PRÁTICAS EDUCATIVAS, MEMÓRIAS E ORALIDADES

Rev.Pemo – Revista do PEMO

Perceptions of high school students about digital experimentation of chemistry

ARTICLE

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Abstract
In basic education, Chemistry experimentation should be understood as an activity that allows the articulation between theory, phenomenon, and representation. The difficulties experienced practical classes by the teacher, especially in public schools, are numerous and lack material, infrastructure, training, etc. However, the teacher, even without having a laboratory in their school, can use resources that are accessible to students to carry out experimental classes, one of these resources is the digital technologies. In this sense, this research aimed to analyze the perceptions of high school students regarding a Digital Experimentation of Chemistry (DEC) in a public school. The research with a qualitative approach and classified as descriptive was carried out in five stages through participant research. The results show a favorable posture of the students towards DEC, which contributed to the learning of chemical concepts. Furthermore, it was observed that it is possible to have the DEC as an ally since it can serve as a complement to the practices carried out in the laboratories.
Keywords: Digital technologies. Experimentation. Chemistry teaching. High School.

Percepções dos estudantes do ensino médio sobre a experimentação digital de Química

Resumo
Na educação básica, a experimentação química deve ser entendida como uma atividade que permite a articulação entre teoria-fenômeno-representação. Todavia, as dificuldades vivenciadas em aulas práticas pelo professor, principalmente nas escolas públicas, são inúmeras, pois carecem de material, infraestrutura, treinamento, etc. Entretanto, o professor, mesmo sem um laboratório disponível, pode utilizar recursos acessíveis aos estudantes para realizar aulas experimentais, um desses recursos são as Tecnologias Digitais. Nesse sentido, esta pesquisa teve como objetivo analisar as percepções de estudantes do ensino médio sobre uma Experimentação Digital de Química (EDQ). A pesquisa de abordagem qualitativa e classificada como descritiva foi realizada em cinco etapas por meio de uma pesquisa participante. Os resultados mostram uma postura favorável dos estudantes em relação à EDQ, que contribuiu para o aprendizado de conceitos químicos. Ademais, observou-se que é possível ter a EDQ como aliada, uma vez que pode servir de complemento às práticas realizadas nos laboratórios.

DOI: https://doi.org/10.47149/pemo.v6.e13662
https://revistas.uece.br/index.php/revpemo
ISSN: 2675-519X

Palavras-chave: Tecnologias digitais. Experimentação. Ensino de Química. Ensino médio.

1 Introdução

Unfortunately, the learning of curricular components involving the natural sciences has shown low levels, especially when compared to the results of other countries surveyed around the world (Oliveira, 2019). The latest Programme for International Student Assessment (PISA) by the Organization for Economic Co-operation and Development (OECD), carried out in 2018, revealed that 55% of students did not reach the basic level of learning in the natural sciences required to exercise full citizenship, which is one of the factors that led Brazil to rank 57th out of the 79 nations surveyed (Oliveira, 2019).

Among the curricular components of the Natural Sciences surveyed through PISA, Chemistry stands out, considered by some students to be one of the most difficult subjects (Souza; Leite; Leite, 2015). In the Chemistry curriculum, one of the components of the sciences whose level of student learning was measured in PISA, learning deficits have been observed among Brazilian students, caused by a variety of reasons (Queiroz; Alves, 2022; Souza; Leite; Leite, 2015). In addition, there are many factors that make it difficult for students to learn chemistry. Often, the traditional way of teaching with only the direct transmission of content and formulas, memorization of symbols and names, the lack of contextualization with the student's daily life, interdisciplinarity, generates great disinterest in the subject on the part of the students (Albano; Delou, 2024; Souza; Leite; Leite, 2015).

In addition to these factors, there is another that may also be hindering student learning: the lack of experimentation. In this context, the absence of experimental classes may be contributing to students' difficulties in constructing knowledge. In chemistry teaching, experimental activities have great potential to arouse students' interest and contribute to the process of building knowledge. Through experimentation, students are encouraged to formulate hypotheses, make careful observations and analyze results, which strengthens their scientific skills and their understanding of how theories apply in real contexts. Thus, the absence of these activities in chemistry classes can contribute to the low level of learning observed in the PISA results.

Lessons with chemistry experiments can refer to something that only takes place in a science laboratory within a school unit. In this case, there will be an involuntary exclusion, because not all Brazilian schools have this infrastructure (laboratories equipped and fit for use). However, when there are experiments that can be carried out in the classroom, they can help the process of teaching and learning science, especially in schools that don't have the minimum laboratory conditions to carry them out (Leite, 2015).

Even if the school has a science laboratory that can be used, the number of students per class is often very high in basic education. This means that practical science lessons may not take place, due to the educational reality experienced by teachers and students. In a class with around fifty students, it is more common for teachers to choose to spend time with these students in the classroom rather than taking them to the laboratory. Taking a large number of students into the laboratory, above the capacity of that space, can result in dispersion during the experimental lesson, causing some students to lose interest in what the teacher is teaching. Similarly, the teacher is unlikely to be able to keep up with the learning of all the students in the laboratory class, given the context.

Faced with the difficulties faced by teachers, both in schools without laboratories with adequate infrastructure and in those that have them but their teachers don't use this space due to the excessive number of students per class, these professionals tend to teach experimental lessons only in the classroom, with everyday materials from supermarkets, pharmacies and construction warehouses (Oliveira; Gabriel; Martins, 2017). However, the space set aside for science laboratories (chemistry, physics and biology) is not always used. In some cases, these laboratories are deactivated or used for various purposes, such as storage, a support room for students who need tutoring or as a library.

In this sense, experimentation can be carried out in the classroom using some alternative materials (Oliveira; Gabriel; Martins, 2017; Queiroz; Alves, 2022). However, in the specific case of Chemistry, not all of the contents of its high school curriculum provide viable experimentation in the classroom. Some high school chemistry content has

DOI: https://doi.org/10.47149/pemo.v6.e13662
https://revistas.uece.br/index.php/revpemo
ISSN: 2675-519X

experiments that require more sophisticated equipment and reagents. The question arises: How can teachers carry out the experiments required in chemistry content when there are not enough laboratories or space for them?

Considering this research question, and given the difficulties and limitations in carrying out experimental classes in basic education in various Brazilian schools, this research aimed to analyze the perceptions of high school students on the use of Digital Experimentation of Chemistry (DEC) in a public school, using Digital Information and Communication Technologies (DICT). We therefore set out to investigate the use of Digital Experimentation of Chemistry (DEC) by elementary school students, analyzing their perceptions.

A possible alternative can be characterized by the technological resources that students already have or that the school itself has, even without adequate infrastructure conditions for carrying out common practical activities. The use of DEC could be promising, as it integrates DICT with experiments in the chemistry curriculum.

2 Methodology

This is a qualitative study that sought to highlight students' perceptions of the DEC and is classified as descriptive. As it is a descriptive study, it seeks to relate variables relating to experimentation in the Chemistry curriculum. According to Gil (2010, p. 26) “descriptive research aims to describe the characteristics of a given population. They can also be designed to identify possible relationships between variables”.

In terms of the methods employed, the research can be classified as Participatory Research. According to Gil (2010, p. 43), it is “a research model that differs from the traditional ones because the population is not considered passive and its planning and conduction are not the responsibility of professional researchers”. In addition, the population being analyzed interacts in the discussion of the various problems that make up the sample of those being researched. According to Gil (2010, p. 43), the “selection of the problems to be studied does not emerge from the simple decision of the researchers, but

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ISSN: 2675-519X

from the population involved itself, which discusses them with the appropriate specialists". In participant research, the researcher, in the process of observation, "actively participates as a member of the group he/she is studying, using this privileged position to obtain information about that group" (Apolinário, 2011, p. 136).

The research was carried out in five stages. The first stage consisted of drawing up proposals for the application of the DEC. For this stage, we sought to develop proposals that would make it possible for teachers and students of basic education to carry out digital experimentation in chemistry.

In the second stage, the participating teacher chose one of the proposals drawn up, the digital simulations and the content that would be covered in the DEC. The content was chosen with a view to applying the DEC, taking into account the content available in the Pernambuco Curriculum Parameters (PCPE) (Pernambuco, 2013) for secondary education (Table 1), covering the first and second year, and that there were simulations available in the Simulations PhET application.

Table 1 - Content chosen for the DEC.

Grade	Contents	Learning Expectations (LE)	Unit
1st year	Acid and base theory and pH measurements	EA159 - Understand the procedures used to calculate pH and pOH values, based on concentrations of H^+ (H_3O^+) and OH^-	II
1st year	Molecular kinetic model	EA105 - Apply the molecular kinetic model to explain variations in the volume of gases when they are heated or cooled.	IV
1st year	Molecular kinetic model	EA103 - Recognize that the movement of particles is associated with their kinetic energy and that they can have different speeds.	IV
2nd year	Concentrations of solutions	EA40 - Calculate the concentration of a solution given by the amount of solute in moles in relation to the volume of the solution in liters.	I

Source: Authors.

The feasibility of the DEC using this content makes it possible to change the order of the units, so that a topic from the first unit (Unit I) can be seen in other units, and it is up to the teacher to assess what is best for their students' learning, as defined by the PCPE. In this way, in Unit I, an DEC was applied in a 2nd year class, with the theme "Concentration

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ISSN: 2675-519X

of solutions”, and another DEC in a 1st year class, with the theme “Theory of acids and bases and pH measurements”. Each DEC took place in just one class in each grade. In Unit II, two remaining DECs were applied in two different 1st grade classes involving the “molecular kinetic model”.

The third stage consisted of applying the Digital Experimentation of Chemistry with high school students. Fifteen high school students from a state school located in the metropolitan region of Recife, Pernambuco, took part in the research. The students participating in each class signed a Free and Informed Agreement Form and their guardians signed a Free and Informed Consent Form (FICF). All the students were invited to take part in the research on a voluntary basis. The DEC was carried out over the course of the school year, which is divided into four units, each dealing with a piece of high school chemistry content. The students carried out the DEC based on the content selected by the subject teacher. The research was approved by the ethics committee (Report No. 5.062.563).

In the fourth stage, a structured interview related to the students' perception of the DEC was carried out using intensive direct observation, which consists of observation and an interview. According to Markoni and Lakatos (2010, p. 173), “intensive direct observation is carried out using two techniques: observation and interview”. The resourcefulness and behavior of the students during the DEC was taken into account in the research through observation, which consists of “a data collection technique to obtain information and uses the senses to obtain certain aspects of reality. It consists not only of seeing and hearing, but also of examining facts and phenomena that one wishes to study” (Lakatos; Marconi, 2010, p. 173). This was a systematic observation that “takes place under controlled conditions, to respond to pre-established purposes” (Lakatos; Marconi, 2010, p. 173). The structured interview was conducted “based on a previously established script that guides the researcher on what they want to know” (Malheiros, 2011, p. 196), and was applied individually to each student taking part in the research. The interview had 12 questions (Table 2), which were applied at a different time to the DEC.

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ISSN: 2675-519X

Table 2 – Interview questions on the application of the DEC.

1. Is chemistry difficult for you to understand? What makes it difficult, if you answered yes to the first question?
2. Throughout your school life, have you ever had a lesson using technological resources? If so, what was it like?
3. How would you rate the use of audiovisual resources (computers and simulator programs) in chemistry lessons? Tell us about your experience with this type of activity.
4. Did you find it difficult to carry out the experiments in the DEC?
5. Name the positive points (in your opinion) of the chemistry lessons carried out using digital experimentation.
6. Name the negative points (in your opinion) of the chemistry lessons carried out using digital experimentation.
7. Have you ever been in a chemistry laboratory?
8. Do you think it's important to prepare by using digital simulations before going into a chemistry laboratory?
9. In the DEC activity you did, what caught your attention the most? Why?
10. What suggestions can you make to improve activities involving DEC?
11. Was the script for the DEC activity easy to follow?
12. Did you like chemistry before the DEC began?
a) Yes. Has the application of these lessons strengthened your love of chemistry even more? Why?
b) No. Has the application of these digital lessons changed your opinion of chemistry? Why?

Source: Authors.

Audiovisual recordings were used to collect the interview data and the answers were transcribed into a document for later analysis.

Finally, the last stage consisted of analyzing the responses of the students who took the DEC. Data analysis is “an attempt to highlight the relationships between the phenomenon studied and other factors. These relationships can be established according to their cause-effect relational properties, correlations [...]” (Lakatos; Marconi, 2010, p. 151). The research sought to understand the perceptions of regular education students regarding the ease of application and learning of the DEC. The students' responses will be compared with reports already found in the literature in the area.

In order to keep the identity of the participants confidential, a code was created with four alphanumeric symbols, the first three symbols in normal writing and the fourth symbol subscripted ($E0A_0$). For example, for a 1º year class A student who took part in the DEC, their code will be $E1A_1$, where “E1” refers to Student 1 (and can go up to E15), the letter “A” refers to the student's class and the “$_1$” (subscript) is their grade.

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https://revistas.uece.br/index.php/revpemo
ISSN: 2675-519X

3 Results and Discussion

Initially, to carry out the activity (the first stage of the research), three routes of action were proposed for applying the lesson with DEC.

Route 1 is recommended for the teacher applying the proposal who is in a school with wi-fi internet access, or any other type of fast access to the web on its premises, as well as having a computer lab in full working order. However, all of their students do not have mobile devices (smartphones, tablets, etc.) compatible with downloading applications and software that simulate experiments, so the solution is to move them from the classroom to the computer lab and carry out the DEC on the computers in the Teaching Unit.

Route 2 is for classes where all the students have smartphones or mobile devices that allow them to download and install a simulator application. In this case, the DEC will be carried out in the classroom, without the need to move to any other extra-class space. Once it has been identified that the Teaching Unit does not have access to the internet, but all the students have mobile devices (smartphones, tablets, etc.) to download the application related to the experiment, it is important that, before the lesson, the teacher informs the students of the name of the application, so that they can download it in out-of-school places (home, shopping mall, squares, etc.), as a prerequisite for the DEC activity.

Route 3 is aimed at schools in more precarious conditions than those observed on routes 1 and 2, where the school does not have a suitable computer lab and not all students have mobile devices to carry out the DEC. Therefore, the teacher administering the DEC should ask students who have compatible mobile devices to download simulator apps (either at school or out of class) and then encourage them to form groups in the classroom to carry out the activity. Figure 1 summarizes each possible route for applying the DEC.

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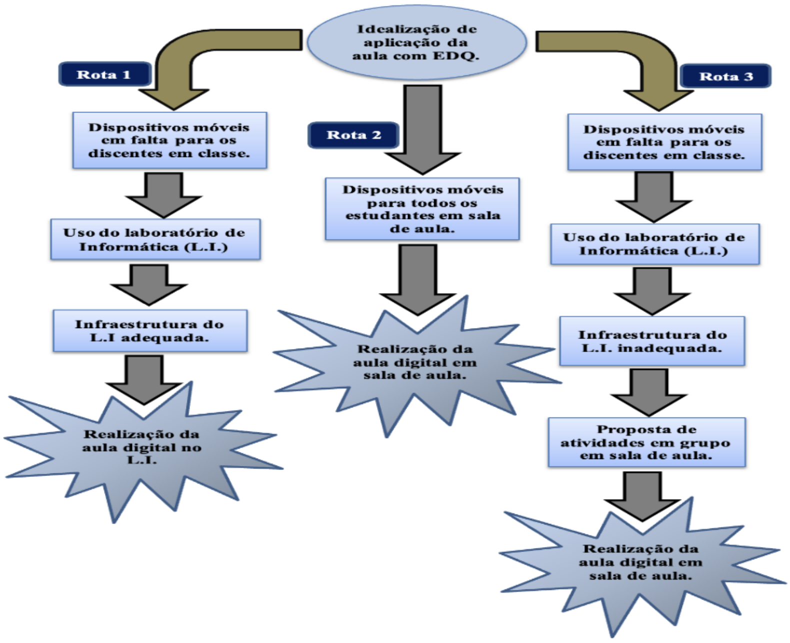
Figure 1 - Possible routes for applying DEC in class.



Source: Authors.

For this research, the route chosen by the teacher of the subject was number 1 (second stage), because many students in the Teaching Unit, where the DEC was applied, did not have mobile devices that supported downloading the simulator application for practical chemistry activities. As the school (the teaching unit where the research took place) had good quality internet access, it wasn't necessary for the students to download apps. They accessed the chemistry experiment simulator site chosen for the DECs, as shown in route 1. The students already found the school computers with the simulations page open in the Teaching Unit's computer lab.

The choice of digital simulations to carry out the DEC was based on the survey and analysis carried out by Lira and Leite (2022), who investigated applications that allowed digital experimental chemistry activities to be carried out, without being limited to the execution of pre-programmed scripts. The aim was for the digital simulations to be carried out in DEC to enable the teacher to plan the experiment and/or the student to be free to choose the solutions to be used. The research (Lira; Leite, 2022) identified only one

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application that worked offline (requiring only a single internet access to download), that was not restricted to predetermined experiments and that allowed students to make mistakes while handling the virtual experiment, generating a sense of analytical reality (simulating a real environment). In addition, the simulation application should not contain cartoons or be limited to a simple quiz. In this context, the application selected for the DEC was Simulations PhET (Physics Educational Technology), developed by the University of Colorado.

The didactic intervention took place at different times in each class, according to the Teaching Unit's timetable. The interview took place during the school's break, in a private room, as some students mentioned that they would feel more comfortable being interviewed in this way. It should be noted that the interviews were conducted individually, so each student participant was interviewed phlegmatically and without interference (Gil, 2010).

In relation to the first question, "Is chemistry difficult for you to understand?", all the students taking part in the survey said that they found chemistry difficult to understand. These answers continue to agree with the data found in research on chemistry teaching, which indicates that the subject is considered one of the most difficult curricular components to understand (Albano; Delou, 2024; Lira; Leite, 2022; Souza; Leite; Leite, 2015). In addition to the initial question, "What makes this subject difficult, if you answered yes to the first question?", the students gave a variety of answers, claiming that chemistry is difficult because of the "presence of mathematics" (33.3%), the "lack of practice", i.e. the absence of experimentation in chemistry classes (80%) and the "abstraction present in the subject's content" (66%). Some students mentioned more than one of these characteristics.

When asked if they had ever had lessons using technological resources (Question 2), all the students said that they had never had lessons with digital technological resources with which they could interact virtually in the classroom. According to Leite (2022), one of the possible causes for this reality - that some students have never experienced didactic activities with the support of DICTs - lies in the teachers' perception of these tools, since the

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> impression is that teachers see technology as a very expensive educational resource, not just in financial terms, but mainly in terms of time. It can take a considerable amount of time for teachers and students to become familiar with a particular digital technology before they can use it effectively (Leite, 2022, p. 21).

Still in response to the second question, 53.3% of the students surveyed made an additional comment, associating the classes supported by DEC with the online classes they had during the Covid-19 pandemic (academic years 2020 and 2021), in which it was necessary to use computers and smartphones. As $E2B_1$ comments: "*Just like this experimental Chemistry class with these computers, the remote classes during the pandemic I also needed computers to study, the two cases were very similar*", and $E3C_1$: "*It was very similar to the online classes I had last year and the year before*".

With regard to the use of computers and simulation programs (Question 3), the students commented on their experiences, evaluating that the dynamics of the lesson with DEC as a complement to the Chemistry lessons was good, since the Chemistry contents were being worked on in the classroom in a purely theoretical way, through lectures. During the activity, the students associated DEC with a video game, according to one of the statements "*This thing looks like a video game*" ($E1A_1$).

It's important to note that, initially, it was observed that the students were not in favor of the DEC as an integral substitute for real practical chemistry activities; for them, the ideal is for it to be a complement. This observation is relevant, since the DEC proposed in this research does not seek to be a substitute for experimental classes, but rather one that can be used when class conditions are not possible (either due to technical or infrastructure limitations).

In the context of the students' experience with digital resources, the students' responses indicate that they have a close relationship with DICTs, according to the following statements: "*I usually use a computer at home to play video games*" ($E1B_1$); "*I use my cell phone for almost everything I do: chatting with my friends, recording videos and accessing my social networks*" ($E4A_2$); and finally "*Nowadays everyone uses the internet for everything*" ($E3C_1$). According to Leite (2022), digital technologies are very

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close to students' everyday lives. However, teachers need to be trained to use them in their teaching practices so that their use is as natural as it is in people's daily lives.

In relation to question 4, “Did you find it difficult to carry out the experiments in the DEC?”, the majority of students (73.3%) said that their difficulties were related to the specific nature of the chemistry content, even after the teacher had approached the subject in class. However, after applying the DEC, the students reported improvements in their understanding of the content. In some cases, they had some initial difficulties in understanding how the PhET Colorado simulations (the application selected for the DEC) worked. Over the course of the explanation of how to use the tool, the difficulty was resolved, as some participants pointed out: “*As we had already seen this subject in class, my doubts were still about some of the chemistry content and also understanding how that little game worked, but as you explained that day how to use the game, I was able to understand*” (E2A$_2$) and “*Although we had already seen the theoretical subject in class, even so I still had doubts about chemistry, as I also had doubts about knowing how to deal with that simulation. But with the explanation I was able to understand how to interact with the simulation. It's a game*” (E3A$_2$).

What can be seen in this fragment of the students' reports is the role of the teacher, who, in addition to having knowledge of the specific content and pedagogical character, also needs to have knowledge of technologies, according to the assumptions of Technological Pedagogical Content Knowledge (TPACK) (Cibotto; Oliveira, 2017; Leite, 2022). At first, the students had doubts both about the chemistry content, probably due to the non-existent practical activities, and about the digital resource being used at the time. If the teacher didn't know how to use the technology, DEC would become unfeasible.

When asked about the positive points of chemistry lessons using digital experimentation (Question 5), the students who carried out the practical activities “pH Analysis” and “Concentration” indicated that the greatest advantage was the time needed to carry out the activities. According to E2B$_1$, DEC is agile, because: “*This virtual activity is faster, you don't even have to stand up to do these practicals*” (E2B$_1$). E4A$_2$ points out that “*If I make a mistake here, it's quicker to start again than if I did the real activity, with me*

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touching the real materials” ($E4A_2$). These statements are in line with the findings of Leite (2021), who emphasized that the use of technology enables greater dynamism and speed in the teaching and learning process.

For the students who carried out the “States of matter” and “Study of gases” experiments, the advantage for them, in addition to carrying out the practical activities quickly and dynamically, as already mentioned by the students in the “pH analysis” and “Concentration” simulations, was the possibility of “seeing” what is not even seen under a microscope, such as molecules and atoms. As evidenced by $E2B_1$'s statement: “*On this computer you can see the molecules of the gases moving, it's not like in the textbook where they're obviously stuck on the page*”, as well as $E1C_1$'s: “*The little balls keep moving, you can't see that in normal classes, not even with simple experiments. Only here can you get a sense of how the molecules behave when you change something in them*”. However, it was necessary for the researcher to intervene during these speeches, warning them that what they were seeing on the computer was a representation of the molecules and atoms, not a real view.

It was possible to see in some of the students' speeches how practical ICT made their actions. When an error occurred, it could be easily corrected in the digital experimental activities, which would take longer in the case of an error in real experiments. As $E3A_2$ explains: “*If I make a mistake, it's easier to go back to the beginning than if it were a real experiment, like resetting a video game*” (sic). This possibility of restarting the digital experiment may also justify the use of the DEC as a test resource for real laboratory practices, as is the case with simulators.

For the students who carried out the “Study of gases” and “States of matter” practicals, the DEC may have acted as a resource for curbing the abstraction of certain chemistry content, as $E1B_1$ and $E2C_1$ mentioned above. This abstraction was cited by them as a strong candidate characteristic for causing difficulties in understanding chemistry, along with the presence of mathematics and the lack of practical activities, as reported by $E4A_2$:

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> *there is content that you can get a sense of without having to work with your imagination, like concentration, you don't have to imagine anything because I'm seeing the mixtures, but there are some subjects I saw last year that I had to mentalize the situation, so I believe that in addition to the lack of experimentation, there are also subjects that force you to imagine (E4A$_2$).*

Considering question 6, "Name the negative points (in your opinion) of chemistry lessons conducted with digital experimentation", 53.3% of the students pointed out a disadvantage in DEC, observed especially by the students of the "pH Analysis" and "Concentration" experiments. For them, one of the disadvantages of the lesson with the DEC resource is the lack of physical contact with the materials and reagents, since in the digital experiment they only see and interact virtually with the experiments. These impressions can be seen in the following reports: "*In this computer one, I can't touch things. In person I can*" (E3A$_1$) and "*In face-to-face practice I can feel things better than just through a computer screen"* (E3A$_2$).

As for the students in the "Study of gases" and "States of matter" experiments, another disadvantage mentioned was related to the graphic representation, since they are fanciful colors and shapes that don't represent the reality of molecules. For the first disadvantage reported by the students in their answers, some real-world sensations are compromised, especially the organoleptic properties of matter, which make it possible to identify certain substances through the five human senses. Table 3 shows what happens to organoleptic properties in the digital environment compared to the real world.

Table 3 - Real/virtual organoleptic properties comparison

Organoleptic properties	Real	Digital
Color	Yes	Yes
Brightness	Yes	Yes
Odor	Yes	No
Taste	Yes	No
Texture	Yes	No

Source: Authors.

As for this disadvantage (related to organoleptic properties), the purposes of DEC are varied and aim to optimize student understanding of a given subject. They can serve

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as a complement to avoid possible errors in real experiments, as E3A$_1$ and E3A$_2$ mentioned earlier.

On the other hand, the disadvantage pointed out by students in the "Study of gases" and "States of matter" experiments is the same as that observed in textbooks, where molecules and atoms are represented in fanciful colors and shapes for didactic purposes. This situation can be characterized as an epistemological barrier to learning, since analogies, when not used appropriately in the teaching and learning process, can hinder the cognitive construction of a given area of knowledge.

Thus, an epistemological barrier present in the use of spheres to represent gas molecules, whether in textbooks or in the digital simulation itself, is the animistic obstacle. According to Bachelard (1996), the epistemological obstacle of the animist type focuses on the excessive use of comparisons and analogies, since it concerns the use of metaphors and analogies to explain physical and/or chemical phenomena.

With regard to question 7, "Have you ever been in a chemistry laboratory?", all the students said they had never been in a laboratory. Research (Leite; 2018; Guaita; Gonçalves, 2022; Lira; Leite, 2022) has observed that many Brazilian public schools do not have a science/chemistry laboratory that is fit for use and that the space allocated to the laboratory is not always used, as in some cases they are deactivated or used for various purposes. As these spaces fall into disuse, they are spontaneously used for other purposes by the school community. Thus, the lack of laboratories cited by the students, even though they physically exist, results in them not being used effectively for practical lessons.

When asked if they thought it was important to have some preparation by means of digital simulations before going into a chemistry laboratory (Question 8), the students said that it was necessary for the school to have an environment for this preparation, since it is necessary for the school to have a physical laboratory that can be used. The preparations are not just for practical school activities, but also for their education, as E4B$_1$ says: "*I think it's interesting to have these virtual activities because they serve as rehearsals, either for the school laboratory or for an activity I might do at home or something that helps me learn*". In addition, the students' answers showed their preference for carrying

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out practical activities in person. Ideally, these practices should always be present in their education, whether in the classroom with some simple experiments, in the Teaching Unit laboratory or in their own daily context, as $E4A_2$ said:

> *If we can't do certain chemistry practices in the school laboratory, we can still do these activities digitally, which will help me if I ever do them outside of school, either at home or at a university. At least in my case, I'm becoming more interested in chemistry after these virtual activities, I feel like doing them physically, taking these things, it should be simple ($E4A_2$).*

In this sense, we can see the importance of DEC, which goes beyond promoting practical digital activities quickly and dynamically, but also awakens an interest in experimentation in those involved with chemistry in basic education. It's worth noting that the reality of many public schools is the opposite of these activities, where teaching is limited to the blackboard and chalk to explain this area of knowledge. As $E3C_1$ points out: "*The classes I had in Science/Chemistry, the teacher only used chalk and the blackboard, he didn't do any practical activities in class*". It is necessary to rethink the teaching methods of the various areas of knowledge, especially chemistry, in the context of teacher training in their undergraduate programs (Queiroz; Alves, 2022; Souza; Leite; Leite, 2015). Furthermore, in order to improve the quality of teaching, we need to pay more attention to undergraduate courses, which could generate good results in the medium and long term.

When asked what most caught their attention in the activity they carried out (Question 9), the students unanimously highlighted the playful nature of the EDQ, which was a novelty for all of them who were unfamiliar with the digital resource, demonstrating a favorable attitude towards the methodology used. The students also felt that, if it wasn't possible to have a face-to-face experimental lesson at school, either due to lack of materials or the absence of a laboratory, it would be interesting to offer this type of lesson. In addition to the playfulness, the students pointed out that the practicality of the activities also caught their attention, as they said it was very quick to do the digital practices. For the students, "*a click is all it takes for digital experimentation to take place in a practical and fast way*" ($E2C_1$), without having to "*wait to get the results of an analysis*" ($E1A_1$). Still on the subject of practicality, $E2A_2$ reports that: "*If we had to prepare each solution of this*

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physically, it would be more work. Having to measure each quantity, prepare the materials to pour into the water and calculate the concentration. Here it's more practical”, revealing that ICT can make the experimental activity more agile.

When asked to give suggestions for improvements to the activity, “What suggestion can you give to improve activities involving DEC?”, there was a diversity of responses from the students. Some pointed out the Teaching Unit's technical issues, such as computers that malfunctioned during the lesson, the internet that fluctuated during the application of DEC and other problems, as well as the application of DEC in other curricular components, such as Physics and Biology. As suggested by $E4A_1$: “*there should be experimental activities in Physics and Biology, it would help a lot to understand*”. $E2A_2$ suggested the use of platforms that would more faithfully represent the student's experience in the laboratory, through a three-dimensional perspective, asking: “*if the proposal is really to simulate us in the laboratory, then there could be a platform that better represents a person in the laboratory. Like, with a bench, reagents and materials*”.

The three-dimensional perspective mentioned by $E2A_2$ can be contemplated with virtual and/or augmented reality, which is in the idea of the metaverse, as well as instruments that enable virtual experimentation. Digital laboratories with virtual and/or augmented reality are still being developed in the field of chemistry; however, research has shown a significant increase in studies in this area (Leite, 2021; Guaita; Gonçalves, 2022). Lira and Leite (2022) point out that there are still few studies involving applications with three-dimensional (3D) characteristics and that most of these presented experiments with pre-programmed scripts, where the only possible error for the student is not pressing the button to proceed with the digital script.

Regarding the question “Was the script for the DEC activity easy to follow?”, all the students unanimously answered yes. According to the students' reports, the script that was printed out and given to them, along with the DEC's digital interactions, was easy to understand, highlighting the concomitant explanation of each subject in the lesson in which the DEC was applied. The script that the students used consisted of a practical guide for carrying out the DEC of each proposed experiment, describing the actions to be carried out

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by them, just like the scripts used in face-to-face experimental classes. According to $E4B_1$: "*It's easy, because all you have to do is read the steps and carry out each action described in the script. It's like a path to follow with signs indicating where to go*".

In relation to question 12, "Before the DEC began, did you like Chemistry?", which had two alternatives (Yes. Did the application of these lessons strengthen your liking for Chemistry even more? Why?; No. Did the application of these digital lessons change your opinion of the subject of Chemistry? Why?), 33.3% of the students answered no to this question, while 66.7% answered yes.

The students who took the DEC and said they didn't like this curricular component pointed out that Chemistry is difficult to understand, but that the DEC helped them understand the curricular component better, as $E3C_1$ explained:

> *My first impression of this subject at the beginning of the year was that it was very difficult and I didn't like it. But I see that this can improve depending on the way it's taught, whether it's through things that are in my house and I didn't know they had chemistry in them, or the use of experiments, such as the classes with DEC that sparked my interest in chemistry ($E3C_1$)*.

In $E3C_1$'s speech, in addition to the importance of DEC, the relevance of contextualizing the content can be seen, in that both (DEC and contextualization) helped this student to change his perception of chemistry. As for $E2B_1$, he associated his love of video games with DEC, changing the way he saw chemistry. While in the games he plays there are few or no didactic objectives, in DEC the main objective was the construction of knowledge. According to $E2B_1$: "*I didn't like it, but some resources can help make it easier, such as classes with digital experimentation in chemistry, because they are similar to games. As I like games, I soon started to like chemistry*". Another student commented: "*I didn't like it, I thought it was complicated. But with experimental lessons and these computer simulations, I started to like chemistry*" ($E3B_1$).

The students who answered that they already liked Chemistry said that, after the application of the DEC, they came to like the curricular component even more. Among the students' comments, there is a convergence that the DEC is a resource that can at least draw the student's attention to the content of the lesson. This observation can be seen in

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the following reports: “*It's certainly a different lesson, even for those who have difficulties learning, an activity like this attracts their attention*” ($E2A_2$) and “*The content isn't easy to learn, at least for me it got me interested in at least understanding why those virtual simulations I did had those results*” ($E3A_2$).

Two relevant aspects were also observed in the students' speeches. The first refers to the absence of chemistry in elementary school science subjects, and the second to the importance of experimentation (whether face-to-face or digital) for students' education. With regard to the first aspect, some students reported that they did not have the subject of Chemistry during elementary school, and only had their first contact with it in secondary school. In elementary school, chemistry content is generally presented in science, sharing the workload with biology and physics content. In secondary school, the short time allocated to teaching chemistry is being exacerbated by the implementation of the new secondary education system, as highlighted by Branco and colleagues (2018, p. 62):

> there will be a reduction from 2,400 hours, considering the total workload of high school before the Reform, to 1,800 hours, referring to the BNCC, which implies a considerable reduction in the content to be covered, which further empties and makes teaching more precarious. It is worth remembering that, under the changes introduced by Law No. 13,415/2017, only Mathematics and Portuguese will be compulsory subjects in the three years of secondary school.

With regard to the second aspect (the importance of experimentation in education), it should be noted that schools without adequate infrastructure in their laboratories for experiments can contribute to poor education for their students, since different skills and abilities end up being curtailed.

Finally, it is believed that the DEC proposal, acting as a facilitating resource for students' understanding and learning, enabled them to present a favorable attitude to its insertion in the classroom context. Furthermore, as a digital teaching resource, the DEC has proved capable of providing students with access to practical chemistry activities, which are not normally carried out by teachers because they require a lot of effort and time on their part, creating gaps in the students' education.

4 Conclusions

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In this research, the perceptions of high school students at a state school in Pernambuco on the application of digital experimentation of chemistry were presented. It is understood that DEC can be considered a viable alternative to contribute to the process of teaching and learning chemistry, especially when it involves experimental activities.

With the advent of DICTs, the implementation of digital chemistry practical lessons by high school students can be made possible in schools that don't have the appropriate infrastructure to carry out a common practical activity in the laboratory. To this end, routes were developed to enable experiments to be carried out using digital technologies. Thus, considering the locus of application of the proposal, Route 1 was selected in this research, which takes into account the school space with computers suitable for the application of DEC.

It is important to note that, in the DEC proposal, the students had control over the practical activities to be carried out, and could even redo the experiments in the event of an error in the (digital) manipulation of the experiment. Furthermore, by giving the students autonomy to decide how they wanted to carry out the experiment, it ensured that they didn't feel “trapped” in a single way of carrying out the experimental activity. This prevented the execution of “cake recipe” type experiments, common in some laboratory practices, in which the student only follows a pre-programmed script, in which almost no importance is given to the organization, planning, research, analysis or interpretation of the results by those involved (Leite, 2018).

This shows that digital technologies can contribute to the teaching and learning process, and the teacher, by making use of them through the use of digital teaching resources (Leite, 2022), can transform not only the classroom (or laboratory) environment, but also the way students see and construct their own learning. Simulations based on ICT can act as agents that provide experiences in the chemistry laboratory. Even when it is possible to use the chemistry lab, simulations can still be useful as introductory, preparatory and/or complementary activities for experimentation in the chemistry lab.

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In situations where the school infrastructure is inadequate for carrying out practical activities, the research showed that it is possible to carry out experimental activities (even if they are virtual) and that the students' involvement in the DEC was considered positive. Thus, the students' involvement and interest in the development of the digital experimental lessons was noticeable, including requests for other digital practical activities to be carried out on chemistry content during the school year. In addition, the students' perceptions were almost entirely positive towards DEC, according to the reports obtained in the survey. The research shows that the DEC proposal can be applied to different chemistry contents, broadening the possibilities for its use in teaching practice.

Finally, the DEC is an alternative for teachers, mainly because it shows that its application is not complex, but above all, it needs the teacher's planning for it to occur in a favorable way. It is considered that this research presents an experience that can be replicated by other teachers, so that they can use DEC in their teaching practices, in order to contribute to the construction of their students' knowledge. This applies both to environments that have the infrastructure and materials to carry out an experimental activity and to those environments that do not have the appropriate infrastructure to carry out experimentation in the chemistry laboratory.

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DOI: https://doi.org/10.47149/pemo.v6.e13662
https://revistas.uece.br/index.php/revpemo
ISSN: 2675-519X

Responsible publisher: Genifer Andrade

***Ad hoc* expert:** Juliana Roberta Paes Fujihara e Fernando José de Almeida.

How to cite this article (ABNT):
LIRA, Douglas Lopes de.; LEITE, Bruno Silva. Percepções dos estudantes do ensino médio sobre a experimentação digital de Química. **Rev. Pemo**, Fortaleza, v. 6, e13662, 2024. Available at: https://revistas.uece.br/index.php/revpemo/article/view/13662

Received on July 26, 2024.
Accepted on August 20, 2024.
Published on Octuber 10, 2024.