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Teaching Organic Functions via the Chemical Senses[1]

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Abstract

Several teaching methods have been devised to advance students' learning of Chemistry and develop their practical and reasoning skills. This intervention research design, of a qualitative nature aimed at promoting and assessing student understanding of organic functions as related to food flavors and aromas. To this end, we collected data regarding the participants' knowledge of organic functions before and after the intervention. The participants' answers indicate that their knowledge of organic functions and the link between the latter and their senses of taste and smell greatly improved as compared to what was assessed at the start of the study, suggesting that the intervention contributed to student content learning. At the end of the study, the participants were able to associate flavors and aromas of the food used in the teaching-learning activities to specific organic functions and identify their structures.

[1] Enseñanza de Funciones Orgánicas a Través de los Sentidos Químicos

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Keywords: Teaching; organic functions; taste; smell.

1. INTRODUCTION

Many secondary school students have great difficulty in learning topics of Chemistry, e.g., organic functions, which causes them to feel unmotivated and lose interest in the subject altogether. Their difficulty is exacerbated by conventional teaching methods, e.g., lectures, which favor the transmission of content to the detriment of its integration to the students' daily lives and other curriculum subjects. Indeed, in most lecture-based classes, the teacher's role is reduced to transmitting ready-made knowledge of which students are passive recipients (Guimarães, 2009).

One way to mitigate this lack of student interest and motivation is resorting to teaching methods that foster student reasoning and reflection (Darling-Hammond, Flook, Cook-Harvey, Barron, & Osher, 2020; Huang, 2015; Nuora & Välisaari, 2019) as well as integrating contents from various fields of knowledge (Catalá Rodes & Palacios-Arreola, 2020; GOMES, DA SILVA, Do Carmo, & Maia, 2019; Novoa Jerez, Alfaro, Alfaro, & Guerra, 2020; Vera-Monroy, Mejia-Camacho, & Gamboa Mora, 2020; Vidal & Melo, 2013).

Several teaching tools and strategies have been proposed to advance the teaching of Chemistry and encourage student participation in the teaching-learning process, e.g., games, infographs, concept maps, teaching cases, and lab activities. These approaches enable teachers to integrate topics of Chemistry to students' everyday lives and to other curriculum subjects in addition to promoting student-teacher interactions and better content learning (Focetola et al., 2012).

According to some scholars, lab activities are essential to the teaching of Chemistry as they can motivate students and foster their engagement in subsequent teaching-learning activities. When contextualized, lab classes can promote student motivation, engagement, and learning of content from related subjects (Francisco Jr, Ferreira, & Hartwig, 2008).

One of the topics that interest students the most is the functioning of the human body and the way it interacts with the environment (Vidal & Melo, 2013). The way we interact with the world around us is a good example of topics that allow easy integration of knowledge across different scientific disciplines and contextualization to the students' everyday lives.

Chemistry has much to do with the way we interact with the environment as we do so mainly through our senses, such as smell and taste. Both smell and taste may be classified as chemical senses in that they make use of receptor cells found in the nose and mouth to identify chemical substances present in the environment. Once detected by our senses, smell and taste information is transmitted along the plasma membrane, a phenomenon called synapse (Chandrashekar, Hoon, Ryba, & Zuker, 2006; Cheok & Karunanayaka, 2018).

Olfaction or the sense of smell involves the detection and perception of airborne chemicals. Chemical molecules enter the nose and dissolve into the mucous layers of a membrane known as olfactory epithelium. Thus, for instance, to be able to identify the smell of any given substance, its odorous molecules must separate from it, which happens due to the substance and environment having different concentrations of the volatile chemicals.

When these volatile chemicals dissolve into the mucous layers of the olfactory system and interact with its receptor cells, an electrical signal is generated and transmitted to the olfactory areas of the brain, e.g., the olfactory cortex, hippocampus, amygdala, and hypothalamus, in which the odor is interpreted and converted into a perception (Silva, 2011; Vidal & Melo, 2013).

Our nervous system recognizes each diverse volatile molecule by means of a set of specific chemoreceptors. Humans have about 400 types of olfactory receptor cells, which allow us to distinguish more than one trillion scents (Bushdid, Magnasco, Vosshall, Keller, & Mixture, 2016). At birth, we are already able to identify different odors around us; newborns are capable of recognizing their mother's scent and instinctively know that a particular scent belongs to their mother alone (GOMES et al., 2019). A smell is detected and interpreted according to its structure, i.e., the spatial shape of its molecules. The intensity of the scent is given by the concentration of volatile chemicals in the substance and, consequently, in the air (Guimarães, 2009).

Taste buds perform a similar task to that of the olfactory epithelium. They enable us to detect the four basic flavors, namely, sweet, salty, bitter, and sour (Cheng & Robinson, 1991; Kapsimali &

Barlow, 2013). A fifth flavor has recently been discovered: umami (Kurihara, 2015).

The sour flavor is given out by hydrogen ions in the substance, which block the K^+ channels. The intensity of the sensation is proportional to the concentration of hydrogen ions in the substance: the more acidic, the stronger the sensation. On the other hand, the salty flavor has a simpler mechanism. It is caused by the presence of ionized salts in the substance and varies from one salt to another because salts give out other flavors besides salty (Breslin & Huang, 2006; Chandrashekar et al., 2006).

The sweet flavor, in turn, is not caused by any single class of chemicals. It is dependent on the link to sugars, a set of organic compounds that includes glycols, alcohols, aldehydes, ketones, amides, esters, amino acids, proteins, etc. Most substances that give out a sweet taste are made up of organic chemical substances.

Interestingly, very small changes in chemical structure, e.g., the addition of a simple radical, can often change a flavor from sweet to bitter. The bitter flavor, like the sweet one, is not caused by a single type of chemical agent. Most substances that give out a bitter taste have organic chemicals. Two classes of chemical compounds are particularly responsible for giving out a bitter flavor: long-chain organic chemicals containing nitrogen and alkaloids (Cheok & Karunanayaka, 2018; Silva, 2011).

It is important to remark that many substances are identified by our senses of smell and taste together, frequently supported by our senses of touch, pressure, temperature, and pain (Cheok & Karunanayaka, 2018; Ertl, 2017; Sowndhararajan & Kim, 2016). The interaction between some chemicals in the environment and our olfactory and gustatory systems allows teachers to address and contextualize many topics of Chemistry, e.g., intermolecular forces, solubility, organic and inorganic functions, and organic reactions.

This study focuses on the pertinence of organic functions to students' everyday lives and their interference with the senses of smell and taste, by investigating and understanding the functions present in molecule structures and the way they affect food flavor and aroma.

1.1 Aroma Sensations

'Aroma' is a topic that provides teachers with a plethora of concepts with which to work in the classroom and school labs. Related to the senses of smell and taste, it entails the interaction of volatile molecules with the tongue and nose receptors. It constitutes, therefore, a good Chemistry and Biology teaching case.

Taste is primarily sensed by receptor cells, known as gustatory receptors, in taste buds or papillae. They can be found on the tongue, palate, pharynx, epiglottis, and larynx. Around 5000 taste buds are located on the tongue, and each contains from 50 to 100 receptor cells (Cheng & Robinson, 1991). The cells in the papillae are innervated by nerve fibrils that convert and communicate information to the brain (Araujo, 2003).

Microscopically, papillae resemble tulips (Figure 1), whose sensitive area, the apical terminal (containing taste hairs or microvilli), is located inside taste pores. When this structure is in contact with saliva, food particles dissolve into it and provide taste information to the brain through nerve fibrils (Araujo, 2003).

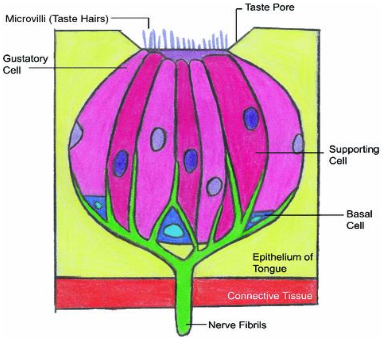


Figure 1. A human taste bud.
Source: Cheok & Karunanayaka, 2018

Papillae may be classified according to their shapes:
1. Similar to threads or fibers, *filiform papillae* are found on much of the tongue surface, even where no gustatory receptors exist;
2. Resembling fungi, *fungiform papillae* have a large contact surface and are distributed along the dorsal part of the tongue, especially on its extremities;

3. Resembling leaves, *foliate papillae* are located on the edges of the tongue;
4. Large with more than 300 corpuscles each, *circumvallate papillae* are located at the back of the tongue (Chamma et al., 2018).

Each flavor is detected by a particular area of the tongue, as shown in Figure 2 (Breslin & Huang, 2006; Chamma et al., 2018; Chandrashekar et al., 2006). The tip of the tongue detects the sweet flavor whereas its sides detect the sour and salty flavors. The bitter flavor is detected at the back of the tongue.

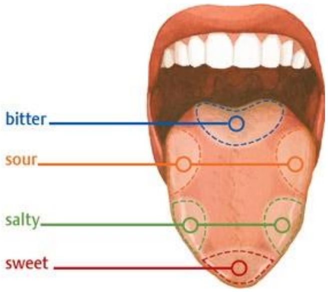


Figure 2. The human tongue and taste sensors.

Source: <https://kcaporellicc.wordpress.com/taste-sensation-and-perception>. Accessed on 06/08/20

Unami, a word of Japanese origin meaning ‘savory,’ is associated to a pleasant taste sensation, different from the other flavors depicted in Figure 2. Food that gives out this flavor is made up of L-glutamate and is detected all over the tongue (Nuora & Välisaari, 2019; Sowndhararajan & Kim, 2016).

As aforementioned, the senses of smell and taste are chemical in that they involve chemoreceptors. Some molecules present in food stimulate the gustatory receptors whereas their volatile compounds stimulate the olfactory ones. Odorous molecules can also be released through chewing and are detected by the olfactory epithelium. Gustatory, olfactory, and somatosensory (e.g., texture) sensations contribute jointly to flavor despite common belief that we taste with the mouth alone.

The sense of smell is associated to an important automatic physiological activity: breathing. Odorous molecules constantly flow into our system as air enters our nasal passages where the olfactory receptors are located (Sowndhararajan & Kim, 2016).

Olfactory cells contain cilia (hairs) that respond to chemical stimuli. The hair membranes are coated with a yellow mucosa consisting of protein molecules capable of binding to different odorous molecules. Upon breathing, the cilia capture the molecules that carry the odor. These molecules alter the electrical behavior of the cell, generating a stimulus, which is transmitted to the olfactory bulb in the brain through nerve fibers. Then, the odor stimulus travels from the bulb to other regions of the brain. Figure 3 shows succinctly how volatile molecules are detected and identified by the brain.

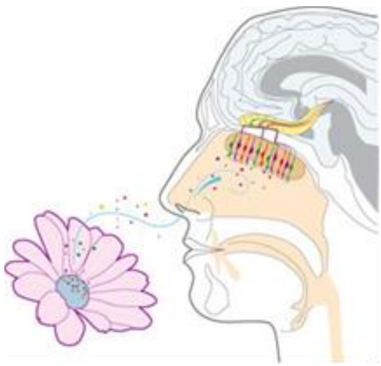


Figure 3. Scent molecules released by a flower enter the nose.
Source: <https://www.todamateria.com.br/olfato/>. Accessed on 05/20/2019

2. MATERIALS AND METHODS

An intervention research design, of a qualitative nature, was employed to assess the participating students' knowledge and understanding of organic functions as related to the senses of smell and taste. Data were collected by a questionnaire with eight multiple-choice questions responded by the participants before and after the intervention (ANNEX I). The first two questions (Q1 and Q2) focused on the participants' knowledge of the sense of taste; Q3 and Q4 on the sense of smell; and Q5 through Q8 on the organic functions of alcohol, phenol, ketone, aldehyde, ester, ether, carboxylic acid, amine, and amide.

The post-intervention questionnaire comprised the same questions and an additional open-ended question regarding the participants' opinion about the intervention (response was optional).

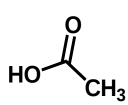
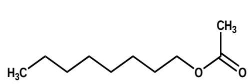
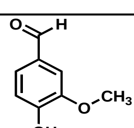
Focusing on organic functions and the way they affect smell and taste, the study was conducted with 25 3rd-year secondary school students. At first, a brief lecture presented the topic to foster student understanding of the content in question. During this preliminary presentation, an infograph was shown to the participants to bring the theory closer to their everyday lives.

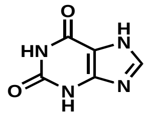
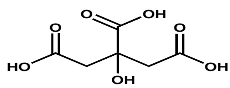
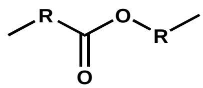
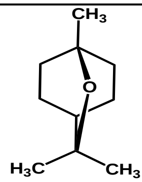
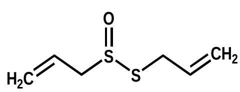
Twelve flasks containing the substances for the experiments were numbered (Figure 4): 7 for the taste experiments and 5 for the smell ones. The following substances were used: orange extract, vanilla extract, vinegar (acetic acid), lemon (citric acid), eucalyptus oil, coffee, jelly beans, table salt, sugar, garlic, and water.

Figure 3. Materials used for the smell and taste experiments.

After tasting each food item or smelling the aromas, the participants were asked to identify the functional group of compounds responsible for the sensations observed, as shown in Table 1.

Table 1. Food items employed in the experiments.

Food Item	Functional Group present in structure	Structure	Information
Vinegar[a]	Carboxylic acid		It belongs to the family of carboxylic acids and has 2C in its structure, also known as ethanoic acid; it tastes sour.
Orange extract[b]	Ester		Simple esters tend to give out a pleasant odor, generally associated to the organoleptic properties (aroma and flavor) of fruits and flowers; they taste sweet.
Vanilla extract[c]	Aldehyde; phenol; ether		Vanillin is the main component of vanilla extract or aroma; sweet taste.
Caffeine[d]	Amine; amide		Caffeine is an organic compound from the family of alkaloids. Alkaloids, in turn, are cyclic amines that have heterocyclic rings containing nitrogen. In addition to being an alkaloid, caffeine is an amide (a substance

			that has nitrogen attached to a carbonyl group); it tastes bitter.
Lemon (citric acid)[b]	Carboxylic acid; alcohol		Citric acid is a weak organic acid ($C_6H_8O_7$); solid at room temperature; white or translucent; odorless; sour taste.
Jelly beans[b]	Ester		Esters are food additives that give artificial flavor and aroma to industrialized products; sweet taste.
Eucalyptus oil	Ether		Eucalyptus oil contains 70% or more of 1,8-cineol (eucalyptol); it is antibacterial, cough suppressant, expectorant, nasal decongestant, and anti-inflammatory respiratory medicine; strong aroma and fragrance.
Garlic	Ester		Its main component is allicin; for this reason, garlic can reduce atherosclerosis and fat deposits, normalize lipoprotein balance, and decrease blood pressure; it has an anti-thrombotic and anti-inflammatory function.

Source: [d](Chen, Chen, Giudici, & Chen, 2016); [b](Vandenberghe, Rodrigues, de Carvalho, Medeiros, & Soccol, 2016); [c](Pacheco & Damasio, 2010).[d](Ertl, 2017);

2.1 Taste Experiment

First, the food samples, e.g., salt, coffee, sugar, vanilla extract, orange extract, lemon, and vinegar, were dissolved in water to enhance the taste sensation in the sensitive areas of the tongue. Then, the participating students were blindfolded, given the solutions with the help of a dropper, and asked to identify the food samples and the organic functions of their main chemical components. Finally, the participants were given a jelly bean and asked to identify its organic function.

2.2 Smell Experiment

The goal of this experiment was to identify the samples, i.e., vanilla extract, orange extract, eucalyptus oil, garlic, and vinegar, from the odors they released. Paper strips were used to apply the products. The participants were given the strips and asked to identify the odors and associate them to the functional groups of chemical compounds present in the samples.

3. RESULTS AND DISCUSSION

In general, the diagnostic questionnaire (Figure 3) responded by the participating students after the presentation of theory indicated that their previous knowledge of the senses of smell and taste (Q1 and Q2) was insufficient: 7 % and 23% correct answers to Q1 and Q2, respectively.

Q3 (on the location of nerve cells specialized in detecting smells) presented 35 % correct answers (i.e., B). In the subsequent questions on smell and esters, only 5 % and 2 % of the participants checked the correct answers to Q4 and Q5, respectively, revealing misconceptions about the content; them.

The last three questions assessed the participants' knowledge of oxygenated and nitrogenized functional groups. It seems that some participants had more prior knowledge about this content as compared to that assessed in the other questions: 43%, 38%, and 42% of them checked the correct alternatives for Q6, Q7, and Q8, respectively.

In general, as shown in Figure 4, the participants lacked prior knowledge about the senses of smell and taste and functional groups.

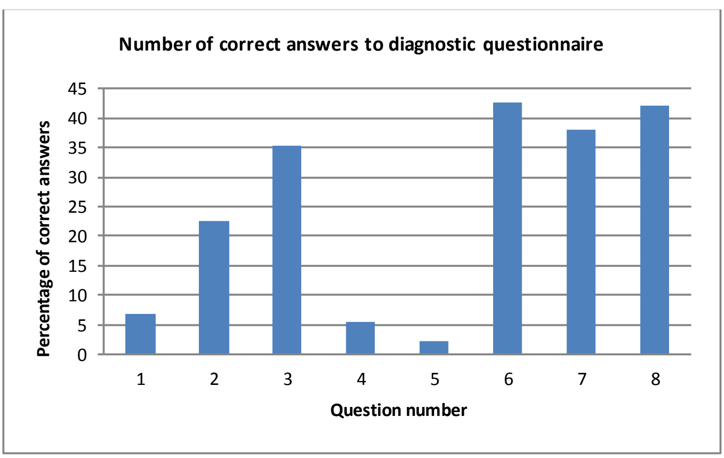


Figure 4. Participants' answers to Q1-Q8 on the diagnostic questionnaire.

The post-intervention questionnaire comprised the same eight questions found in the diagnostic questionnaire to enable the assessment of the participants' content learning after participating in the experiments. Figure 5 shows the frequency of correct answers.

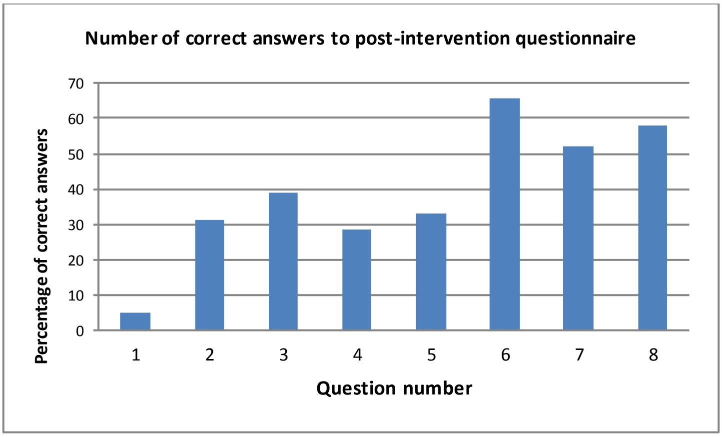


Figure 5. Participants' correct answers to Q1-Q8 on the post-intervention questionnaire.

Comparing Figure 5 to Figure 4, it is possible to affirm that the participants' ability to learn content was insufficient concerning the sense of taste as indicated by the low number of correct answers to Q1 (5%). Nevertheless, the percentage of correct answers to Q2 (about the classification of cells specialized in identifying tastes) was considerably higher (31%). Likewise, a higher number of correct answers was observed for Q3 (39%), Q4 (29%), and Q5 (33%). Moreover, student learning of functional groups of organic compounds was much higher: 66%, 52%, and 58% of correct answers to Q6 (amino functional group), Q7 (aldoxila functional group), and Q8 (organic functions of enols, esters, alcohols), respectively.

In light of these results, it is possible to affirm the smell and taste experiments were capable of motivating the participants and advancing their learning of the Chemistry topics in question. However, it should be remarked that this learning process has not ended. In order to consolidate learning, Chemistry teachers should revisit the content addressed in this intervention, according to their students' level of maturity, by means of other teaching techniques, methods, and resources (Cunha, 2012; Mamlok-naaman, 2011; Nuora & Välisaari, 2019; Stojanovska & Velevska, 2018)

With regard to the participating students' evaluation of the teaching method employed in the intervention, it is possible to affirm that it was favorable in view of the fact that 95% of them approved of it and commended its use to enhance the teaching of Chemistry in school. They declared that the use of similar experiments could advance content learning and understanding as well as foster teacher-student interactions, teamwork, and contextualization of theory (Figure 6).

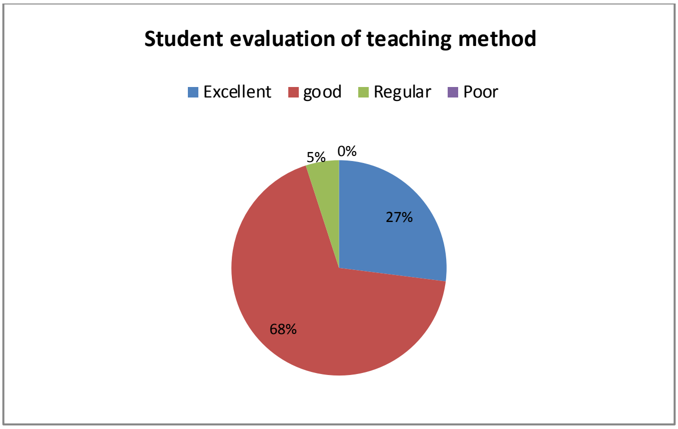


Figure 6. Student evaluation of the methodology employed in the intervention to teach organic functions.

During the intervention, many students expressed their satisfaction with participating in the class and their improved understanding of the content in question. At a given moment, the students were asked whether the teaching resources were sufficient or insufficient for effective learning. Most of them stated that the teaching steps followed during the intervention were essential for them to understand the content. In short, their learning experience was both pleasant and effective. However, they also considered that the presentation of the theory and infograph before the experiments was important for them to understand the content. Therefore, teaching resources by themselves might not suffice; well-crafted lectures, reading assignments, and teacher mediation may still be indispensable to the teaching-learning process (Figure 7).

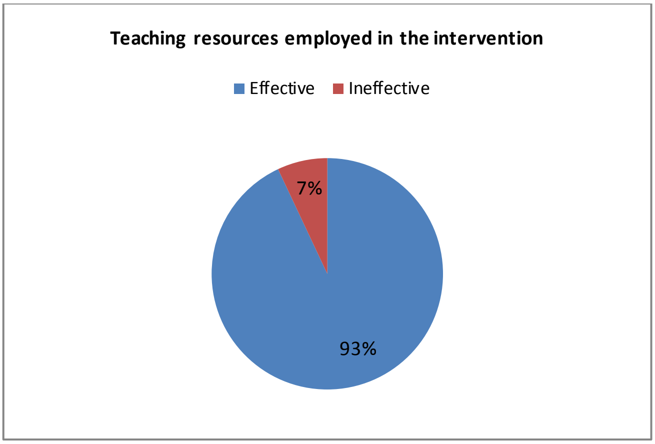


Figure 7. Student evaluation of use of teaching resources to promote learning.

4. CONCLUSION

Many students see no connection between Chemistry and their everyday lives and the environment. For them, Chemistry is but a never-ending collection of numbers and formulas to be memorized. For this reason, Chemistry is deemed a complex and challenging school subject that many students flunk. This is partly due to Chemistry being mostly taught by conventional means without using resources and methodologies that foster student learning.

The teaching of organic functions associated with the senses of smell and taste provided a good way to motivate student learning. The smell and taste experiments raised the participating students' interest in the topic addressed in the classroom and enabled them to see the connection between Biology and Organic Chemistry. The interdisciplinary approach adopted by the researchers promoted the learning of organic functions beyond mere memorization of information; the research participants were able to link successfully the structures of organic groups to the functioning of the senses of smell and taste.

After the intervention, the students seemed more motivated and interested in learning Chemistry and capable of connecting the theory about organic functions to the functioning of the human body. In addition, our results indicated the effectiveness of the teaching method employed in this study. Using alternative low-cost teaching resources, the smell and taste experiments encouraged the participants to discuss topics of Chemistry in an enjoyable, contextualized, interdisciplinary way.

Lastly, our research results also suggest that well-crafted, contextualized lectures remain important teaching tools provided that more active learning methods are not set aside as they can make the Chemistry classroom more dynamic, creative, and motivating.

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