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Activity

Alcohol or Ethanol? Teaching Organic Chemistry Nomenclature in an Informal Environment

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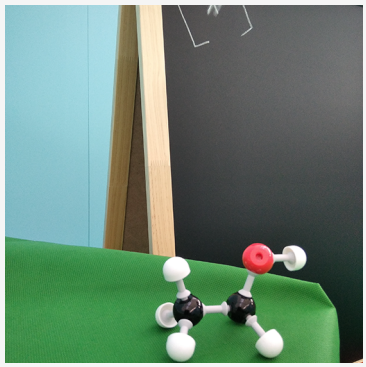
ABSTRACT: The basics of organic chemistry nomenclature were introduced in a laboratory organized in a nonformal environment such as a science festival. The laboratory, divided into three distinct but interconnected activities, was aimed not only at secondary school students but also at lay people. The intent was to explain the importance of associating a name to a molecular structure and conversely and that this is relevant not only for scientists but also in everyday life in order to better understand the properties of commonly used molecules. The overall goal was to stimulate interest in chemical topics with the aid of fun and engaging activities.



KEYWORDS: *Middle School Science, High School, General Public, Science Festival, Organic Chemistry, Nomenclature*

Organic chemistry has become a fundamental part of everyday life. Although a rigorous understanding of organic chemistry is not required, connections between the macroscopic properties of molecules used in everyday life and the chemical structures responsible for those properties are often important. For example, their knowledge helps to discriminate between different types of disposable plastics, to understand the list of additives on food labels,[1] or to make connections between the generic names of pharmaceuticals and their active principles. However, while physicists, mathematicians, and biologists use a language understandable to everyone, chemists do not, as they mainly use symbols and formulas that are poorly understood by lay people.[2] Organic chemistry nomenclature therefore plays an important role at any level, not only for undergraduates, as it translates those symbols and formulas. Even though all organic compounds can be named systematically using the IUPAC nomenclature,[3] many common compounds use nonsystematic (traditional) names, and awareness that different names may exist for the same substance is the basis for a proper use. Although the relevant literature is replete with examples of alternative, game-based methods to teach organic chemistry nomenclature in undergraduate introductory organic chemistry courses,[4−10] to the best of our knowledge, no effort has been reported to introduce the rudiments of nomenclature to lay people. We chose a game-based activity because such approaches have been shown to have a significant impact on learning and engagement over time.[11]

The laboratory described in this article has been realized within the Science Festival of Genova. The Science Festival of Genova is one of the leading events for the dissemination of scientific culture and has become, over the years, an international benchmark. About 200,000 visitors attend the 10-day event every year. Scientists, researchers, popularizers, artists, and authors, as well as associations and businesses, meet with the public to allow science to be touched, seen, and understood without boundaries in an open discussion free from academic jargon. Since 2003, exhibitions, meetings, workshops, performances, lectures, and other activities have allowed the public to observe and interact with science from different disciplines and nuances, increasing public engagement and understanding of science's critical role in modern society. The Festival is organized every year, and each edition is characterized by a keyword: the 2022 keyword was "languages", and within this frame, we presented the activity "Alcohol or Ethanol?". The laboratory was mainly aimed at secondary (middle [grades 6−8] and high [grades 9−13]) school students (ages 11−18) but also at the general public (i.e., adults and families).

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LEADING IDEA OF THE ACTIVITY

The highlights of this laboratory were to explain that (i) a common language is necessary to talk about chemistry; (ii) for each molecule, it is necessary to assign a name that is unique and can be traced directly back to its structure; (iii) the traditional name of molecules does not allow this operation, so a systematic nomenclature is needed; (iv) a molecular formula can be used to describe more than one molecule, so it is ambiguous. Introducing the rudiments of organic chemistry nomenclature to school students and lay people in a nonformal environment such as a science festival has various challenges,[12−14] different from those of undergraduate courses, but it also holds some new potential.[15−18] First, since there are no exams or tests, the interest of participants should be stimulated by offering fun and engaging activities. Second, the activities should be calibrated to require very little prior knowledge. We assumed that participants attending a science festival knew at least the main chemical elements (H, C, O, S, halogens) and the meaning of a molecular formula, and were able to recognize simple Lewis structures. Third, the participants would have to get all of the important information in less than an hour, since this was the time available for the laboratory according to the Festival organization.

The laboratory consisted of three distinct activities, named "one name one structure", "build your molecule", and "the wheel of fortune". Participants were supervised by facilitators, mostly students in scientific degree programs, who were appropriately trained (Figure 1). In addition to the three activities listed above, there were also posters in the lab room that explained (i) the different ways organic molecules can be written (from Lewis structures to segmented structures), (ii) why IUPAC nomenclature was created, and (iii) the main rules of systematic nomenclature.

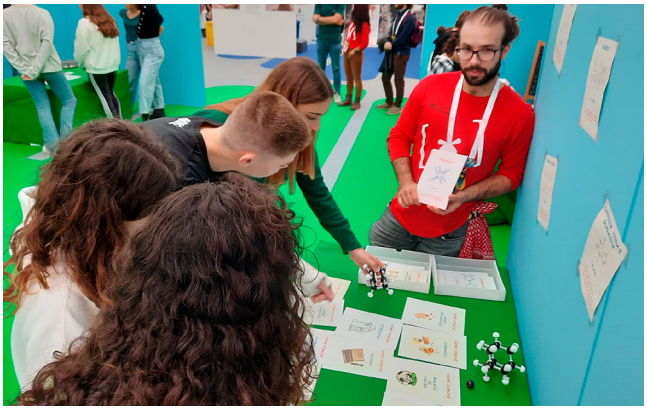

Figure 1. A facilitator with a group of participants attending the "one name one structure" activity.

Aware that the informal setting would not allow for a rigorous assessment of participants' learning, we set as the overall goal of this laboratory to stimulate interest in chemistry. It has been shown, in fact, that stimulating interest in specific topics can increase motivation to continue to explore them further.[19−21] In addition, we wanted to test whether age, prior knowledge, and school of origin would have an influence on this interest.

DETAILED DESCRIPTION OF THE LABORATORY

Prior to playing each of the three activities, participants were introduced to the laboratory by one of the facilitators. Ice-breaking questions included the keyword of the 2022 Festival, the difference between atoms and molecules, the formula of water, where in everyday life the compound "alcohol" could be found, and if they had ever heard about the name "ethanol". These questions helped the facilitator introduce the overall aim of the laboratory, that is, to find a common and informative language for chemists all over the world and to realize that traditional names as well as formulas are not sufficiently informative on the structure of molecules.

Participants were then accompanied to the three locations where the activities were assembled. The details of the three activities are described below.

"One Name One Structure"

Participants received two decks of 18 cards each. The first deck contained the traditional names of 18 organic molecules. Catchy names (curious or funny) were selected, such as "diabolic acid", "luminol", "asparagine", "mandelic acid", "cubane", etc. The second deck contained the molecular formulas and the bond-line (zigzag) structures of the same 18 molecules, with a hint about the origin of their traditional names (full details can be found in the Supporting Information). Participants were asked to match the 18 pairs of cards. In this game the facilitators also illustrated the connection of some of these molecules with everyday life. At the end, the facilitators pointed out that without the hint, it would not have been possible to pair the cards correctly unless the structures of the molecules were remembered by heart. The game was also implemented on a web platform (playingcards.io), and participants were invited to play remotely with their friends on any occasion.

"Build Your Molecule"

The facilitator, recalling the concepts expressed in the introduction, reminded participants that while the word "water" gave no information regarding the structure of the molecule, the alternative use of the formula "H_2O" allowed for an understanding of how the molecule was made. This, however, was not always true. Each participant was given a set of molecular model kits corresponding to the molecular formula $C_4H_{10}O$. Following the rule that carbon atoms had to form four bonds, hydrogen atoms had to form one bond, and oxygen atoms had to form two bonds, they had to build molecules using all of the atoms and compare their structures. At the end, the facilitator highlighted how the same molecular formula could correspond to different molecules, called isomers, and that each isomer had different properties and therefore could not share the same name. The facilitator, taking advantage of the fact that both alcohols and ethers could be obtained from the same formula, also introduced the concept of a functional group and how functional groups could determine major properties in the molecules.

"The Wheel of Fortune"

The wheel shown in Figure 2 was constructed by joining five concentric disks and a jig. The five disks, from the outermost to the innermost, contained the suffix of the functional group, its locant, the root related to the number of carbon atoms, the substituent, and its locant, respectively. Participants drew from a deck the structure of an organic molecule and were supposed to determine its systematic name. The structures were

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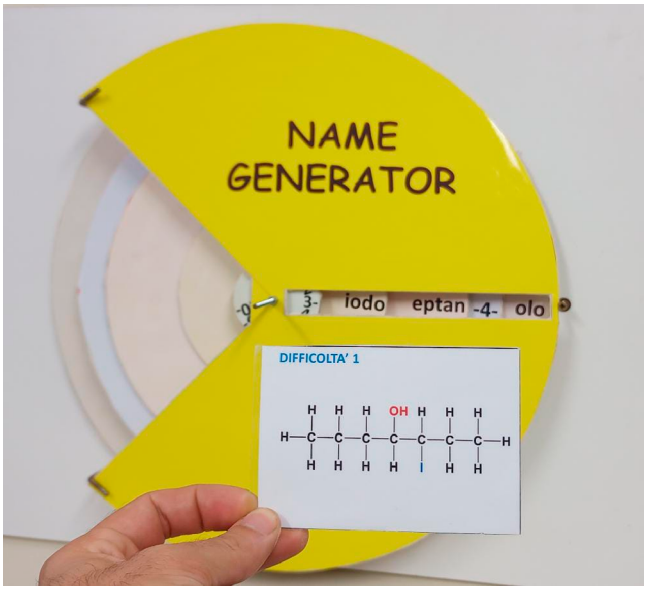

Figure 2. Name generator for systematic nomenclature.

"facilitated", since the main functional group and the substituent were easily recognizable since they were red and blue colored, respectively. Participants were provided with a sheet explaining in a simple way how to build the name, starting from the root, moving to the suffix and finally to the substituent. Very limited numbers of functional groups (alcohol, aldehyde, ketone, carboxylic acid, and thiol) and substituents were used. At the end, the facilitator emphasized how, starting with the molecule's name, its structure could be easily traced back, and how name and structure were now linked by a bidirectional relationship. Finally, the facilitator revealed that the word "ethanol", as opposed to "alcohol", was totally informative, as, through the systematic nomenclature, the name could be traced back to a precise chemical structure.

The activities were carried out in groups of 3−10, and in the case of school classes, these were divided into three distinct teams that participated in a competition. Each team could play all three games for a given amount of time (about 15 min) and earn points for each pair of cards identified, for each isomer found, and for each molecule named correctly. At the end, the team that had scored the most points was designated as the winner. Although it was initially planned to follow the order given for the activities, we realized that different orders could be equally effective.

EVALUATION OF THE LABORATORY

At the end of the laboratory, facilitators asked participants to fill out a questionnaire. Being aware of the difficulties of conducting an assessment in informal settings,[22,23] we used an online platform (LimeSurvey) and selected 12 questions, aimed at evaluating prior knowledge, appreciation, and perceived efficacy of the activity. A rigorous evaluation of the cognitive impact of the laboratory was not possible, but the powerful role of emotions in chemical education has been recently reviewed by Flaherty.[24] Participants could access the survey by simply framing a QR code.

Table 1 shows the questions, the possible answers, and the response frequencies. Students also had to report which school (middle vs high) and type (classical, scientific, art and humanities, vocational) they went to.

We first analyzed the responses given by students.

The questionnaire was completed by 236 middle school (MS) students and 219 high school (HS) students. A complete statistical analysis of the results can be found in the Supporting Information. Here the most salient findings are reported.

With regard to the questions aimed at evaluating prior knowledge, almost all students answered "yes" to the question "Have you ever heard of chemistry before?". However, a statistically significant association was observed between group membership and the response to question 3: "school" was chosen by 94% of HS students but only by 83% of MS students, while less significant differences were found for the "family" and "internet" options. As expected, a statistically significant association was also observed between group membership and the response to question 1, as only 44% of MS students knew that the same substance could have multiple names, while a positive answer was given by 71% of HS students. Interestingly, a statistical difference was found again between MS and HS concerning question 4, as the average score was 2.69 for the former group and 3.15 for the latter group.

With regard to questions 5−7, aimed at evaluating how the activity was appreciated, the answer "definitely yes" was chosen by the majority of the participants, and a significant difference was found only for the question "Was the laboratory interactive?", again with HS students scoring higher (3.87) than MS ones (3.73).

Questions 8, 11, and 12 aimed at evaluating the perceived efficacy of the activity. Although HS students' mean score for the question "Were the topics easy to understand?" was significantly higher (3.35) than that of MS students (3.11), for both groups we observed mostly positive (>3) answers. Question 12 also received a high score from HS students (4.10 on a 5-point scale), and a slight difference was observed with MS students (3.94). On the other hand, the question "Would you be able to explain the difference between common and systematic names of molecules to a friend?" displayed the highest difference between the two groups, with MS students scoring on average 2.50, meaning that negative answers equaled positive ones.

Finally, both groups equally recognized the importance of these topics at school (3.49) and in everyday life (2.78), although to a lesser extent.

Additional analyses were carried out, including (i) a comparison of the results obtained by MS and HS groups with those obtained by adults; (ii) a comparison of the results obtained by HS students in grades 9−10 vs 11−13; and (iii) a comparison of the results obtained by HS students with classic, scientific, arts and humanities, and vocational programs. Although statistically relevant differences were found in many cases, none of them were remarkable or were in striking disagreement with what has been previously reported. These analyses are available in the Supporting Information.

CONCLUSIONS

In this paper, we have reported on a laboratory, performed within a science festival, aimed at introducing the organic chemistry nomenclature. By dividing the laboratory into three different activities, each focusing on a specific aspect, the problems and possible solutions associated with the need to give informative names to molecules were explained. Compared to a traditional lecture in which these same aspects are proposed in a unidirectional mode by a speaker, the use of

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Table 1. List of Questions and Overall Response Frequencies

	Question	Response frequency	
1	**Did you know before doing the workshop that the same substance can have several names?**	No: 218 (42.00%)	
		Yes: 300 (57.80%)	
		Missing: 1 (0.19%)	
2	**Have you ever heard of chemistry before?**	No: 16 (3.08%)	
		Yes: 501 (96.53%)	
		Missing: 2 (0.39%)	
3	**Where have you heard about chemistry before?**	School: 457 (88.05%)	
		Family: 107 (20.62%)	
		Internet: 154 (29.67%)	
		Other: 21 (4.04%)	
4	**Is the information you received today in agreement with what you already knew?**	Not at all: 39 (7.51%)	
		A little: 131 (25.24%)	
		Somewhat: 147 (28.32%)	
		Completely: 181 (34.87%)	
		Missing: 21 (4.05%)	
5	**Did you enjoy this experience?**	Not at all: 7 (1.35%)	
		A little: 12 (2.31%)	
		Somewhat: 114 (21.97%)	
		Completely: 378 (72.83%)	
		Missing: 21 (1.54%)	
6	**Was the laboratory interactive?**	Not at all: 6 (1.16%)	
		A little: 12 (2.31%)	
		Somewhat: 73 (14.07%)	
		Completely: 427 (82.27%)	
		Missing: 1 (0.19%)	
7	**Were the activities engaging?**	Not at all: 4 (0.77%)	
		A little: 8 (1.54%)	
		Somewhat: 92 (17.73%)	
		Completely: 413 (79.58%)	
		Missing: 2 (0.39%)	
8	**Were the topics easy to understand?**	Not at all: 13 (2.50%)	
		A little: 49 (9.44%)	
		Somewhat: 259 (49.90%)	
		Completely: 196 (37.76%)	
		Missing: 2 (0.39%)	
9	**Do you think knowing these topics is important for a student?**	Not at all: 9 (1.73%)	
		A little: 22 (4.24%)	
		Somewhat: 182 (35.07%)	
		Completely: 302 (58.19%)	
		Missing: 4 (0.77%)	

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Table 1. continued

	Question	Response frequency
10	**Do you think knowing these topics is important in everyday life?**	Not at all: 31 (5.97%) A little: 145 (27.94%) Somewhat: 231 (44.51%) Completely: 108 (20.81%) Missing: 4 (0.77%)
11	**Would you be able to explain the difference between common and systematic names of molecules to a friend?**	Not at all: 58 (11.18%) A little: 130 (25.05%) Somewhat: 200 (38.54%) Completely: 126 (24.28%) Missing: 5 (0.96%)
12	**Compared to before you attended this laboratory, how capable do you feel you are now of naming a molecule?**	Much less: 11 (2.12%) Somewhat less: 18 (3.47%) Same as before: 59 (11.37%) Somewhat more: 286 (55.11%) Much more: 140 (26.97%) Missing: 5 (0.96%)

playing cards, molecular model kits, and a name-generating wheel allowed participants to directly engage and interact, thus stimulating interest and motivating further learning. The evaluation performed at the end of the activity demonstrated that most participants enjoyed it, no matter their age or school background. All students, even MS ones, assessed that the topic was sufficiently easy to be understood, and at the end of the activity participants felt they were able to transfer the information to other people. Finally, participants walked away from the Science Festival with the feeling that chemistry is important, certainly in school but also in everyday life. According to Eastes,[25] the recurring answer of adults to the question "What do you think about Chemistry?" is "I always hated it!" or "I never understood it!". Hopefully, by acting on the affective domain of adults and future adults, laboratories such as *Alcohol or Ethanol?* can stimulate interest in chemistry topics and motivation to explore them further.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.2c01125.

Playing cards, name generator instructions and structures, and statistical analysis (PDF)

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Notes

The authors declare no competing financial interest.

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