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Science modeling and the development of scientific literacy based on the theme of acid rain

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ABSTRACT

In this article, we aimed at understanding the indicators of Scientific Literacy (SL) mobilized in a pedagogical practice based on the assumptions of Science Modelling (SM), as well as assessing the challenges and potential. The SM process went through into three stages: (i) perception and apprehension; (ii) understanding and explanation; (iii) meaning and expression e approached the concepts of acid rain in a 1st year of High school in chemistry class at a public school located in the northwest region of the state of Rio Grande do Sul. The corpus of analysis includes the writing, re-writing and poster-making of 25 students. Data analysis followed the Content Analysis procedure, involving pre-analysis, exploration of the material, treatment and interpretation of the results. The results show that most of the students' understanding of the subject evolved over the course of the SM stages, with the highest percentage of SL indicators being mobilized in the signification and expression stage. In addition, the explanation indicator was most evident in the students' production. Some limiting aspects of the practice were also observed, such as the school's lack of infrastructure, some students' lack of interest and the short time available for the practice. The SL indicators identified in the students' productions demonstrate the potential of SM for the development of SL.

KEYWORDS: Chemistry Teaching; Science Teaching; Experimentation.

Modelagem nas ciências e o desenvolvimento da alfabetização científica a partir da temática chuva ácida

RESUMO

No presente artigo, buscamos compreender os indicadores da Alfabetização Científica (AC) mobilizados em uma prática pedagógica fundamentada nos pressupostos da Modelagem nas Ciências (MC), além de avaliar seus desafios e potencialidades. O processo de MC perpassou as etapas (i) percepção e apreensão, (ii) compreensão e explicitação, (iii) significação e expressão e abordou os conceitos presentes na temática da chuva ácida em uma turma de 1º ano do Ensino Médio na área de Química, de uma escola pública localizada na região noroeste do estado do Rio Grande do Sul - RS. O corpus de análise integra as escritas, as reescritas e a confecção de cartazes por 25 alunos. A análise dos dados seguiu o procedimento de Análise de Conteúdo, envolvendo a pré-análise, a exploração do material, o tratamento e interpretação dos resultados. Os resultados demonstram a evolução da compreensão dos alunos sobre a temática no decorrer das etapas da MC, sendo que, na etapa de significação e expressão, houve maior percentual de mobilização dos indicadores da AC. Além disso, o indicador explicação obteve maior evidência na produção dos alunos. Alguns aspectos limitantes da prática foram observados como a falta de infraestrutura da escola, o não interesse de alguns alunos e o curto tempo disponível para a prática. Os indicadores da AC identificados nas produções dos alunos evidenciam as potencialidades da MC para o desenvolvimento da AC.

PALAVRAS-CHAVE: Ensino de Química; Ensino de Ciências; Experimentação.

INTRODUCTION

This article addresses the themes of Science modeling (SM) and Scientific Literacy (SL) and aims to discuss how the assumptions of SM can contribute to the teaching and learning processes of the phenomenon of acid rain. The interest in the theme arises from the academic background of the first author of this text, based on the experiences and studies developed in the Tutorial Education Program (PETCiências) at the Federal University of Fronteira Sul (UFFS), *Campus* Cerro Largo/Rio Grande do Sul, regarding the fundamentals of SM.

In view of the experiences lived by the author and considering the need to develop the student's ability to understand and interpret the world, exercising their protagonism, Science Education should be guided to address "how Science is constructed, its tools, processes, and interrelations" (Maia & Justi, 2020, p. 251). In this sense, with such knowledge, the student can develop their autonomy, making more conscious decisions and acting based on scientific contributions.

Chassot (2003) points out that Science can be considered a language used to understand and explain our natural world; therefore, by being scientifically literate, the student builds the ability to read the language in which nature is written. In this way, the author highlights the possibility of improving people's quality of life through the development of SL, as the understanding of Science allows for understanding everyday events and manifestations of the world.

With this, we bet on the assumptions of SM to enhance AC, since the modeling process presupposes problem-solving, involving students in the process of obtaining data and information, in organizing and representing the obtained information, in raising and testing hypotheses, and finally, in expressing and evaluating the results through a model, which represents the phenomenon under study. According to Biembengut (2016), the modeling process – the development of a model – is present in different areas of knowledge and has connections with the stages of research, from the choice of the topic to the expression of the results. This leads to the use of the concept of Science modeling, which, when considered for teaching, is advocated by Biembengut (2016) as a teaching method with research and, in this way, can favor the development of SL.

In this scenario, we carried out a pedagogical practice based on the assumptions of SM with the aim of understanding the indicators of SL mobilized in the different stages of the SM process, as well as evaluating its challenges and potential. Based on the above, the guiding question of this research is to answer: What indicators of SL development emerge in a pratice Science modeling?

In the following sessions, we present the fundamentals of SM based on Justi (2006, 2015) and Biembengut (2016) and of SL based on Chassot (2003), Sasseron and Carvalho (2008), Lorenzetti and Delizoicov (2001) and Lorenzetti, Siemsen and Oliveira (2017). The methodological procedures, the results found, and the considerations about the developed study are also presented.

THEORETICAL REFERENCE

The authors Oldoni and Lima (2017) point out the importance of the school space as a scenario for the transformation and (re)construction of knowledge, as

students have easy and quick access to information and have great difficulty in critically evaluating the truthfulness of what is disseminated. The critical bias enables understanding and evaluation of the information received, and its development goes through the teacher's intermediation, who, with pedagogical intent, must prioritize the critical and reflective development of their students.

In this movement to seek a teaching model that aims for critical, coherent, and systematic development in relation to society, the author Hodson (1992, *apud* Justi, 2006) points out the importance of the conditions of *learning* Science, learning *about* Science, learning to *do* Science, and *(de)veloping* with actions of Science.

Learning *science* is linked to obtaining theoretical and conceptual knowledge, learning *about* science involves understanding the scientific nature, knowledge of its working methods, and its complex interactions in society and in science. Learning to *do* Science involves research, hypothesis formulation, and problem-solving. Finally, the (*de)velopment* with actions of Science relates to the ability to (re)act appropriately in situations that are imposed on it, whether intentionally or naturally, with commitment and criticality, understanding the importance of Science.

These conditions can be enhanced in the classroom, and we believe that the SM process can contribute in this regard. We understand, in agreement with Justi (2006), that the SM tends to provide students with the ability to effectively participate in the production of scientific knowledge and reflect on the purposes of Science, exercising the autonomy, critical thinking, and reflection of the student.

According to Justi (2015), the SM process plays an important role in Science Education, as it promotes the development of student protagonism through investigation, exploration, organization of information, discussions, raising and validating hypotheses, expression and validation of results, which fosters a broader understanding of Science and its theoretical and practical contributions. Furthermore, through the SM, knowledge objects can be approached in a contextualized manner based on problem situations related to the students' reality.

To develop such skills, Biembengut (2016) points out that SM goes through three stages: (i) *perception and apprehension*; (ii) *comprehension and explicitness*; and (iii) *signification and expression*. The first step consists of the *perception and understanding* of information about a subject that can be proposed by the teacher or the students, in addition to aiming to establish relationships between the known and the unknown. As information becomes *understandings*, we move on to the second stage, which involves raising awareness of the topic, formulating the *explications* and hypotheses, discerning the essential elements for understanding the situation. Finally, the stage of *meaning and expression* of knowledge seeks to translate the subject's understandings through symbolic representations or models, which can be mental models, prototypes, experiments, drawings, paintings, among others (Biembengut, 2016).

The word model has semantic plurality and, in this text, is understood as representations of ideals, events, processes, objects, and understandings, created with a specific purpose. Also, a model can be a way of partially representing reality,

created from the understandings and ideas of each individual and, essentially in Science, from what is known of scientific theory.

According to Justi (2006), a model is understood as an epistemic artifact because, in the process of obtaining a model, there is knowledge construction. This author argues that the construction of scientific knowledge involves several stages and, in the modeling process, develops learning in the stages of construction and validation of models, as it is a representative structure of a form of "scientific thinking" (p. 177).

In light of the above, we understand that the stages of the SM process enable the development of the SL, which Chassot (2003) points out to us as essential for experiencing perspectives through Science, understanding it, developing it, and leading it for the quality of life. This way, scientific knowledge should help us in decision-making and in developing arguments in the face of the situations experienced, critically and reflectively, favoring the awareness of the numerous relationships between Science and society.

In this direction, the authors Lorenzetti and Delizoicov (2001) argue that SL promotes reading and understanding of the world, with the perspective of transforming it. The authors clarify the importance of teaching Science as part of the student's reality, not as something separate or dissociated from their experiences, which leads us to emphasize the need for the contextualization movement in the classroom. Thus, the SM process must work with problem issues from the students' daily lives.

In this sense, students should be exposed to Science in its entirety, in order to become aware of the relationships between their context and the concepts studied (Lorenzetti, Siemsen & Oliveira, 2017). Thus, the development of SL goes beyond the need to teach notions and scientific concepts, and SM highlights the important role of *knowing*, *learning* and *doing* Science through the elaboration and resolution of contextualized problems that cross the students' context, so that they seek strategies for resolution and express the results found through models.

Thus, according to Sasseron and Carvalho (2008), it is possible to mobilize indicators of SL put into practice when we are subjected to the resolution of a problem. These indicators are divided into three groups, as presented in Table 1 below:

Table 1

Indicators of SL according to Sasseron and Carvalho (2008)

Group	Subgroup	Explanation
Data work obtained in an investigation	Information serialization (I1)	It should arise when aiming to establish foundations for action.
	Organization of information (I2)	It occurs at times when there is a discussion about how a work was carried out.
	Information classification (I3)	It is presented when one seeks to confer hierarchy to the obtained information. It constitutes a moment of organizing the elements with which one is working, seeking a relationship between them.
Structuring of thought	Logical reasoning (I4)	It understands how ideas are developed and presented and is directly related to how thought is expressed.
	Proportional reasoning (I5)	It refers to the way variables relate to each other, illustrating the interdependence that can exist between them.
Understanding of the analyzed situation	Hypothesis raising (I6)	Points out moments when assumptions are raised about a certain topic.
	Hypothesis testing (I7)	It relates to the stages in which the previously raised assumptions are tested.
	Justification (I8)	It appears when, in any statement made, a guarantee is used for what is proposed; this makes the statement gain endorsement, becoming more secure.
	Forecast (I9)	It is made explicit when an action and/or phenomenon is stated that occurs associated with certain events.
	Explanation (I10)	It arises when one seeks to relate information and hypotheses that have already been raised and explanations that are still under construction, which will gain greater authenticity throughout the discussions.

Source: Prepared by the authors (2024).

Based on the above, we seek to understand whether these indicators are mobilized during the development of an SM practice.

METHODOLOGICAL PROCEDURES

Considering the objective of this research, which consists of understanding the indicators of SL development that emerge in SM practices, we classify the work as being of a qualitative nature in the form of a case study (Lüdke & André, 2013). The case considered is the development of SL with high school students through SM practices. In this way, this study considers the context in which the practice is situated, as this can explain actions, perceptions, behaviors, and interactions.

The pedagogical practice based on SM was developed in a public school in the northwestern region of the state of Rio Grande do Sul, involving 25 students from the 1st year of High School in the area of Chemistry, spanning 4 classes of 45 minutes each. The classes had as their main theme the phenomenon of acid rain, because the practice was developed in the month of the Environment (June) and involved environmental issues in the area of Chemistry and Sciences. Moreover, the theme of acid rain emerged a *priori* due to the first author's experiences during her undergraduate studies. Finally, the practice in question followed the intervention proposal described by Pauli and Bonotto (2023), and its context is described below.

In the first stage of the SM process, the *perception and apprehension,* we asked the students to orally present their initial understandings of the phenomenon of acid rain. As homework, the students were supposed to conduct an *online* search on the phenomenon of acid rain, answering the questions: What is acid rain? What causes acid rain?

Afterwards, for a better understanding of the topic, it was necessary to introduce the concepts of acidity and basicity in the classes. Thus, we studied the concept of hydrogen ion potential (pH), covering the contents of the pH scale and contextualizations with examples from our daily lives, understanding whether there is more or less concentration of H^+ ions in certain solutions. Some cited examples were: (i) acidity of the stomach, of the soda, of the lemon, of the coffee, of the milk; (ii) basicity of caustic soda, of soap, of antacid, and of bleach.

We also present examples of natural and synthetic acid-base indicators. Furthermore, we conducted an experiment with the acid-base indicators phenolphthalein and methyl red, using test tubes to test two ingredients: lemon juice and bleach. After specifying the colors intended for each indicator, we asked questions to analyze the students' understanding of acid-base indicators, which were: What color do you think will stand out in this solution? Which solution has the highest concentration of H^+ ions? And of ions HO^-?

After this moment, we present scenes from series that involve the theme of acid rain, aiming to spark students' curiosity through visual resources. To this end, we use scenes from the series *The 100,* which takes place in the year 2052, depicting planet Earth after 97 years of nuclear apocalypse – in the series, there is a reference to a type of rain that is fatal to those exposed to it, causing severe injuries. In the same vein, the series *The rain* also presents a fatal rain in a post-apocalyptic world.

Furthermore, to bring the theme to our reality, we present news/reports that show the occurrence of the phenomenon in our country. The objective of this exhibition is to discuss the content, contextualizing it and making it explicit

according to aspects present in the student's reality, in order to bring them closer to the object of study.

In the following class, we asked the students to share with the class the information they researched about the phenomenon of acid rain. After this moment, we request the students to write (for submission) their initial understandings about acid rain, reflecting on what it is, how it occurs, why it occurs, and what the implications are for the Environment. At the discretion of each student was the possibility of relating the information previously presented in the classes about pH, the series, and the reports.

In the second stage of the SM process, the *understanding and clarification,* we conducted another experiment with the intention of simulating the implications of the phenomenon of acid rain with some chemical reagents involved in the natural reaction of this phenomenon, aiming to awaken the students' interest in the theme, as experimentation brings with it a playful character that can motivate student participation. Furthermore, the experiments allow for the formulation of more abstract statements, bringing context to the students, working with the transformation of scientific thought (Giordan, 1999).

The materials used for the experiment were: sulfur powder; lamp; glass jar with lid; metal spoon; spatula; wire; tape; wooden tweezers; acid-base indicator paper; colored flower petals. The experimental procedure developed as follows: first, with a wire, we attached an "L" shaped spoon to the lid of the glass jar, and inside the glass jar, we stuck the acid-base indicator paper with the help of tape, according to Figure 1. Then, we put a little sulfur powder in the spoon attached to the lid of the jar, using the spatula, and the spoon on top of the lit lamp to cause the combustion of the sulfur, holding the jar lid with the wooden tongs to avoid burns. After the combustion of sulfur occurs, with the release of sulfur gas, we immediately covered the glass jar and waited for the results.

Figure 1

Development of the acid rain experiment

Source: Prepared by the authors (2024).

Throughout the experimental procedure, we used guiding questions for the students' hypothesis formulation stage, which were: What do you think will happen when burning sulfur? And when covering the glass jar, what will happen to the rose petals? Will the acid-base indicator papers undergo changes? What number will indicate on the numerical scale of these indicators? If all rain is acidic,

why does not all rain have harmful effects on the Environment? Why have we (still) not identified problems with acid rain in our region?

During the experiment, we presented the students with the sequence of chemical reactions that occur to form acid rain, with examples of the formation of sulfurous acid (which was represented in the experiment), sulfuric acid, nitrous acid, and nitric acid. The reactions are presented in Table 2 below:

Table 2

Sequence of chemical reactions for the formation of acid rain

Formation of sulfurous and sulfuric acid	Formation of nitrous and nitric acid
$S_{(s)} + O_{2(g)} \rightarrow SO_{2(g)}$ $SO_{2(g)} + H_2O_{(l)} \rightarrow HSO_{3(aq)}$ $S_{(s)} + O_{2(g)} \rightarrow SO_{2(g)}$ $SO_{2(g)} + ½\ O_{2(g)} \rightarrow SO_{3(g)}$ $SO_{3(g)} + H_2O_{(l)} \rightarrow H_2SO_{4(aq)}$	$N_{2(g)} + 2\ O_{2(g)} \rightarrow 2\ NO_{2(g)}$ $2\ NO_{2(g)} + H_2O_{(l)} \rightarrow HNO_{2(aq)} + HNO_{3(aq)}$

Source: Prepared by the authors (2024).

In the following class, in the stage of *meaning and expression*, we asked the students to form groups to create posters that expressed their understandings of acid rain, which should contain a written part and another with representative drawings. For the completion of the content, we request students to rewrite their understandings of the phenomenon of acid rain, as well as their insights regarding the practice of experimentation, in order to analyze and evaluate the teaching and learning processes with this SM activity.

Therefore, the constitution of the research data occurred through the production of writing, rewriting, and the creation of models by the students, as well as through the writing of the researcher's class diary, as in the diary we report events that we portray as isolated, but that have connections with various situations in the classroom. Thus, the diary is an instrument with the potential to detect problems, explain, and change conceptions (Porlán & Martín, 1997).

The students' records were submitted to the procedures of Content Analysis (Bardin, 2016), which presents three main stages: i) *pre-analysis,* which involved the floating reading of the students' responses, which constitute the *corpus* of analysis, aiming at the systematization of initial ideas; ii) *exploration of the material,* with readings and re-readings of the *corpus* of analysis, seeking to recognize the indicators of the development of SL in the students' responses and the frequency of each of them; iii) *treatment of results and interpretation,* seeking the significance of the data obtained, proposing inferences and explanations, considering the initially planned objectives or new discoveries made during the analyses.

In this sense, considering the objective of the research, we sought to understand the mobilization of the SL indicators in the writings and rewritings of the students, as well as in the models produced by them, in light of the understandings of Sasseron and Carvalho (2008) about such indicators.

To maintain the anonymity of the students, we use the encoding A1, A2, A3, ..., A25. It is worth noting that not all students participated in both stages of the SM, as

they were absent from class on certain days. Thus, in the stage of *perception and apprehension,* 19 students participated, in the stage of *comprehension and clarification,* 20 students were present, and in the stage of *signification and expression,* 24 students participated. Also, those who participated only in the first stage received the symbol * and those who participated only in the second stage were coded with the symbol #.

Considering that the pedagogical practice of SM was developed in the supervised internship component of the Chemistry Teaching course and the understanding of the indicators of SL arises from the developed practice and was constituted as an activity carried out strictly for the purpose of education, without the identification of the subjects, we follow the ethical precepts according to the established norms. The following resolutions are CNS Resolution No. 466/2012, which regulates research involving human beings, and CNS Resolution No. 510/2016, which presents applicable norms for research in Human and Social Sciences.

RESULTS AND DISCUSSIONS

Initially, we highlight students' understandings based on oral questioning: What is acid rain? What can cause acid rain? The students' responses focused on "it's rain that is acidic," "rain that burns," and occurs "because of pollution," demonstrating that the students only had a superficial understanding of the theme. As a result, the concept of acidity was brought into the classes for a better understanding of the topic.

The contextualization of the theme based on excerpts from the series *The 100* and *The Rain* led to some comments, as some students were familiar with them and made connections with the theme. However, as it was already close to the end of the class and the students were eager to leave, the interaction decreased, which initially made it difficult to relate the theme to the students' reality. The same happened with the news and reports presented to them. Despite the initial obstacles in contextualizing the theme, we understand that this movement is important because, as mentioned earlier, connecting scientific knowledge with students' life issues is essential for them not to see Science as something dissociated from reality, which hinders learning (Delizoicov & Lorenzetti, 2001).

Subsequently, the initial writing of the students in the first stage of the SM (*perception and apprehension*) highlighted, mainly, the environmental issue of acid rain, emphasizing that it is a consequence of atmospheric pollution (10/19), as exemplified: "Acid rain is one of the consequences of atmospheric pollution..." (A2).

Other answers involved the pH content that was presented to the students in the first class (5/19), such as: The lower the pH of a substance, the greater the concentration of H^+ ions and the lower the concentration of HO^- ions. These responses highlight the understandings and initial relationships between the known and the unknown, which is anticipated in the first stage of the SM.

Some initial responses also show that students conducted their online searches at home, because: "... I know this through the research I did that was requested in the last class" (A1). Thus, these writings present more scientific terms

that had not been exposed in the classes (9/19), as presented in the passages: "it is a rain that concentrates acids such as sulfur dioxide" (A15) and "the rain, most of the time, has a certain degree of acidity due to the presence of oxides in the air" (A18*).

The students' rewriting about the phenomenon of acid rain presents new relationships, especially by highlighting the execution of the experiment that simulated the consequences of this phenomenon on the environment. Thus, the students explained some steps of the experiment and highlighted their results (18/20), as per the excerpt: The gas reacted with the water and the oxygen in the air, which were inside the glass tube, forming sulfurous acid. That's why the petal lost its color and the pH strip that was inside the tube showed that the environment became acidic, simulating acid rain." (A10). In addition, most used scientific terms, such as "sulfurous acid," "sulfuric acid," "sulfur dioxide," and "lamp," which they did not know before. Student A2 also included the chemical formulas of the acids.

It is also worth noting that the students mentioned in their writings and rewritings that acid rain occurs in regions with greater industrialization, due to the burning of petroleum derivatives (8/25), especially in automobiles and factories, as exemplified in the excerpt: "... It is more common in urban centers and highly industrialized areas" (A16). This understanding was strongly evidenced in the making of the posters, discussed below.

Finally, considering all the students' responses on the theme of acid rain, the Content Analysis conducted was based on three previously established categories, which make up the SM process. In each category, the aim was to identify the SL indicators. Table 3 below presents the quantification and synthesis of the analytical process.

Table 3

Analytical process synthesis inferred from the stages of the SM

SM Steps / SL Indicators	Perception and apprehension	Understanding and clarification	Meaning and expression	Total
Information Serialization (I1)	0	0	0	0
Organization of information (I2)	10	11	24	45
Information Classification (I3)	15	4	15	34
Logical reasoning (I4)	15	12	24	51
Proportional reasoning (I5)	1	2	6	9
Hypothesis raising (I6)	1	1	0	2

Hypothesis Testing (I7)	0	0	0	0
Justification (I8)	12	11	24	47
Forecast (I9)	6	0	16	22
Explanation (10)	18	19	24	61
Total	78	60	133	271

Source: Prepared by the authors (2024).

The stage of signification and expression of the SM mobilized a greater quantity of indicators of the SL, aligning with Justi's perspective (2006, p. 177), which argues that the SM process favors learning, especially in the stages of construction and validation of models, as it constitutes a representative structure of "scientific thinking." The author also emphasizes that the construction of scientific knowledge involves several stages, given that the teaching and learning process must be dynamic and value the skills of all students.

Furthermore, we consider that the forecasting, survey, and hypothesis testing indicators were better addressed during the questioning conducted by the teacher in the development of both experiments, especially in the simulation of the acid rain phenomenon.

This can be observed in the following dialogue:

Teacher: "What will happen after the burning/combustion of sulfur powder?"

Student A: "Formation of a gas"

Teacher: "And what gas will that be?"

Student A: "Oxygen gas"

Teacher: "Think carefully, if I burn the sulfur powder, what gas will be released?"

Students: "Sulfur gas"

(***Our highlights, extracted from the research teacher's class diary.***)

The dialogue shows that, when answering the teacher's question, the students formulated a hypothesis and later tested it by observing the change of colors in the acid-base indicator paper in the experiment container, considering that sulfur gas has an acidic character. Furthermore, due to the fact that it mobilizes most of the SL indicators in written productions, there are indications that the modeling strategy favors the development of students' scientific understandings, promoting a movement of construction and reconstruction of knowledge through the use of models.

Next, the mobilization of the SL indicators at each stage of the SM will be exemplified and discussed, based on the writings and representations created by the students, seeking to understand how the presented results were achieved. This presentation structure of the results is inspired by Sasseron and Carvalho (2011).

Regarding the mobilization of the SL indicators in the first stage (*perception and apprehension*), some context units extracted from the students' productions will be presented and the identified indicators will be explained.

> One of the things I remember is that acid rain is a reaction with oxygen mixing with gases in the atmosphere, resulting from the burning of fuels. This rain can cause damage to cars, motorcycles, soil, animals, crops, buildings, etc. In fact, I have a pool at home and, before this rain occurred, the water was clean, but after the acid rain, the pool water turned green, perhaps due to the chlorine that is in the pool (A6, 2023).

Analyzing the passage, we initially recognize an **explanation** "one of the things I remember is that acid rain is a reaction with oxygen mixing with gases in the atmosphere..." followed by a **justification** "...coming from the burning of fuels." Throughout the writing, the subject performs the **classification** and **organization of information** and makes a **prediction** in **"**This rain can cause damage to cars, motorcycles, soils, animals, crops, buildings, etc.", and finally, **raises a hypothesis:** "maybe because of the chlorine in the pool". Your writing presents organized understandings in a coherent manner, allowing the reader's understanding and, therefore, **logically organizes your reasoning.**

Still about the initial understanding of the phenomenon of acid rain, student A1 writes:

> I know that acid rain is a phenomenon that occurs or can occur due to a large amount of pollution in the atmosphere, which happens when sulfur and nitrogen oxides released into the atmosphere react with rainwater, thus generating acids with an extremely low pH. I know this from the research I did that was assigned in the last class (A1, 2023).

The student starts with a statement "I know that acid rain is a phenomenon" and a **forecast** "it can happen due to a large amount of pollution in the atmosphere..." gaining approval with the **explanation** and **justification** that "it happens when sulfur and nitrogen oxides released into the atmosphere react with rainwater...". Thus, the subject presents his thought **logically organized** to structure, **organize** and **classify information**.

In the second stage of the SM (*comprehension and clarification*), we can perceive the evolution in the students' writings, as expressed in the following passage.

> During the experiment conducted in the laboratory, we were able to observe on a table the materials that would be used such as a test tube, sulfur powder, a lamp, wooden tweezers, and roses (flower). Well, it all started by taking the test tube from the stand and inserting the sulfur powder where there was already a paper inside the tube that changes color according to acidity and a glued rose petal. After the sulfur powders were placed, the lamp was lit and picked up with the wooden tweezers because it does not conduct heat. Thus, the powder became liquid the more it heated up and began to emit smoke, so the air outlet was closed. At the end of the experiment, the acidity measuring paper turned slightly pink, the smoke trapped inside the glass was bleaching, thus leaving the petal stained with white spots (A4, 2023).

Initially, the subject demonstrates the **organization and classification of information** in the excerpt "during the experiment conducted in the laboratory we could observe on a table the materials that would be used such as a test tube, sulfur powder, a lamp, wooden tweezers, and roses (flower)," thus beginning the **explanation** of the experiment: "everything started by taking the test tube from the stand and inserting the sulfur powder where inside the tube there was already a paper that changes color according to acidity and a rose petal stuck." We can also note the presence of the **justification** "... and is picked up with a wooden tweezers for not conducting heat." Also, in the passage "thus, the powder became liquid the more it heated up...", there is a mobilization of the **proportional reasoning,** as it establishes a relationship between two variables, the temperature and the sulfur

powder, expressing that the more the test tube heated up, the more liquid the sulfur became. The ideas are organized and presented, allowing the reader to understand the execution of the experiment, and are therefore **logically organized.**

Another example to be highlighted in the second stage is the following:

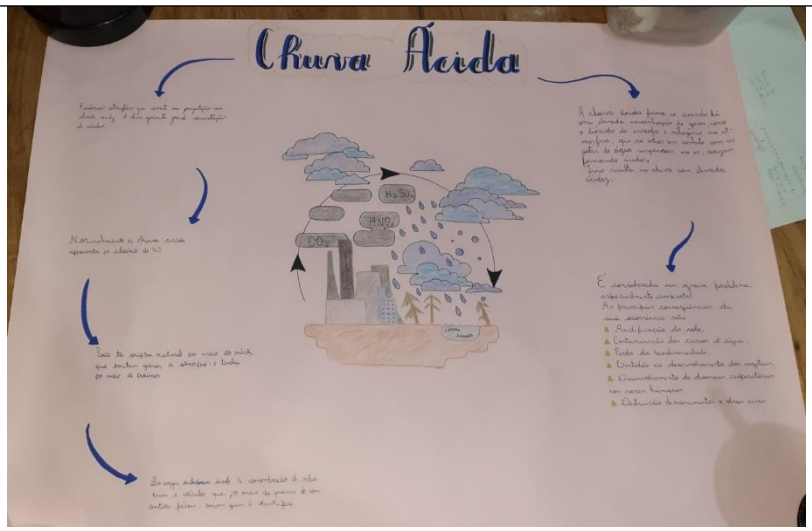
> Acid rain forms when there is a high concentration of gases, such as sulfur dioxide and nitrogen in the atmosphere, which, upon contact with water droplets suspended in the air, react to form acids. Atmospheric phenomenon that consists of high acidity of rain and presents a large concentration of acids. Normally, acid rain has a pH below 5.5. Flower experiment: The gas reacted with the water and the oxygen in the air, which were inside the glass tube, forming sulfurous acid. Therefore, the petal lost its color and the pH strip that was inside the tube showed that the environment became acidic, simulating acid rain (A10, 2023).

The student begins writing with the **justification** of the occurrence of acid rain: "acid rain forms when there is a high concentration of gases, such as sulfur dioxide and nitrogen in the atmosphere...". Afterwards, the **explanation:** "atmospheric phenomenon that consists of the high acidity of rain and has a high concentration of acid." The experiment also presents **explanation:** "the gas reacted with the water and the oxygen in the air, which were inside the glass tube, forming sulfurous acid." The writing also shows its line of **logical reasoning** by **organizing and classifying information** coherently to reach the conclusion: "it showed that the environment became acidic, simulating acid rain."

Finally, the third stage of the SM (*meaning and expression*) resulted in the creation of 4 posters, which represented the phenomenon of acid rain and/or its consequences for the Environment. The posters presented below denote the model representation of the students' understandings of the studied theme.

Figure 2

Model made by Group 1

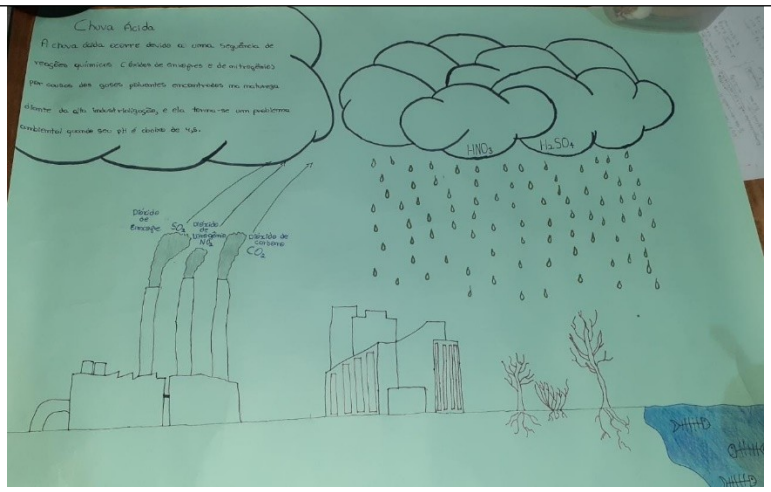


Group 1 - "ACID RAIN → Atmospheric phenomenon that consists of precipitation with high acidity. The rain has a high concentration of acids → Normally, acid rain has a pH below 5.5 → It can have natural origins through solutions that emit gases into the atmosphere, and also through processes → Of anthropogenic origin, due to the concentration of industries and vehicles that, through the burning of fossil fuels, release gases into the atmosphere. ACID RAIN → Acid rain forms when there is a high concentration of gases, such as sulfur dioxide and nitrogen in the atmosphere, which, upon contact with water droplets suspended in the air, react to form acids. This results in rain with high acidity. → It is considered a serious problem, especially environmental. The main consequences of its occurrence are: soil acidification; contamination of watercourses; loss of biodiversity; slow development of plants; development of respiratory diseases in humans; destruction of monuments and civil works.

Source: Prepared by the authors (2024).

Figure 3

Model made by Group 2

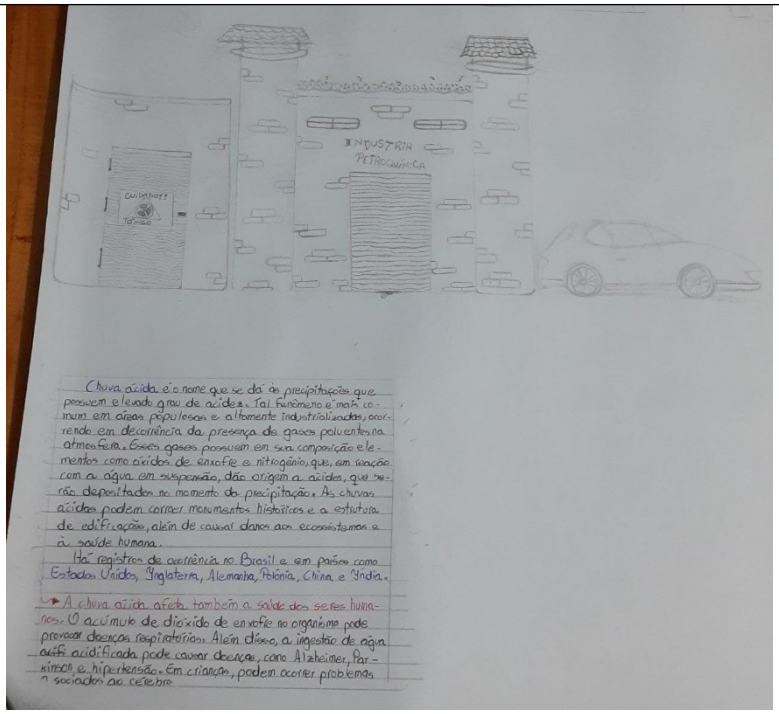


Group 2 - "Acid rain - Acid rain occurs due to a sequence of chemical reactions with sulfur and nitrogen oxides because of polluting gases found in nature due to high industrialization, and it becomes an environmental problem when its pH is below 4.5."

Source: Prepared by the authors (2024).

Figure 4

Model made by Group 3

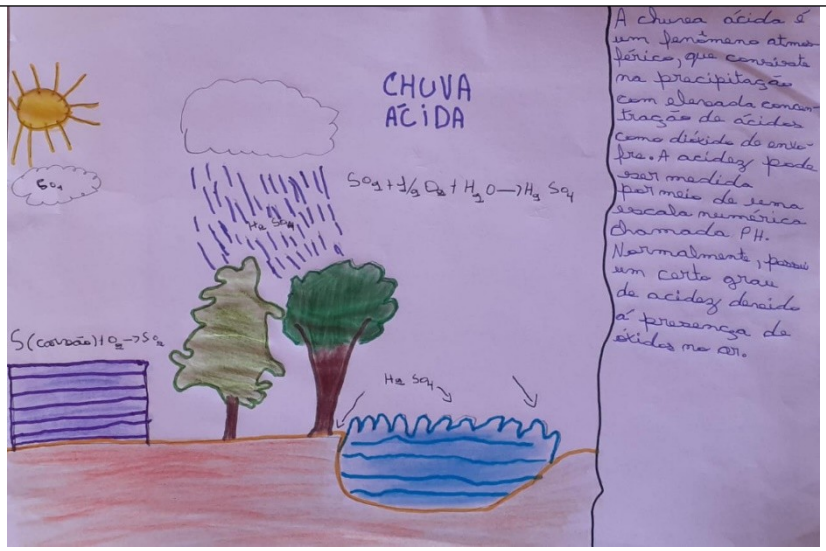


Group 3 - "Acid rain is the name given to precipitation that has a high degree of acidity." This phenomenon is more common in populated and highly industrialized areas, occurring due to the presence of polluting gases in the atmosphere. These gases contain elements with sulfur and nitrogen oxides in their composition, which, when reacting with water in suspension, give rise to acids that will be deposited at the time of precipitation. Acid rain can corrode historical monuments and the structure of buildings, as well as cause damage to ecosystems and human health. There are occurrence records in Brazil in countries such as the United States, England, Germany, Poland, China, and India... The accumulation of sulfur dioxide in the body can cause respiratory diseases. In addition, the intake of acidified water can cause diseases such as Alzheimer's, Parkinson's, and hypertension. In children, problems associated with the brain can occur.

Source: Prepared by the authors (2024).

Figure 5

Model made by A17



Student A17 - "Acid rain is an atmospheric phenomenon that consists of precipitation with a high concentration of acids such as sulfur dioxide." The acidity can be measured using a numerical scale called pH. Usually, it has a certain acidity due to the presence of oxides in the air.

Source: Prepared by the authors (2024).

The models presented by the students demonstrated a similar line of reasoning in both drawings, as they represented industries and cars next to dry (lifeless) trees. This representation highlighted the students' understanding of the sources of gases that can cause acid rain (industries and automobiles) and their consequences on the environment (trees and lifeless fish).

In addition, emphasis was given to the scheme of chemical reactions that gases, mainly sulfur and nitrogen, undergo until the precipitation of acid rain. Thus, we realize that the students sought to represent the sequence of chemical reactions discussed during the classes, demonstrating an understanding that acid rain results from a series of chemical reactions in the environment, culminating in its precipitation in nature.

With a special focus on the model created by Group 1, which addresses a scheme with various information about the phenomenon in question, we initially analyzed the indicator of **explanation** in "atmospheric phenomenon that consists of precipitation with high acidity...", followed by a **forecast** "it can have a natural origin through solutions that emit gases into the atmosphere, and also through processes." Afterwards, the group **justifies** the occurrence of acid rain using **proportional reasoning,** as "acid rain forms when there is a high concentration of gases, such as sulfur dioxide and nitrogen in the atmosphere...", which demonstrates the group's understanding. In light of the above, the **logical reasoning** that the students used to **organize and classify the information** provided in the prepared model is evident.

In light of the results presented, we highlight the potential of the SM practice for the development of SL, as the mobilization of SL indicators in the three stages of SM demonstrated that the students underwent a process of scientific literacy. They

had the opportunity to organize the presented information, formulate and test hypotheses, as well as express their ideas logically, which favored their autonomy and critical thinking.

We believe that working with the theme of acid rain can sensitize students to reflect on a future with less pollution, promoting the improvement of people's quality of life, a principle of SL (Chassot, 2003). Furthermore, through the reconstructed scientific knowledge, students can glimpse opportunities to transform the world by learning about and practicing Science, as taught by Lorenzetti and Delizoicov (2001).

Despite the limitations of time and infrastructure, we realized the potential of this practice for the qualification of students' learning, especially in the stage of signification and expression of models. At this stage, the students demonstrated their understandings through models, showcasing their knowledge.

CONCLUSIONS

Considering the objective of this research, we textualize in this article the indicators of SL mobilized in a practice of SM. The mobilization of these indicators during the stages of the SM highlights the understanding of the production of models as representations of something, enabling the approach to what cannot be seen or directly witnessed and, also, as an epistemic artifact, that is, a tool of thought used in the production of scientific knowledge.

The development of the SM practice also allowed for the identification of challenges and potential. As for the challenges, the limitations related to the inadequate infrastructure of the school laboratory stand out, which hindered the execution of the acid rain experiment, and the reduced time for practice, due to the supervised curricular internship, which has a set duration. Moreover, the lack of engagement from some students during classes presented itself as an obstacle, which can be mitigated by the introduction of new dynamics associated with SM.

The potentialities include the opportunity for students to witness, through modeling, the simulation of a previously unknown phenomenon, which enhanced their learning, as indicated by the analyses of the rewrites and models created. Moreover, the process of encouraging students to think through problem-posing questions proved essential for making predictions, formulating hypotheses, and validating them, promoting critical thinking, autonomy, and reflection, which are principles of formative assessment.

Finally, it is important to emphasize that the processes of teaching and learning are complex, dynamic, and non-linear, given that education involves thinking subjects, each with unique desires, interests, and learning times, immersed in different contexts. Thus, the exercise of empathy, didactics, and innovation in the classroom is essential. These notes invite reflection on teaching practice and the investigation of new methodologies that adapt to the reality of students and better meet educational objectives.

NOTES

1. Link to access all students' responses on the theme of acid rain: https://docs.google.com/document/d/1ZDJjay_vwKGYgLSM2KqFC91slidJnKkBzJQ6intAu4s/edit?usp=sharing.

2. Link to access the synthesis of the analytical process: https://docs.google.com/document/d/1ez2Nghe0RUB_rS2mCFMQ1ETvEn_gd5FNPNLTLCg-xUc/edit?usp=sharing.

3. The authors acknowledge the Jorgelina Rivera for English translation of this work – agency Traduz Rivera.

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