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Mixtures and Their Separation Methods: The Use of Didactic Games, the Jigsaw Method and Everyday Life as Facilitators to Construct Chemical Knowledge in High School

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One of the difficulties found in Chemistry teaching, mainly in High School, is to establish relations among society, environment, science and technology. It is notorious and has required Chemistry teachers to have certain skills, including some that refer to several situations in everyday life. Therefore, this study aimed at introducing three methodological proposals to teach the content "methods of mixture separation". The first proposal aimed at addressing concepts and procedures based on different situations found in everyday life. The second offered students some strategies to encourage them to form different points of view and opinions. It favored both intellectual autonomy and access to production of chemical knowledge collectively and collaboratively (the jigsaw method). The third was related to the use of didactic games to make learning easier. The use of games in Chemistry teaching is a methodology that has been used because it enables students to have pleasure and fun while learning. Four classes of freshmen (first year in High School) that attend the Instituto Federal do Triângulo Mineiro - Campus Uberlândia Centro (IFTM-UDICENTRO), located in Uberlândia, MG, Brazil, took part in this study. Results suggest that all methodologies under investigation are also efficient in online lessons. Teachers can use them all together or individually. In addition, the didactic game under study was adapted so that it could be played in online Chemistry lessons, since the world has still been affected by the infectious disease caused by the coronavirus. The adaptation of the game called "SeparaMix" has not been published in the literature yet.

Graphical abstract

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1. Introduction

Mixture is a system composed of two or more substances which may be simple or compound. Mixtures may be classified into solid-liquid, liquid-liquid, liquid-gas, solid-solid, solid-gas and gas-gas [1]. The mixture in which at least one of the substances that composes it may be detected by means of a microscope, or even to naked eye, is called heterogeneous. The mixture in which substances cannot be determined is called homogeneous, also known as solution [1]. This term, however, is usually used as a synonym for homogeneous mixtures of gases, solids or liquids (solutes) dissolved in liquid (solvent). Mixtures of gaseous components are always homogeneous due to the large intermolecular space which makes diffusion easier [1].

Even though the content related to mixtures and their different separation methods taught in class is a simple issue in the High School curriculum, it is hard for some students to understand chemical concepts because they are often taught mechanistically [2]. In everyday life, people can perceive examples of mixtures which make them think about separation methods. For instance, atmospheric air, water – when it is treated and when coffee is prepared –, petroleum and blood. Depending on the number of phases, mixtures may be separated either by chemical processes or by physical ones (with or without any human intervention), such as decantation, filtration, extraction, simple distillation, fractional distillation, centrifugation and chromatography [2].

Based on this theme and other issues in Chemical Education, it is always relevant to reflect on the best way to teach abstract concepts and on difficulties faced by students to learn them. Studies carried out by several researchers in the area of Chemistry teaching have pointed out the importance and usefulness of practical lessons in the search for more significant learning. Experimental practices act as mediators in the cognitive construction of scientific knowledge and encourage an individual's investigative personality. From this perspective, introducing Chemistry in students' school life through practical activities may be efficient in the teaching-learning process [3,4].

Dissemination of the new coronavirus has changed Chemistry teaching in High School since the beginning of 2020. It had to be totally re-adapted and its experimental part was completely interrupted due to the new global reality. Thus, practical lessons that used to take place in laboratories and in in-person lessons were interrupted. Chemistry and the other courses have been taught virtually and online. Relations between teachers and students and the teaching-learning process have been intermediated by digital platforms, such as Google Classroom and Google Meet [5].

The first methodology introduced by this study uses the term "everyday life" as the guiding principle of the teaching process. This way of teaching different contents has been characterized as a resource which can connect people's simple everyday situations with scientific knowledge. It deals with contents related to phenomena that take place in individuals' everyday life and promotes concept learning by using real life [6]. Scholars have recommended caution because everyday life in Chemistry teaching has often been used as a kind of passing trend which merely aims at teaching scientific concepts. They also advocate that, if this perspective is well used, it is useful, since it uses everyday phenomena in lessons as examples intertwined with theoretical knowledge in an attempt to make it more comprehensible [6].

The second proposal uses the well-established jigsaw method to explore concepts and construct scientific knowledge about mixtures and their separation methods. Silva et al. (2020) addressed this proposal and stated that this cooperative learning strategy was developed by Elliot Aronson in an educational project in Texas, USA, in 1978. This approach was created to help to construct a study environment that seems a community in which all students are valued; undesirable aspects, such as excessive competition among participants, are either mitigated or eliminated, while interest in mutual cooperation is encouraged [7].

To propose and experience the third teaching methodology, a didactic game – whose focus was the theme of mixtures and their separation methods – was applied. The use of games in Chemistry teaching has been seen as a pedagogical possibility which can add pleasure and fun to learning [8]. It has been known that the Chemistry course makes teachers face much difficulty to address contents and concepts in the microscopic world; thus, it also requires students to make much effort and reach abstraction to comprehend several concepts [8]. As a result, the use of games in lessons or mobile applications is an alternative solution to mitigate such difficulty, since games are tools that make the teaching-learning process of chemical concepts easier ("learning through play") [8].

Therefore, this study aimed at evaluating the teaching-learning process by applying three methodologies, *i.e.*, an investigative activity which uses students' everyday life, the cooperative learning method called jigsaw and the use of virtual didactic games. How can the three methodologies help Chemistry teachers in their teaching practice? The justification for doing this study lies in the need to introduce different teaching methodologies to Chemistry teachers so that they help students construct chemical knowledge.

2. Material and Methods

The subjects of this qualitative theoretical study were 121 freshmen that attend the Instituto Federal do Triângulo Mineiro - Campus Uberlândia Centro (IFTM-UDICENTRO), located in Uberlândia, MG, Brazil. They formed four classes of freshmen attending technical courses in Commerce (A and B), System Development and Digital Game Programming. The first decision was related to how the experiment would be applied, considering that students were not attending in-person Chemistry lessons due to the COVID-19 pandemic. Thus, the whole study was carried out online with the help of both digital tools Google Classroom and Google Meet.

Regarding the first methodology, the theme "mixtures and their separation methods" was chosen because this topic is very common in students' everyday lives. Four apprentices (sophomores) of the teaching project that was approved in 2021 volunteered to virtually help all four classes of students involved in the study to carry out a research project on laboratory material used for separating mixtures (beaker, filter paper, magnet, stirring rod, universal stand, glass funnel, Petri dish, test tube, centrifuge, apparatus for simple and fractional distillation, etc). The volunteers also taught an extra lesson – about different types of homogeneous and heterogeneous mixtures and their separation processes – in which they applied a questionnaire with the following questions:

1) Why can't you separate salt from sand by the method of decantation?

2) Which process of mixture separation under study can you find in your everyday life?
3) Can you propose an effective way to separate water, salt and sand? How?
4) Why can salt be separated from sand in the process of fractional dissolution?
5) How would you separate metal residues that are contaminating crystal sugar?
6) How are components of petroleum separated?
7) Do water treatment plants use some process of mixture separation to enable you to get clean water in your home? Which ones?
8) Can you find some questions that address concepts of mixture separation in previous editions of the National College Entrance Test (ENEM)? Discuss the questions with your Chemistry teacher.

Data collected by the questionnaires were used to discuss results.

Concerning the second methodological proposal, firstly, a lesson plan and the application of a script based on the cooperative learning method called jigsaw were carried out. Afterwards, every class was divided into 6 groups of 5 students; their organization took into consideration the cooperative principle of heterogeneity [9-10]. In every group, every student was in charge of a specific theme of the content "mixture separation" (flotation, sieving, magnetic separation, decantation and simple filtration) and played a role in the group (editor, mediator, narrator and spokesperson). It should be highlighted that every group had to decide which role would be played by two of their members and that all proposed activities should be virtually carried out and organized by the groups by means of Google Meet.

When the proposal was implemented, the teacher that was responsible for the course gave a 15-minute theoretical speech by means of Google Meet about processes of mixture separation that would be used in the online workshop. Besides, physical and chemical properties of some substances, such as density, solubility, miscible and immiscible substances, related to the processes were also addressed. Afterwards, the beginning of the discussion among all groups was based on the following question:

How important are processes of mixture separation?

Editors were asked to write down the answers given by every member of the group and to send them to the teacher by means of Google Classroom. Every student of groups in charge of the same theme were also asked to join in order to form groups of experts. Every group of experts was responsible for a specific theme in the content "mixture separation", *i.e.*, flotation, sieving, magnetic separation, decantation, simple filtration and others. In these groups, students searched for a YouTube video which showed a specific experiment of the group's theme and discussed concepts associated with that experiment.

After having watched the videos of the experiments, students who belonged to the groups of experts discussed observations made throughout every experimental practice and described their results. According to Santos et al. (2020), at this specific moment, every student has the opportunity to present what s/he has learnt to the other members of the group, so that the knowledge needed to close the work can be clarified [11].

In order to close the cycle and help students internalize the knowledge introduced by the lessons, the third methodological proposal was carried out. It consisted of the use of a didactic game whose theme was "mixtures and their separation methods". Thus, the game "*SeparaMix*", which had recently been reported by the literature, was applied [12]. It should be highlighted that the game was created by researchers Rogézio Damas Guimarães and Elza Paula Rocha who graduated in Chemistry (teaching degree) at the Universidade Federal de Goiás (UFG), in Goiânia, GO, Brazil. The game comprises a board, a die, four pawns and nine cards with figures of methods of mixture separation addressed by the game, whose rules keep the same [12]. On the other hand, it should be emphasized that the game was adapted to online lessons by the authors who carried out the study reported by this paper. The adaptation to the virtual mode has been described for the first time in the literature.

Gimp and Unity were the software programs used for adapting the game. The former is a free image editor which enabled the pieces and the board to be made (**Fig. 1–3**). At first, it was also used for playing the game. The latter is a tool that enables 2D and 3D games to be developed. It was used for ending the game, making it playable in any computer [13].

Fig. 1. Pawns in the game.

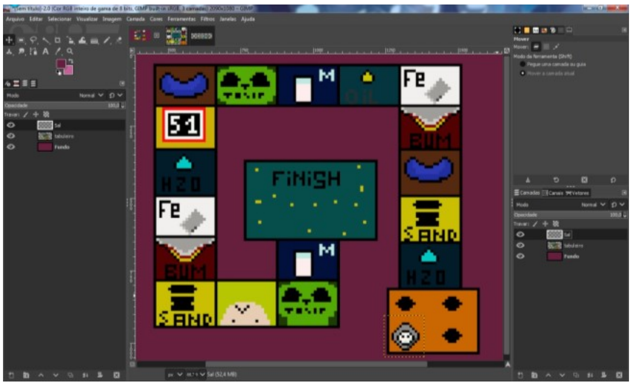

Fig. 2. Board built by Unity.

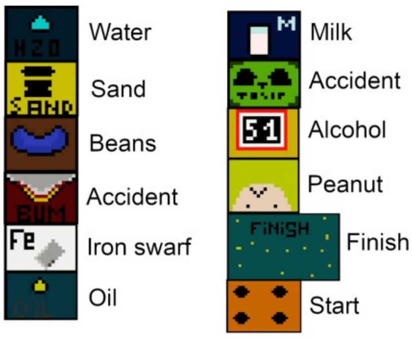

Fig. 3. Representation and meaning of every square on the board.

Some basic instructions for beginners:

1) The one who wishes to play the adapted version of "SeparaMix" should install Gimp in his/her computer by using the link https://www.gimp.org/downloads/.
2) Afterwards, download the file "board", which must be opened together with Gimp. Use the link https://github.com/GabrielHunt/Tabuleiro-Mix.git.
3) Either a 6-sided virtual die (**Fig. 4**) or a common physical one (in case you are playing with other people at home) is needed. The virtual die is available at https://www.google.com/search?q=dice+roller.

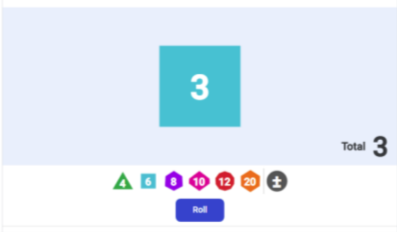

Fig. 4. Virtual die.

4) Select the type of die (in this case, the 6-sided one) and press "roll".
5) Finally, open the file of the board at Gimp and move the pieces according to the rules of the game [12].

3. Results and Discussion

This section has to start by pointing out the importance of bringing students' reality, their experiences and their everyday life to the lessons, so that they can be discussed from a scientific point of view. Observations carried out in the three stages showed that most students feel the need to use experimentation in Chemistry lessons to make them more interesting, to internalize contents and to relate them to everyday situations.

Regarding the first proposal, students' everyday lives were the center and starting point to introduce the theme "mixtures and their separation methods". To answer the first question – Why can't you separate salt from sand by the method of decantation? –, a student answered (wrongly) that both sand and salt are soluble in water. Another student said that "salt and sand are the same size"; he may have referred to salt crystals and sand grains (granulometry). Besides these students, twenty others supported this argument, even though they differentiated the dimensions of the solids. Most students got the right answer when they said that the decantation method is used for separating solids from liquids. Some students stated that the same process can be used for separating liquids that have different densities by using a separation funnel, for instance. Most students who got the right answer said that they had learned it with the apprentices who had volunteered to teach the extra lesson. When students were asked the second question – about everyday processes – few could associate separation methods or propose some analogy (they did not even remember the filtration process used for brewing coffee). The third question generated a long discussion since every student wanted to talk about his/her separation method, although most could not propose a logical sequence of processes involved in it. To answer the fourth question, few students cited the same examples used in the lesson and associated fractional dissolution to simple sugar dissolution. Ninety percent of students stated that they would dissolve sugar in water, sand would keep insoluble and then they would be able to carry out simple filtration. Concerning the fifth question, 30% of students suggested some methods, such as sieving and mixing all components of the mixture in water. Five students suggested that the iron swarf should be separated with the help of tweezers; they did not perceive that it would also be a type of picking which requires an apparatus, rather than hands. Seventy percent of students mentioned that the ideal method to separate metal residues is magnetic separation with the help of a magnet. The sixth and seventh questions also generated a long discussion. Many students said that the issues were interesting and that many ENEM questions require knowledge about petroleum and water treatment. Some students suggested YouTube videos which address both processes in detail. Thus, both questions enabled students to work on several methods of mixture separation. The eighth question instigated students to look ENEM questions – about the theme – applied before 2020. Students commented that the questions they selected addressed people's everyday lives. They were enthusiastic about solving them in the lesson and find out whether they were able to solve them.

At the end of the application of the first methodology, it may be stated that the learning process of the content "mixtures and their separation methods" based on everyday experiences was effective due to the result of informal talks and debates generated by students. It has been known that this type of learning is favored by students' involvement in the process of construction of scientific knowledge, which is the consequence of their higher interest in learning. Regarding their interest, the learning process results from empowerment favored by "learning". According to Vaciloto et al. (2019), the teaching proposal enabled by Science-Technology-Society-Environment (STSE) has been very effective in Science nowadays, since it makes students face reality and develop reflexive and critical thinking about Science and society [14]. This thought was expressed by a student's report: "*Studying Chemistry this way (using STSE) enables me to give a new look at life reality*".

The application of the questionnaire in the first methodological proposal (students' everyday life), which was used for evaluating students' previous knowledge, provided an important basis for the introduction of the second methodological proposal (the jigsaw method). The cooperative learning method called jigsaw applied to the content "mixture separation" and answers collected by the questionnaire led to the identification of changes in students' language. They started using certain terms, such as phases, miscible, volatile and particles, which are not common in their everyday lives to describe specific situations. In-depth understanding of phenomena and processes may be attributed to their direct relation to the content "mixture separation". The jigsaw method may favor improvement in students' written skills since scientific vocabulary is enriched by group discussions [9]. It implies that the classes gave more articulate answers when they were writing about the use of processes of mixture separation contextualized in everyday life.

The analysis and validation of students' learning levels after the use of the jigsaw method show that, after group discussions by means of Google Meet, students better understood the content under study. It was reflected by percentages of positive indexes, mainly fast answers given by students when they were questioned by teachers in oral tests applied to every class in distinct moments.

Therefore, cooperative learning, when applied to Chemistry teaching, may not only contribute to the comprehension of specific contents but also enable the development of students' competence and skills, such as data interpretation and analysis, argumentation, evaluation and decision-making [9, 14-15]. As a result, cooperative learning is a tool to develop chemical concepts in lessons, since students share responsibility for their learning with the teacher, besides the feeling of participation in the construction of knowledge based on autonomous, critical and significant principles through social interaction [16].

The last and pioneer methodology was the application of the game "SeparaMix". It was adapted to be used online because teaching in schools has still been taking place online due to the coronavirus pandemic. According to researchers in the area of Chemistry teaching, the use of didactic games in lessons may be considered a way to make them more dynamic and avoid traditional models based on contents in merely expository lessons [17].

Reports in the literature have also shown that didactic games can be used to enchant students and make Chemical Education interesting which enables content internalization. As a result, students feel motivated and interested in certain topics and start to be attracted by a course they did not like before. Finally, these statements corroborate the fact that ludic activities help to conquer students and trigger their interest in learning in a lighthearted and creative environment [17].

In short, this study called readers' attention to ways that make Chemistry teaching more attractive to young adolescents who attend High Schools all over the world. When Martin and his collaborators (2021) deepened their study of "mixture separation", they acknowledged that the theme has been broadly addressed and highlighted that very few studies go beyond binary or tertiary mixtures [18]. Erig et al. (2021) stated that the content "mixture separation" is fundamental but little explored in Chemistry teaching since few experimental activities are used either because there are no laboratories in schools or because teachers do not have time to explore the theme, even though it is directly related to students' everyday life [19]. Finally, to close this item, Coelho & Lima (2020) highlighted that Chemistry teaching in a contextualized way enables students to learn and makes them understand the true senses of daily events [20].

4. Conclusions

This study concludes that Chemistry teachers can propose interesting lessons by using different methodologies to address distinct themes. Three methodologies were used for addressing the theme "mixtures and their separation methods". Students could interact with the lesson and the teacher. By constructing chemical knowledge, students could propose methods to separate the mixtures introduced in the lessons. On the other hand, it should be mentioned that some students could not associate the methods introduced in the first lesson with their everyday lives. It may have happened as the result of how they see Chemistry, *i.e.*, a course that is far away from their reality and their everyday lives, besides rote learning, memorization of formulas, development of sophisticated products and modern laboratories and equipment. In short, this study reinforces that, in agreement with curriculum guidelines issued for High School in the areas of Natural Sciences, Mathematics and their Technologies, the use of strategies in Chemistry teaching requires a detailed analysis which is essential to evaluate efficacy in the teaching-learning process.

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Author Contributions

G.P.S, D.R.M, C.I.F.R, N.A.R.F and M.L.D.M. outlined the whole teaching project which was carried out with four High School classes (first year) at the IFTM-UDICENTRO. All authors conducted the systematic review of the literature. G.P.S and D.R.M adapted the game called "Separamix" to be played online, thus, making online teaching easier in pandemic times. All authors contributed to the writing of the manuscript. M.L.D.M was in charge of the final review and submission to *Orbital: The Electronic Journal of Chemistry*.

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