STUDENTS' PERCEPTION OF AN INQUIRY-BASED METAVISUAL ACTIVITY ABOUT CONCEPTS OF CHEMICAL KINETICS

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Abstract

Students' perceptions of an activity involving visualization are important in assessing their learning of the task. In view of this, this study was developed with undergraduate students from different courses at a public Brazilian university. The research objective was to determine how three students, who are majoring in different courses (chemistry graduation and engineering), perceive their participation in an inquiry-based metavisual activity (IBMA). For this, the students were interviewed and data were categorized according to similarities and differences in the reports. The findings indicate that the IBMA was able to facilitate the reconstruction of concepts with an emphasis at the submicro level, for the students that were majoring in chemistry. The engineering student reported a partial construction of concepts. The student's learning may have been compromised due to the smaller repertoire that he had in chemistry and on models at the submicro level.
Keywords: *chemistry teaching, inquiry-based activity, metavisualization, students' perceptions*

Introduction

Chemistry employs visual representations that aid to understand the phenomena, not only in industry but also in the classroom. According to Johnstone (1993), one of the main difficulties encountered by students is the comprehension and development of the three levels of representation in chemistry: macro, sub-micro, and symbolic levels (Gilbert & Treagust, 2009).

Furthermore, many students perceive chemical diagrams as a mere teaching method that simplifies a particular subject (Fernandes & Locatelli, 2020). Thus, it is necessary to employ approaches that link scientific ideas to the concrete world, with specific phenomena that capture students' interest (Quadros et al., 2018).

According to Zômpero and Laburú (2011), inquiry-based activities foster perspectives go beyond students' inductive reasoning, preparing them to become active thinkers who seek answers and enabling the development of the necessary skills to solve problems. These skills enable the formation of citizens who are better able to face the challenges of modern society, in an active and critical way, by making decisions about scientific issues that affect everyday life (Schnetzler, 2002), through chemical knowledge.

Therefore, constant reflection in the learning process is of paramount importance, which can be achieved through metacognition. According to Schraw (1998), cognitive ability refers to what is necessary to perform a task, whereas metacognitive ability relates to understanding how the activity was performed.

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Given the visual nature of chemistry, metavisualization, that is, metacognitive thinking through visualizations (Gilbert, 2005), has proven to be an effective strategy in the process of constructing and reconstructing concepts using visual tools (Locatelli & Davidowitz, 2021), and can be useful to improve students' understanding in scientific modelling (Chang, 2021). Thus, this work had a didactic approach, using an inquiry-based metavisual activity (IBMA), based on the assumptions of inquiry-based teaching, the experimental laboratory practice, and the modelling of chemical representations from the metavisual strategy.

Regarding modelling, Chang (2021) has cited that there are few studies that focus on the process of constructing visualization, asking about: what are students' difficulties in the process of developing representations and the factors that lead to successful visualization? "Research into these issues would provide fundamental insights with regard to how to support students in successfully developing visualizations and representations during the modelling process" (Chang, 2021, p. 451).

Despite the possibilities for learning chemistry concepts that IBMA can promote in students, several factors need to be considered for its implementation, especially related to the high complexity articulation of the three representative levels of chemistry. A study by Chittleborough et al. (2002) has revealed some limitations that students face in developing more in-depth models, such as a lack of prior knowledge of chemistry and mental models, an excessive amount of information, speeds that the content must be assimilated by the student, and lack of motivation.

Therefore, the students' perceptions of the practical experience of IBMA are important to assess the difficulties inherent in the process as well as whether the strategy was effective for learning chemistry. In addition, understanding how students' perceptions of laboratory activities (and in general) can help teachers adjust them to provide a more positive experience for students (Nyutu, et al., 2021).

Given this, this study aims to ascertain the perceptions of students participating in IBMA, the research question was: What do undergraduate students from different courses report about the didactic experience of an inquiry-based metavisual activity (IBMA)?

Research Methodology

General Background

This study presented a preliminary study of larger research in progress being characterized as qualitative research (Stake, 2010), and as a case study (Alves-Mazzotti, 2006). Participated in this research all students enrolled in the subject of Chemistry Teaching Practices II (PEQ II) of a public Brazilian university, who were present on the day that occurred the application of IBMA, being only three students: two students were studying undergraduate chemistry, and one student engineering. The IBMA involved the study of the rate of the nail reaction in an aqueous sulfuric acid solution, wherein the concepts of this phenomenon were deepened through the elaboration and comparison of chemical representations. Six months after the activity, students were interviewed individually considering their perceptions of the lesson. The results were grouped according to the similarity and divergence of reports.

Sample

The participants of this study were three undergraduate students: two chemistry education students, Ariadne and Cecília, and one engineering student, Yohan (fictional names chosen by the participants themselves). These students were enrolled in the course Chemistry Teaching Practices II (PEQ II) at the Federal University of ABC (UFABC), located in São Paulo, Brazil, during the months of September to December 2022.

The choice of a PEQ II class was motivated by the assumption that the students enrolled had seen the content covered in this research activity during elementary school, and/or in the discipline of General Chemistry, which is one of the compulsory subjects for all undergraduates at the university.

The heterogeneity of the participants is due to the university context, which allows students to enrol in any discipline, regardless of their chosen undergraduate course. Yohan chose to take the discipline because he works as a teacher in a technical school and had an interest in theoretical and pedagogical deepening.

In the PEQ II class, four students were enrolled and, on the day of the application for IBMA, which occurred in October 2022, one student was absent. The low enrollment occurred due to the conflict of PEQ II schedules with other compulsory university courses, which were held back until that moment due to the suspension of classes caused by the Covid-19 pandemic.

Due to the small number of participants, this study is characterized as a case study, which for Alves-Mazzotti (2006) is useful for exploring complex and situated relationships, generating in-depth knowledge about a particular phenomenon.

The collected data were obtained during a class of this specific discipline, where participants volunteered to provide the analytical products for the study. They signed an informed consent form, following the ethical parameters for research involving human subjects.

Instrument and Procedures

The research-developed IBMA has two main phases: in the first phase, the students were guided to solve a problem situation that dealt with the reaction rate with the increase of temperature involving metallic iron with an aqueous solution of sulfuric acid. In groups, they elaborated hypotheses of an experimental plan, considering the provided reagents and materials, such as an aqueous solution of 1.0 mol/L H_2SO_4, nails, a heating plate, test tubes, and a water spray bottle. After outlining the work plan, the group, through the experiment proposed by them, tested the hypotheses listed at the beginning of the activity, observing the phenomena that occurred and discussing their preliminary conclusions.

In the second phase, the group continued the IBMA by discussing and creating symbolic and pictorial representations that represented what was done in the experimental procedure, consisting of four items: a) the chemical equation of the reaction, b) an explanatory model at the submicro level before the reaction, c) an explanatory model at the submicro level during the reaction, and d) explanatory models at the submicro level at the end of the reaction.

At the end of the elaboration on each item, the group compared what they had done with the corresponding visual representation presented by the teacher. The aim was for the students to identify, analyze, and to discuss the differences and similarities of the representations, configuring a metavisual approach. The explanatory models, presented to the group of students, involved concepts about: the level of particle agitation, collision theory, the concept of solvation, the behavior of ions in solution, the function of the spectator ion, notions of stoichiometry, and the size of atoms. Throughout the IBMA, both the course instructor and the researcher made the fewest interventions possible so as not to influence the group's discussions.

Six months after the activity took place, that is, in April 2023, the students were individually interviewed by the researcher, considering their experiences, difficulties, and general comments. Minayo (1993) described interviews as "conversations with a purpose," providing reports from a particular point of view for specific objectives (Charmaz, 2006). Therefore, in the research, sensitive listening was sought to understand the participants based on their use of language, considering how they attribute meanings to their experiences, cognitive processes, and themselves.

For this study, 2 questions were selected and asked to the students, as described in Table 1.

Table 1
Questions to Research Participants about the IBMA

Questions
Could you talk about the main difficulties encountered in the development of the IBMA?
Considering that the IBMA aimed to reconstruct concepts, what did help you in terms of your chemistry knowledge? Did anything change for you?

Data Analysis

The interviews lasted an average of 15 minutes, were recorded in audio, and were transcribed. In addition, the questions also delimited the participants' profiles and were used to assist in the analysis of the IBMA report provided by them, as well as the researcher's field notes.

For the analysis of the results, the students' answers were read several times, based on Bardin's (2011) assumptions, following the three main steps: i) pre-analysis, which refers to the organization and systematization of initial ideas, ii) exploration of the material, which involves the decomposition of data and subsequent regrouping based on categories; and iii) treatment of results.

Research Results

Based on the collected data, it was identified that Ariadne and Cecilia, who are chemistry education students, had similar perceptions about the difficulties related to IBMA and chemistry learning, while Yohan, an engineering student, reported different perceptions. These similarities and differences may be due to the students' context and their mastery of chemistry and are categorized into two subsections, as follows.

Chemistry Education Students (Ariadne and Cecilia)

When asked about the main difficulties involved in the development of IBMA, the following responses were obtained from the students:

> **Ariadne:** "(...) I think basic chemistry because we had a lot of difficulty in determining what reaction was happening. (...) We had trouble understanding the medium as well, what was happening, how to represent it, that was a difficulty from the drawing (explanatory model)."
> **Cecília:** "The equation part and the drawing (...) I always feel very insecure when working with, let's say, the elements and everything else, how it works. (...)."

Regarding learning in chemistry and the reconstruction and construction of concepts that could have occurred during the activity, the students reported the following:

> **Ariadne:** "(...) I remember a lot about your drawing of the collision of atoms. That was something I didn't think of when I did the activity, but then I never forgot about it."
> **Cecília:** "I believe it was more the submicro level part when we had to build a model with the molecules and everything. We started to realize that understanding this part (submicro level) makes it much easier for us to understand the algorithm part (chemical equation), what we saw (in the chemical reaction), and everything else."

Engineering Student (Yohan)

Unlike his group mates, when asked about the difficulties involved in the development of IBMA, Yohan reports that:

> **Yohan**: "(...) I think our biggest difficulty was just visualizing if there was any change, (...) in what didn't have an increase in temperature, because we were looking here, looking there in every way, right? And then what happened when we put it there, we didn't know if the color (of the nail) changed because it was wet (...)."

In addition, for the student, the activity allowed for partial construction of the concepts he had about the activity content, as reported below:

> **Yohan**: "(...) I understood the situation, but then if you gave me, I don't know, other elements that had a different effect, but with the same analogy, maybe I wouldn't arrive at the result, you know? (...). One thing is (to understand), but to prove it is another."

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Discussion

Chemistry Education Students (Ariadne and Cecilia)

The reports of the students regarding the difficulties faced in the IBMA refer to the moments when symbolic and pictorial representations (chemical diagrams) were elaborated. They stated that they had difficulty establishing the chemical equation of the reaction performed in the experiment (symbolic level) and how to explain and represent it through models (submicro level). Such levels are abstract, and many students have problems understanding them, as already reported by Gilbert and Treagust (2009) and Michalisková and Prokša (2018).

Difficulties seemed to have been overcome using the metavisual strategy, as the students reported that drawings at the submicro level assisted their comprehension of chemical reactions, such as collisions between atoms and the construction of molecular models.

In other words, for the students, IBMA aided in the process of reviewing and reconstructing concepts regarding how the reaction occurred, citing aspects that involve the submicro level which, for Cecilia, allowed her to understand what was being observed in the experiment and the related chemical equation, i.e., the macroscopic and symbolic levels, respectively. In this discourse, the student gives evidence that there was articulation between the levels of chemistry, which according to Johnstone (1993), confers a better understanding of the phenomenon.

Among the students, Ariadne was the participant who mentioned specific elements of the activity at the submicro level more frequently during the interview, as evidenced in the excerpt where she talks about the effective collision of "atoms". It can be suggested that this occurred because she was the student in charge of drawing the models in the group, which in a way made her reflect more on the elaboration of the representations. In this regard, a possibility for future work is to instruct the group, as far as possible, to alternate positions at this stage.

It is important to highlight the training of these students because, as they are linked to the chemistry teacher education program, they had already taken courses in which the theoretical deepening of representational levels and their importance for the teaching and learning of chemistry was addressed. In addition, the students report that they participated at least twice in activities that involved modelling, both in PEQ II and other disciplines in the program. Therefore, there is an emphasis in their speeches that relates to the submicro level, as they attributed it as an important aspect for understanding and relating to the other levels. In this sense, the factors described by Chittleborough et al. (2002) such as prior knowledge of chemistry and modelling, as well as the motivation of the students to understand the phenomenon more deeply, prove to have been fundamental to more effective learning.

Engineering Student (Yohan)

The engineering student's perception differed from his group mates, particularly when he pointed out that the main difficulties involved in the IBMA were during the observation of phenomena (macro level) in the experimental procedure developed by the group. The adopted method did not allow them to be certain about the visual differences in the solid iron after corrosion. However, it is important to highlight that the students had access to more materials that could be tested so that such questions could be explored.

Results from Michalisková and Prokša (2018) suggested that some students do not know, from the visual perception of a phenomenon, when there is an expression of a chemical reaction, which may result from their inexperience in activities that involve observation of experiments. Yohan stated in an interview that he had not attended classes involving chemistry during his undergraduate studies, and therefore, it can be assumed that he had participated in few or even no experimental chemistry classes, in view of this, there was little prior knowledge of the student related to the activity, which for Carvalho (2013) is fundamental to give conditions for the construction of hypotheses and tests for the resolution of the situation posed.

Moreover, as already presented in the results, for Yohan, the IBMA provided partial construction of the concepts related to the studied content. In his report, he understood the result of the studied phenomenon, the influence of temperature on the rate of the chemical reaction, but he said he would not be able to replicate the same concept in other problematic situations. This data indicates that the learning process at the submicro level, which explains how the reaction occurred, had little significance for him, which may have been due to the student's superficial involvement in this stage of the activity, as when asked about the construction of models, he stated: "I remember it was Ariadne who did it, so I don't remember much of it".

Silva et al. (2021) stated that students do not perceive visual representations in chemistry as necessary for constructing knowledge, instead perceiving them as mere illustrations, "understood as a product that transmits its content by itself" (p.17). Thus, it can be understood that the student understood the representations as a domain necessary only for the context of the activity or even specific to chemistry teachers, i.e., his classmates, and did not perceive them as elements that assist in problem-solving and understanding of the chemical reaction.

In addition, access to and articulation of models at the submicro level is complex and difficult to assimilate (Fernandes & Locatelli, 2020). The lack of significance that this student may have attributed to the representations may be related to the difficulty in understanding them. Unlike Ariadne and Cecília, it was the first time that Yohan had contact with an activity that involved submicro level modeling, as in the days leading up to the IBMA there were tasks of this nature in the PEQ II discipline, but the student was absent.

For Yohan, explanatory models, as well as their elaboration and comparison, probably represent a high intrinsic burden, causing him to select the aspects that are more familiar, such as the visual phenomena at the macro level. Findings by Kelly (2017) indicated that students prefer simpler models that are explicitly linked to the macro, and in addition, Chittleborough and Treagust (2008) stated that graduates who have little chemical knowledge end up demonstrating "poorer" mental models because they have difficulty interpreting diagrams at the submicro level. This suggests that less proficient students in the manipulation of these representations, such as Yohan, should be involved in a gradual process so that they can understand more complex models.

The student also reported that he did not recall the representational levels, even though the topic was frequently discussed throughout the discipline. For Fernandes and

Locatelli (2020), the unfamiliarity with this concept can directly impact these students' understanding of chemistry, as attested by Yohan.

Although the student, based on the interview, did not show evidence of accessing the submicro level, it is believed that the experience was important to initiate the process of constructing and reconstructing mental models, which is a valuable step for learning chemistry.

Overall, this study allowed us to determine the perceptions of this small group of students considering the difficulties that emerged in the activity and the learning of chemistry. It is recognized that the research is limited due to its characterization as a case study, which means that the data collected is applicable only to the sample analyzed within the context of this research and is not suitable for producing generalizations (Alves-Mazzotti, 2006). However, the findings provide exploratory evidence that may be useful for the advancement of international studies involving metavisual strategies (Chang, 2021; Locatelli & Davidowitz, 2021) and may also contribute to international studies related to the approach of chemical representations in the classroom (Chittleborough & Treagust, 2008; Kelly, 2017; Fernandes & Locatelli, 2020) by means of the level of familiarity that the student has with chemistry, models and experimental practice, whether more experienced (chemistry majors) or novices (engineering student).

In the specific case of students who are less familiar with the strategies used, a gradual introduction and the use of less complex models would be necessary, so that little by little, they can appropriate chemical representations and understand them as important for problem-solving and acquire the ability to use this knowledge for issues in their daily lives.

Furthermore, although there was an assumption that the engineering student had access to chemistry content in high school, this study revealed the gap that this student had in this knowledge, which reinforces the idea that they may perceive chemistry only as a subject in basic education and not as a fundamental training for critical thinking.

Conclusions and Implications

Returning to the question that guided this research: *What do undergraduate students from different courses report about the didactic experience of an inquiry-based metavisual activity*? It can be concluded that the chemistry education students showed evidence of construction and reconstruction of the concepts, as well as possible articulation between the three levels of representation in view of the studied phenomenon. This may have occurred due to the conceptual baggage they already had about chemistry, which allowed them the necessary repertoire for understanding the steps and strategies involved in the IBMA.

The engineering student showed evidence of partial concept construction, limited to the descriptive level, that is, at the macro level. Among the possible reasons for this, the lack of the student's experience with activities involving modelling can be cited, which may have compromised his learning in interpreting models at the submicro level.

It is reiterated that the study has limitations due to the number of participants and the context in which it is set, but the findings may be useful for a more careful approach to chemical models, experimentation, and inquiry-based teaching in the classroom through the students' prior conceptions.

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Declaration of Interest

The authors declare no competing interest.

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