science and the potential to motivate secondary students to join chemistry-related university degrees. The approach used to design this preuniversity initiative and its promising outcomes suggest that this model is worthy of being replicated in other countries and cultures.

MS was designed as a combination of theoretical and experimental lessons for the students of 10th and 11th grades. In the theoretical lessons, by addressing real life situations as examples where the taught themes are relevant, the students managed to consolidate the concepts included in the national curricular program, subject of a national evaluation in the last stage of the 11th grade. The laboratorial part was designed to illustrate some of the concepts from the theoretical lessons, improving their comprehension and exemplifying the phenomena in a hands-on approach. The strategy for the 12th grade participants allowed them to get into close contact with a chemistry-based business and the academic environment, and to clarify distinct possible career paths for chemistry graduates. Furthermore, these students had the opportunity to visit research laboratories and observe state-of-the-art research apparatus.

Overall, the experience was strongly appreciated by all the participants, with emphasis on the proximity created between these students and their supervisors. Furthermore, a relevant outcome is that ten participants from the last two editions (out of a total of 30 12th grade participants) ended up joining chemistry BSc degrees.

The results reported here, although centered in a small population of participants, indicate that the model of MS proposed could, effectively, contribute to improve the students' perception on chemistry and science in general and increase the recruitment to chemistry university degrees, in areas where this has been a long-term challenge, such as in Portugal.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.2c01095.

Comprehensive description of the theoretical lessons and the description of each laboratorial experiment (PDF, DOCX)

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Notes

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