

The history of the evolution of atomic models from the perspective of the New High School

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Abstract: This study aims to develop a didactic sequence to discuss the evolution of atomic models from the perspective of the New High School and analyze the data arising from its development in the context of Basic Education. In this design, we applied the didactic proposition with 40 students attending two 1st-grade high school classes at a private institution in Santa Cruz do Sul — RS. In this bias, through the students' active participation during the stages and the diversification of activities, we observed evidence that the proposed object of knowledge was understood and that the groups were more committed to the activities developed. From this perspective, we can conclude and validate the didactic sequence as helpful in building scientific knowledge on atomic models, to understand it as a strategy that facilitates learning.

Keywords: Atomic Models. History of Science. New High School.

La historia de la evolución de los modelos atómicos desde la perspectiva de la Nueva Escuela Secundaria

Resumen: Este estudio desarrolla y presenta los resultados de la aplicación de una secuencia didáctica destinada a discutir la evolución de los modelos atómicos en la perspectiva de la nueva escuela secundaria. También analiza los datos de su realización en el contexto de la educación básica. En este diseño, la propuesta didáctica fue aplicada en clases de 1^{er} grado de secundaria, involucrando 40 alumnos de una institución privada de Santa Cruz do Sul/RS. A través de la participación activa de los estudiantes durante las etapas y la diversificación de actividades, además de indicios de que los estudiantes comprendieron el objeto de conocimiento propuesto, se evidenció un mayor compromiso, o sea, un mayor interés en las actividades desarrolladas. Desde esta perspectiva, es posible concluir y validar la secuencia didáctica como fructífera para la construcción del conocimiento científico sobre modelos atómicos en el sentido de entenderla como una estrategia que facilita el aprendizaje.

Palabras clave: Modelos Atómicos. Historia de la Ciencia. Nueva Escuela Secundaria.

A história da evolução dos modelos atômicos sob a perspectiva do Novo Ensino Médio

Resumo: Este estudo tem como objetivo desenvolver e apresentar os resultados da aplicação de uma sequência didática voltada à discussão da evolução dos modelos atômicos sob a perspectiva do Novo Ensino Médio, bem como analisar os dados

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oriundos da realização desta no âmbito da Educação Básica. Neste desenho, a proposição didática foi aplicada em duas turmas de 1º ano do Ensino Médio, envolvendo 40 estudantes de uma instituição privada do município de Santa Cruz do Sul/RS. Neste viés, mediante a participação ativa dos estudantes no decorrer das etapas e da diversificação das atividades, observou-se, além de indicativos do entendimento do objeto de conhecimento proposto, indícios de um maior comprometimento, ou seja, um maior interesse pelas atividades desenvolvidas. Nessa perspectiva, é possível concluir e validar a sequência didática como profícua para o processo de construção do conhecimento científico sobre modelos atômicos, no sentido de compreendê-la como uma estratégia facilitadora da aprendizagem.

Palavras-chave: Modelos Atômicos. História da Ciência. Novo Ensino Médio.

1 Introduction

The area of Natural Sciences and its Technologies (CNT, in the Spanish acronym), from the perspective of the Base Nacional Comum Curricular (BNCC) [National Common Core Curriculum], aims to train scientifically literate subjects. In other words, the area aims to develop the individuals' capacity to understand and interpret the world regarding its social, political, technological, economic, and environmental aspects (BRASIL, 2018). The education of individuals should be based on the theoretical and procedural contributions of science, promoting their participation in the construction of a fairer, more democratic, egalitarian, and inclusive society (KURZ; BEDIN, 2019).

Aligned with the provisions of the BNCC, the Referencial Curricular Gaúcho (RCG) [Curriculum Reference for Rio Grande do Sul] adds that Chemistry teaching aims to develop the ability to understand the material world “through the study of the properties of materials and substances in an interconnected way with natural phenomena and artificial processes” (RIO GRANDE DO SUL, 2018, p. 99). Therefore, through this approach, we expect to provide the necessary subsidies on the properties of matter, aiming at contextualizing scientific knowledge to show evidence of its presence in students' daily lives. In this way, we highlight the importance of contextualizing knowledge, since the presence and contributions of Science in society tend to “influence the way we live, think, and act” (BRASIL, 2018, p. 547).

Furthermore, concerning the Chemistry component, the History of Science is particularly relevant due to the opportunity to problematize the social, economic, and cultural spheres that permeate the process of construction of scientific knowledge, because it tends to corroborate the construction of a standpoint of Science associated with the different dimensions of life. Therefore, it constitutes a way of problematizing

the restricted conceptions attributed to the Nature of Science, since, sometimes, the epistemological aspects linked to the cultural, provisional, and historical character of Science and the partiality, non-neutrality of scientific knowledge are disregarded (MORAES; ARAÚJO, 2012; ROSA; STRIEDER, 2019).

According to Martins (2008), the History of Science is crucial to students' cultural, scientific, and social education. It helps them understand historical episodes, especially the interrelationships of History, Technology, and Society, showing that Science and scientific research are not disconnected from their realities; on the contrary, Science is an integral and fundamental part of the historical development of a society. Thus, it is important to reiterate that, besides knowing dates and big names, it is also essential to demonstrate that scientific knowledge comes from "socially produced" constructions, with their impasses and contradictions, influencing and being influenced by political, economic, technological, environmental, and social conditions of each place, time, and culture" (BRASIL, 2018, p. 550). Under the same view, Martins (2008, p. 27) adds that the History of Science has been reduced to

names, dates, and anecdotes; misconceptions about the scientific method; and use of authority arguments. Such factors make the use of the History of Science not simple; it demands, therefore, research work to support its adequate use in the educational process

Moreover, approaching atomic models based on the History of Science can be a subsidy, a possibility of dialogue between teacher and student about the Nature of Science, and, above all, can help develop critical thinking on this subject (SILVA, 2019; VIEIRA; VIEIRA, 2014). After all, as Forato, Pietrocola, and Martins (2018) assure, the History of Science has been deemed adequate for several educational purposes, aiming at the students' basic science education. In this bias, according to the curriculum framework of Rio Grande do Sul, studying from the historical perspective is vital for the students since it promotes reflection on the knowledge socially produced throughout the history of humanity, contributing to the understanding of the process of knowledge construction (RIO GRANDE DO SUL, 2018).

In this context, with the implementation of the curriculum aligned with the BNCC, the CNT area presents specific competencies and abilities that contribute to deepening the learning developed during Elementary School regarding "the conceptual knowledge of the area; the social, cultural, environmental, and historical contextualization of this knowledge; research processes and practices and the

languages of Natural Sciences” (BRASIL, 2018, p. 547). Therefore, in the 1st grade of high school, we propose to approach the evolution of atomic models from the perspective of the History of Science to deepen the students’ ability to identify models that describe the structure of matter and recognize this historical evolution, which is planned for the 9th grade of basic education.

Using the History of Science to approach atomic models is necessary because it discusses scientific concepts allied to atomic evolution (SILVA, 2019). It is also a strategy that helps students understand the topic and humanizes the process of building scientific knowledge. Above all, it brings scientific discoveries closer to the personal, ethical, economic, cultural, and political interests of each period of History (SILVA, 2019).

Given the above, this study proposes and develops a didactic sequence to discuss the evolution of atomic models from the perspective of the New High School (NHS) and analyze the data arising from its realization in the scope of Basic Education.

2 Methodology

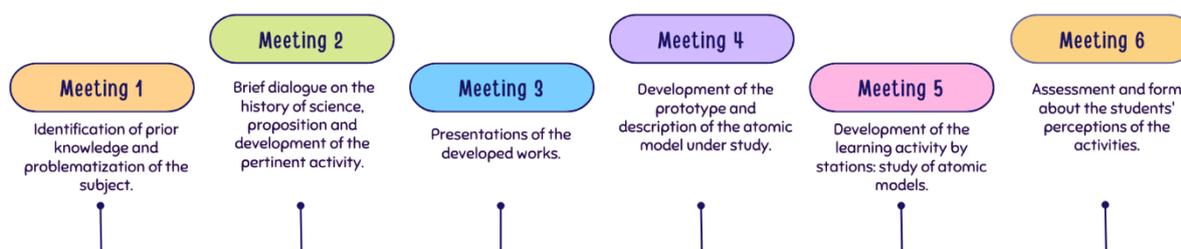
Given the above premises, to answer the question: How can the build-out and application of a didactic sequence on the evolution of atomic models from the perspective of the New High School help develop individuals’ essential skills and competencies for citizenship? This proposal included two classes of students attending the 1st grade of high school at a private school in Santa Cruz do Sul, Rio Grande do Sul, Brazil, with a sample of 40 students between 14 and 16 years old.

In this design, a didactic sequence is defined as the proposition and development of a repertoire of activities, interventions, and strategies to fulfill the objectives listed by the teacher for the given object of knowledge, who thus contributes to mediating the teaching and learning of that knowledge. In corroboration, Zabala (1998, p. 18) reiterates that the didactic sequence consists of “a set of ordered, structured, and articulated activities for the accomplishment of certain educational objectives, which have a beginning and an end that both teachers and students know.” Given the above, we must note that the didactic sequence created to discuss the History of Science articulated to atomic models aligns with Guimarães and Giordan’s (2011) guidelines, since it permeates aspects such as “structure and organization”, “problematization”, “content and concepts” and “methodologies and assessment”.

Guimarães and Giordan (2011) state that the structure and organization of a didactic sequence retain the evaluation of items such as clarity, document writing, time, the actions to be developed, and the references used. In turn, problematization is seen as the proposition of a real situation or, still, hypothetical and conflicting so that the students feel instigated to solve and resolve such conflict. As for the contents and concepts, it is necessary to pay attention to the logical organization of the objects of knowledge outlined for the discussion so that the students can attribute meanings to this knowledge and evidence their presence in the different segments of society. Furthermore, the teaching methodology and the assessment of the process refer mainly to the organization and development of those actions, promoting the necessary subsidies for the student to reach the objectives listed by the teacher at the beginning of the process.

Figure 1 highlights the steps of the didactic sequence as a pedagogical intervention for the historical approach of atomic models, considering the BNCC and the RCG guidelines. Each meeting shown in Figure 1 was developed weekly, with a workload equivalent to two periods of 48 minutes each:

Figure 1: Didactic sequence on the evolution of atomic models from a historical perspective



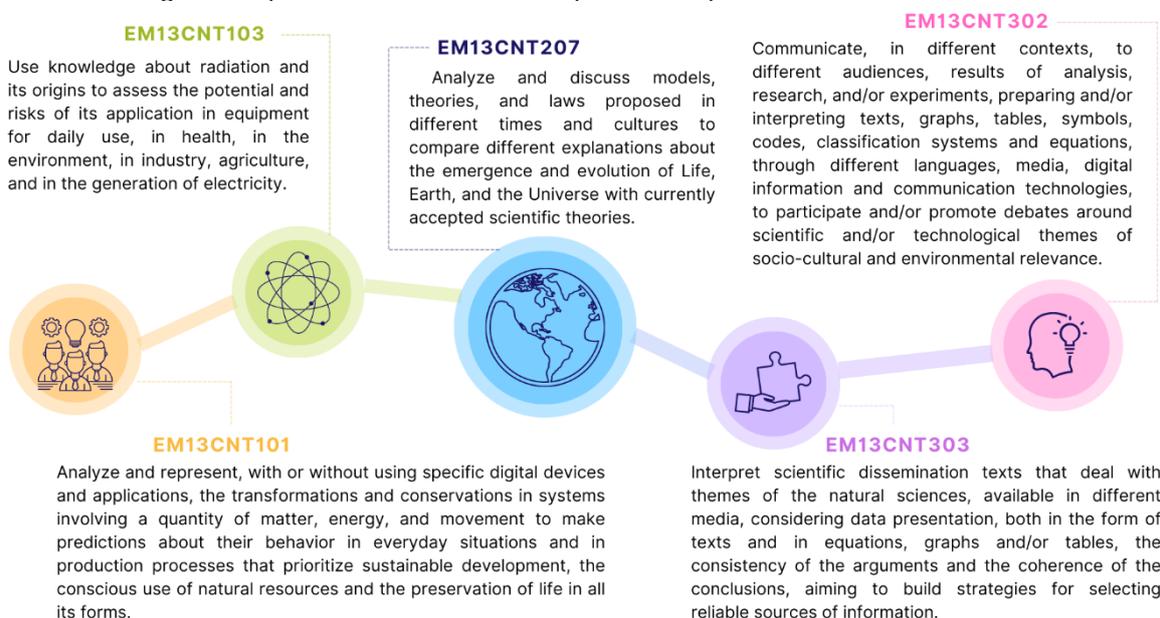
The first meeting of the didactic sequence aimed to identify the students' prior knowledge and collectively construct a definition for the curriculum component Chemistry and where it tends to be observed, either in the students' reality or through the media and means of communication. In the second meeting, we presented the initial problematization on the mentioned topic and briefly exposed the atomic models and the guidelines for the construction of the timeline to portray not only the scientists' biography and the description of the atomic model but also aspects related to the period of discovery — such as historical, political, economic, and social events. Then, in the third meeting, we proposed that the students present the works related to the timeline they carried out in the interval between meetings 2 and 3.

In the fourth meeting, the students produced the prototypes of the atomic

models using resources such as biscuits. In the fifth meeting of the didactic sequence, a set of activities was developed based on the learning station approach (HORN, STAKER, 2015). This activity consisted of the proposition of six stations to discuss the topic. Thus, we suggested that students write poems. We also proposed experimental and dynamic activities, such as Tetris and quizzes, drawing a conceptual map from fundamental concepts about atomic evolution, analysis of experiences, and models proposed from digital resources. The last meeting of the didactic sequence was destined to assess learning and identify students' perceptions regarding the activities carried out.

Besides the highlighted objectives, and with a view to the objects of knowledge listed, the activity was intended to collaborate with the promotion of skills articulated to the three specific competencies proposed for the CNT area, namely EM13CNT101, EM13CNT103, EM13CNT207, EM13CNT302, and EM13CNT303, shown in Figure 2. These, in short, are aimed both at the analysis of natural phenomena and technological processes and at the investigation of problem situations and the proposition of actions that contribute to improving the participants' living conditions.

Figure 2: Specific skills of the three specific competencies of the CNT area.



Source: Adapted from Brazil (2018, p. 556-560)

Still, it is crucial to reiterate that to find possible evidence and data given the objectives outlined for the research development, a set of data construction instruments was used, including observation, logbook, questionnaire, and students' activities. The data were analyzed qualitatively and quantitatively, based mainly on the

activities the students developed during the didactic sequence and on the form available at its end. Therefore, considering the above assumptions, this research has a quali-quantitative approach, since they are equally legitimate approaches, at the same time that the complementarity arising from the articulation of the characteristic analysis processes contributes to a holistic analysis of the investigated phenomenon, i.e., broad and deep visualization of the problem at hand (CRESWELL *et al.* 2007; SOUZA, KERBAUY, 2017). The qualitative approach results from the logbook notes; the quantitative approach emerges from the student's results in the tests and the results of the questions carried out with them.

3 Results and discussion

In the first meeting of the didactic sequence, we aimed to investigate the first impressions related to the curriculum component Chemistry. The objective of this action is to understand the students' previous conceptions and knowledge of this component of the CNT area. In addition, as Carbo and collaborators (2018) reiterate, identifying prior knowledge is important to guide the planning of actions to be developed in the didactic sequence to suggest more proactive strategies and actions for students' learning.

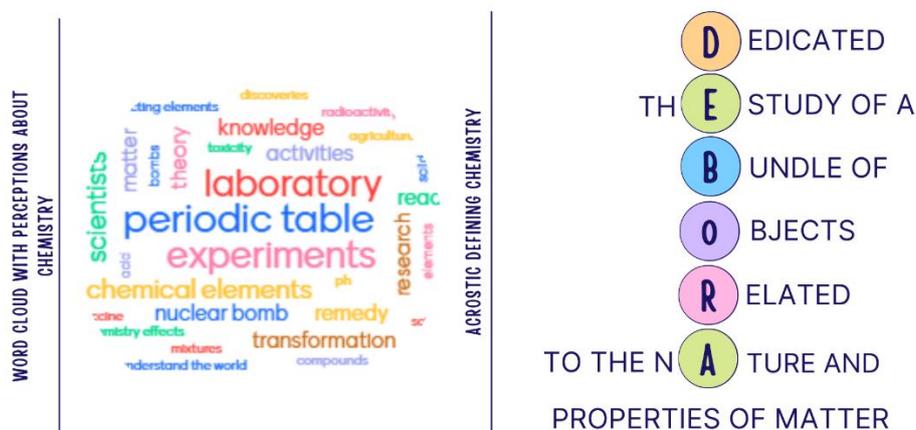
Nevertheless, this moment is relevant since, although already foreseen by the BNCC, the gradual contact with the knowledge related to Chemistry, Physics, and Biology in the area of Natural Sciences at the beginning of High School constitutes the first formal contact with the curriculum unit Chemistry. Therefore, in this meeting, based on questions and problematizing activities, we proposed to create an acrostic for the definition of Chemistry, as exemplified in Figure 3, from the name "Débora" and a cloud of words regarding her contribution to society, also exposed in Figure 3⁴.

In this way, we sought to problematize the various action contexts, i.e., in addition to laboratories, the manufacture of "bombs" and "medicines", as shown in the word cloud of Figure 3, we talked about and reflected on the presence of Chemistry in different segments of society, such as basic sanitation, health, transport, technology, agriculture, food, and processes for obtaining energy, among others, since the objective of the CNT area is guided by the demands of society in their different contexts

⁴ Translation, from Portuguese to English, of the main words mentioned by the students: experiments (experimentos), periodic table (tabela periódica), laboratory (laboratório), bombs (bombas), elements (elementos), activities (atividades), medicines (medicina), agriculture (agricultura), research (pesquisas), chemistry effects (efeitos da química), science (ciência), reactions (reações), formulas (fórmulas) and potions (poções).

(LIMA; IBRAIM; SANTOS, 2021).

Figure 3: Activities students developed after reflecting on aspects that permeate the curriculum unit.



Source: Research Data, 2022

As a preview of the second meeting of the didactic sequence, we made available a clipping of a poem by an unknown author on the Classroom of the classes. The poem encouraged a discussion in class about the evolution of atomic models. This strategy was used with the premise of subsidizing the learning of scientific concepts in students' production contexts, using different languages to "communicate, access, and disseminate information, produce knowledge" (BRASIL, p. 324, 2018), an aspect that meets the competences of the CNT area. Afterward, we offered a brief exposition using an infographic as a pedagogical resource to guide the discussion on the main characteristics of the different atomic models articulated to the historical context in which they were proposed and to problematize the linearity of the advancement of Science (LIMA; IBRAIM; SANTOS, 2021).

Next, we supervised and explained the work proposal - that is, explanations about the formulation of the proposal "A timeline — the evolution of atomic models." In this activity (Figure 4), the items to be covered were: title representing the period, scientist's biography, description of the atomic model and related experiments, illustration of the atomic model, and historical context in which the discovery was made. Such requirements were assigned since, per Lima, Ibraim, and Santos (2021), it is necessary to analyze historical issues in the light of current knowledge in the historical context in order to corroborate the reflection and understanding of scientific knowledge "as provisional, cultural, and historical" (BRASIL, 2018, p. 324).

Figure 4: Students carrying out research on a respective atomic model.



Source: Research Data, 2022

In the third meeting, as mentioned before, the research developed was socialized. Therefore, besides discussing aspects related to the scientist's biography and the proposed atomic model, for the analysis of the theme in a contextualized way, the historical, political, economic, and social facts that possibly influenced the proposition of such a model had to be mentioned (BRAZIL, 2018). A historical approach that interprets a fact without contextualizing it, or is biased regarding its sources and/or historical period, tends to corroborate a misinterpretation, something distorted from the object of knowledge under study (FORATO *et al.*, 2011).

In this contribution, the group responsible for the research and presentation of the Rutherford Model, for example, mentioned that, although the presence of negative particles — electrons — had already been identified, it was still necessary to understand their arrangement in an atom (SANTOS, 2020). In this context, the working group mentions that Rutherford focused on this and other questions regarding the evolution of atomic models, as evidenced in Figure 5.

Therefore, at first, the group discussed the biography of the scientist Ernest Rutherford, who was born in New Zealand to a humble and numerous family (LOPES, 2009). However, from an entrepreneurial initiative carried out by his parents, it was possible to raise the necessary resources to pay for the education of part of the eleven children, among them Rutherford, who, from an early age, showed interest and potential in the area of Natural Sciences (UFRGS, 2022). At the university, as revealed in the scientist's biography, Rutherford was awarded a scholarship and supplemented his income by giving private lessons, which helped him with expenses, books, and material (UFRGS, 2022).

For some time, according to Lopes (2009), Rutherford, interested in Hertz's research on electromagnetic waves, developed devices from alternative materials. However, envisioning joining large research centers, he moved to England. After all,

scientific research, in increasing complexity, requires equipment, adequate environments, books, and specialized peers, which he could only enjoy in places of great economic concentration. In 1893, only 22 years old, Rutherford was already focused on scrutinizing Mathematics and Physics under the guidance of Thomson, the researcher responsible for identifying the electron and proposing the plum pudding atomic model (LOPES; GOMES, 2018).

Figure 5: Rutherford atomic model

A Moderna Teoria Atômica

ERNEST RUTHERFORD

Dupla: Lauren e Luana

Biografia

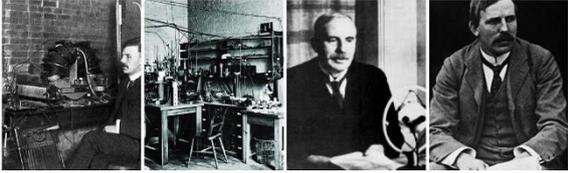
Ernest Rutherford nasceu em 1871 na Nova Zelândia e faleceu em 1937 em Cambridge no Reino Unido, ele foi um físico e químico que pesquisando o urânio descobriu a emissão de raios alfa e beta.

Em 1893 graduou-se em Matemática e Física na Universidade de Wellington. Através de um concurso, ganhou uma bolsa de estudos que o levou à Universidade de Cambridge, na Inglaterra.

No Laboratório Cavendish, em Cambridge, sob a orientação do físico J.J. Thomson. Em 1919, de volta a Cambridge, assume a direção do Laboratório Cavendish. Entre 1921 e 1934 trabalhou com Piotr Kapitzia, um de seus maiores colaboradores e um dos mais importantes nomes da URSS. Rutherford demonstrou novamente sua fé na internacionalização da ciência, ao conseguir a transferência de seu gigantesco laboratório de alta voltagem da Inglaterra para a União Soviética, onde Kapitzia saberia utilizá-lo no progresso da pesquisa.

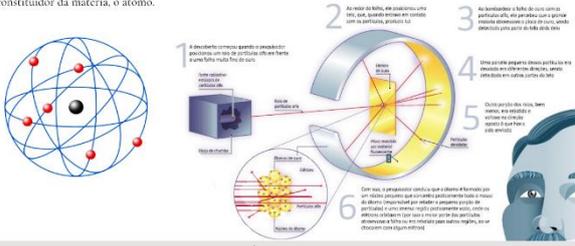
Contexto Histórico

Neste mesmo ano da criação do modelo atômico, no dia 25 de março de 1911 o incêndio na fábrica de roupas Triangle Shirtwaist, o mais mortal acidente industrial da cidade de Nova York, Estados Unidos, se transformou num marco da luta pelos direitos das mulheres. O incidente matou 146 pessoas, 23 homens e 123 delas mulheres.



O modelo atômico de Rutherford

No ano de 1911, Ernest Rutherford apresentou à comunidade científica o seu modelo atômico. O modelo de Rutherford, também chamado de modelo do sistema solar, foi o terceiro na história da Atomística (sendo os dois primeiros o modelo de Dalton e o modelo de Thomson) e foi considerado o modelo que estimulou toda a evolução do conhecimento sobre o constituinte da matéria, o átomo.



"SOL SERIA UM PEQUENO NÚCLEO E OS PLANETAS, ORBITANDO AO SEU REDOR, SERIAM OS ELÉTRONS."

Características:

O modelo atômico de Rutherford apresenta como principais características um núcleo positivo e uma eletrosfera negativa, todas evidenciadas por um experimento que utilizou radiação e ouro.

a) Núcleo (que foi comparado ao sol no sistema solar)
Uma região central do átomo que apresenta:

- partículas positivas (os prótons);
- baixo volume;
- maior massa;
- maior densidade do átomo.

b) Eletrosferas (que foram comparadas às órbitas descritas pelos planetas no sistema solar)
Regiões do átomo que apresentam:

- imensos espaços vazios entre si;
- partículas de natureza negativa (os elétrons).

Construção do modelo

A construção do modelo de Rutherford iniciou-se a partir do estudo das propriedades dos raios X e das emissões radioativas, culminando na utilização de radiação sobre um artefato inerte.

VIDEO SOBRE O MODELO ATÔMICO



Referências

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Source: Research Data, 2022

Still in this period, Roentgen discovered X-rays, and Becquerel, in 1896, reported his findings on radiation from specific elements (UFRGS, 2022). Rutherford, on the other hand, when studying uranium radiation, identified radiations of two different natures since, when passing through the magnetic field, they followed in opposite directions, which suggested that they were constituted by electrically charged particles, named alpha and beta radiations, designations still used today. The radiations that seemed not to be influenced by the magnetic field were named gamma rays (UFRGS, 2022).

Furthermore, the group emphasizes that Rutherford formulated, based on gamma rays, the hypothesis that radioactivity was not a phenomenon common to all atoms but only those from a single classification, which tend to lose energy with

particles emitted (LOPES, 2009). Also in line with the author, this proposition led to the idea that radioactive elements were subjected to a transmutation process over time, resulting in the formation of other elements of lower atomic mass. Numerous experiments were carried out to verify this notion.

The period between the late 19th century and early 20th century was marked by scientific revolutions. Thus, with the apogee of colonialism, Europe experienced a phase of economic prosperity, making it possible to direct resources to finance research. At that time, Marie and Pierre Curie discovered radium and polonium, both products of the natural disintegration of atoms of more massive chemical elements (UFRGS, 2022). Thus, according to the author's biography, aiming to describe the radioactive elements, Rutherford and his colleagues observed that uranium and lead were extremes, with all intermediate elements resulting from disintegration. This finding won him the Nobel Prize in Physics in 1908.

The students mentioned that the experiment made in mid-1908 involving the bombardment of a gold foil with alpha particles led Rutherford to observe how most of the particles traveled through the foil without being deflected. Because of his observations and the calculations performed, he concluded that gold atoms basically consisted of partially empty structures and not massive spheres, as was commonly thought. However, in a specific region of the atom, a grouping of the positive charge was identified, resulting in the deviation of a tiny part of the alpha particles. Also, the students' group mentioned that the model resembled the solar system: the central nucleus of the atom, and the electrosphere, where the nucleus is surrounded by negative particles (SANTOS, 2020).

In addition, based on the proposed biography (UFRGS, 2022), the students mentioned that, as a result of events such as the First World War, Ernest Rutherford had to interrupt his studies on the nucleus and the electrosphere of the atom and focus on military research. Like Rutherford, many students and their collaborators were called to military service. Their work in research was resumed only after the end of the First World War.

In this context, to deepen the discussions held in the previous meetings, the fourth meeting proposed the elaboration of prototypes of atomic models, specifically the atomic models of Dalton, Thomson, Rutherford, Bohr, Sommerfeld, Schrödinger, and Chadwick. At this time, a set of alternative and low-cost materials was made

available, aiming to provide reflections on atomic models, making them more palpable and closer to students, as suggested by Garreto and Machado (2018).

Thus, assuming the atom is one of the central concepts of Chemistry, atomic models are constituted as representations based on experiments that aim to propose explanations for the behavior of an atom (LOPES, GOMES, 2018). In this way, agreeing with the authors, we proposed the elaboration of prototypes of the models from different materials to corroborate a view as close as possible to the conceptual representation of the object in question, because, according to Chassot (1993, p. 100), they are “fundamental tools that we have to understand the world whose real access is very difficult.”

In the fifth meeting, we proposed a set of activities, among which an adaptation of the game named “Tetris”; the organization of four types of block formats, in which the player must organize the blocks to articulate the presented answer with its respective tip displayed on the activity board. This configuration proved to be very fruitful for resuming conceptual aspects related to the object of knowledge under investigation, since the students were instigated and enthusiastic in carrying out the task, which can be seen in Figure 6.

Figure 6: One of the activities proposed in the dynamic learning by stations.



Source: Research Data, 2022

In the second station, we proposed some experiments, such as the “Roll-the-can race” from the book *73 Truques Legais de Ciências Para Surpreender Seus Amigos* [73 Cool Science Tricks to Surprise Your Friends], by Anna Claybourne. In this activity, materials such as an empty soda can, a balloon, and some instructions were made available, such as: “charge the balloon with static electricity by rubbing it in your hair or a piece of woolen clothing. Place the can on its side, on a table or floor, and hold the balloon close to it.” The instructions follow “it will start to roll towards the balloon. Keep moving the balloon, so the can does not touch it, and it will continue rolling. How fast can you make it roll?” (CLAYBOURNE, 2021, p. 88).

After experimenting, the students presented possible connections between the experiment and the discussion on atomic models, as can be seen in the following clippings from the researcher's logbook:

*Helium*⁵: The “water bending” experiment and the “roll-the-can race” experiment have the same principle. That is, when we rub the balloon through our hair or a wool coat, we give the balloon extra electrons, hence a negative electrical charge. This fact explains why the balloon attracts the can, i.e., it attracts the positive particles of the can, causing it to roll very fast. (Clipping from the records made by the students)

Sodium: A phenomenon with this very common principle in our daily lives is when we put on a wool coat because many times my hair is stuck to the coat. (Clipping from records made by students).

Similarly, the third season proposed the collaborative elaboration of a poem about the evolution of atomic theory. The poems depicted Dalton's atom analogy to a billiard ball, Rutherford's experiment, and Thompson's model of the plum pudding. This activity was chosen because, as Pereira (2019) points out, language and artistic expression can constitute promising resources for learning and understanding atomic models, with students gradually appropriating the specific language of the area (BRASIL, 2018).

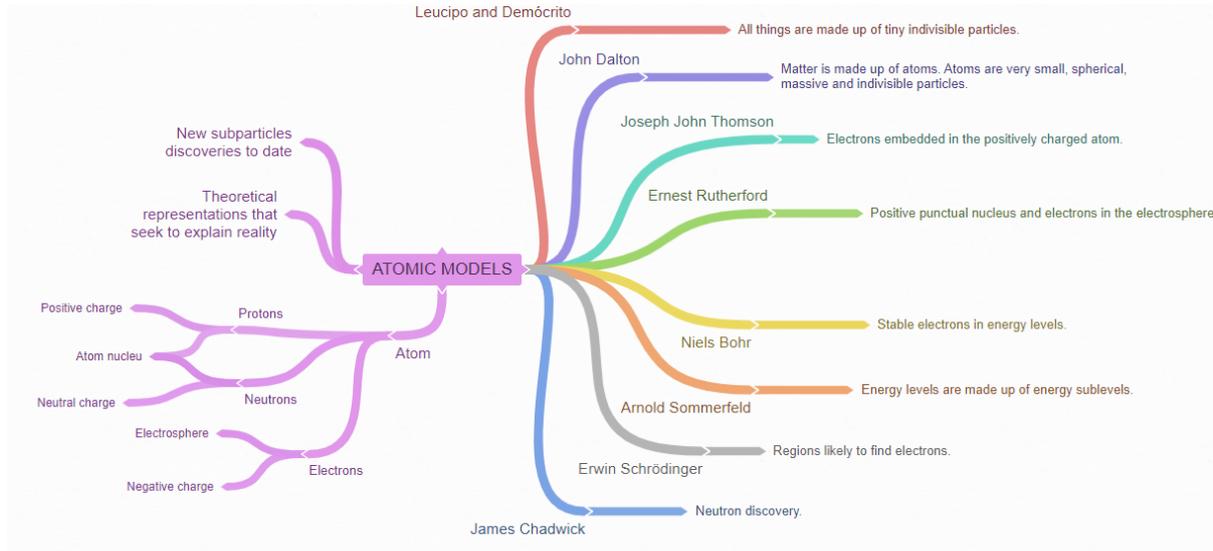
In the fourth station, a mental map was built based on the main concepts that permeate the evolution of atomic models with regard to possible definitions, analogies, and examples. For that, in this station, we used the Coggle⁶ platform. This is a very intuitive platform for creating maps and mental schemas, in which students can, in real time, experience the collaborative construction of the schema. One of the elaborated schemes can be seen in Figure 7.

On the diagram, we must highlight issues about the formulation process. Because besides understanding the subject, students were required to take a critical stand in the face of the development process among peers and mediate conflicts regarding divergent ideas. This aspect is seen in the BNCC since it suggests the proposition of pedagogical actions aimed at understanding, evaluating, communicating, and disseminating scientific knowledge to foster “greater autonomy in discussions through critical analysis, arguments, and positions” on themes inherent to Science (BRASIL, 2018, p. 552).

⁵ Research participant identification code.

⁶ Platform *Coggle*: <https://coggle.it/>

Figure 7: Diagram prepared by one of the groups of participants.



Source: Research Data, 2022

In the fifth station, a series of activities were carried out on the Quizizz platform. This platform, whose objective is to create a question-and-answer game, has seven question formats, five of which are free. Thus, considering the activity above, the students answered twelve multiple-choice questions in the shortest possible time, i.e., both speed and veracity are contemplated in the process. At the end of the task, a ranking displays the position of the students with the highest score. Figure 8 (B) shows the students' scores.

Figure 8: Platform logo (A) and students' scores (B)



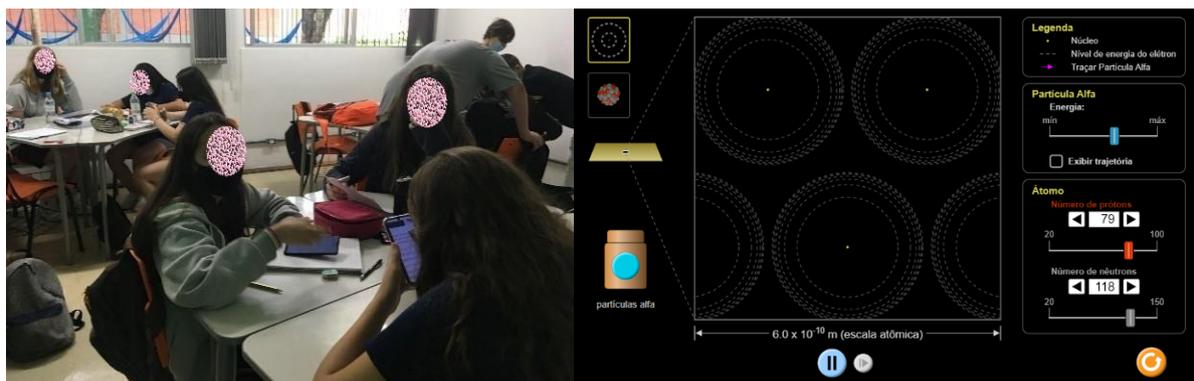
Source: Research Data, 2022

In this station, 14 answers were obtained, considering the participation of 40 students organized in small groups. This number is justified by the fact that a member of the group was responsible for accessing the activity and making the necessary appointments. As for the general percentage of class performance, it gets close to 80%. From the analysis of the fourteen groups from an individual perspective, it was possible to identify that: three groups obtained 100%, one group 91.6%, and another

six groups 83.3% of performance. The other groups obtained a percentage of 66.7% and 41.6%, with two representatives from each percentage, which indicates a need to resume the concepts discussed with these groups in particular.

In the sixth and final station, the interactive simulations of the Thomson and Rutherford models on the PhET platform were explored. In this station, the students explored the specifics of each model and observed the deviations of alpha particles when focusing on the nucleus of the atom being investigated. In Rutherford's experiment, for example, the standard material is Gold, represented by the symbol Au. In this sense, one of the questions asked was for students to identify the element in the periodic table and find its number of protons, neutrons, and electrons. Figure 9 shows the students exploring the simulation and its homepage.

Figure 9: "Rutherford Scattering" Simulation



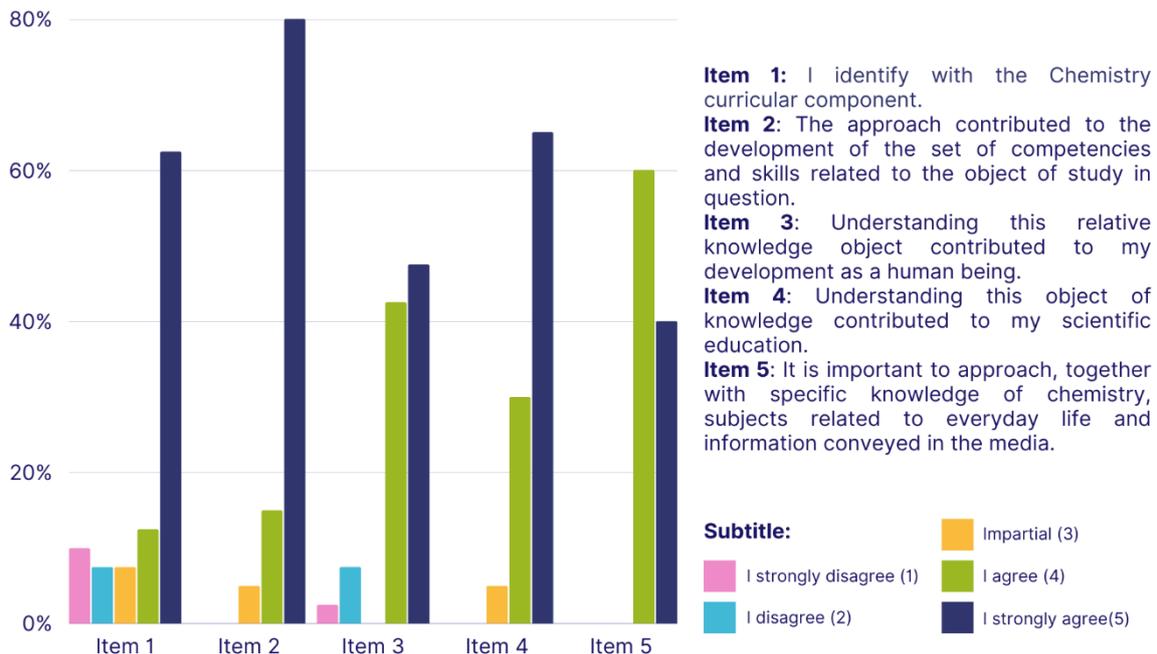
Source: Research Data, 2022

Finally, the last meeting scheduled for the didactic sequence was dedicated to a process beyond knowledge assessment. This moment was for dialogue and reflection on the students' perception of the activities developed. Firstly, regarding the last assessment on the evolution of atomic theory carried out with the group, we must remark that the resulting data are auspicious because 38 out of 40 students did well in the task, which may indicate an understanding of the object under study and a significant understanding of the topic "atomic models."

In this last class, the students answered a form about the perceptions of the activities developed, held a conversation circle about positive and negative aspects, and gave suggestions for the subsequent activities. As for the data from the form, structured according to the Likert scale, numbers 1 and 2 rank disagreement with the statement, numbers 4 and 5 reflect agreement, and number 3 ranks an intermediate position regarding the statements. The data in question can be seen in Figures 10 and

11, presented in the text.

Figure 10: Group perceptions form



Source: Research Data, 2022

Regarding the first item: “I identify with the Chemistry curriculum component,” all five possible answers were checked. Based on Figure 10, we see a high percentage of participants who showed to be familiar with and interested in the component, since the sum of the percentages of grades 4 and 5 totaled 75%. As for the others, 10% of the participants vehemently point out being unfamiliar with the component, while 7.5% of the respondents say they are not familiar or do not have a clear position on the statement.

Regarding the second question: “the approach contributed to the development of the set of skills and abilities related to the object of study at stake,” 95% of respondents checked grades 4 and 5, respectively, 15% and 80%. Thus, based on Carbo and collaborators (2019), one of the teaching premises is to provide students with different ways and strategies to learn. According to them, those strategies should assume a flexible, diversified character and encourage collaborative work but also provide opportunities for each person’s idiosyncrasies.

The item “understanding this object of knowledge related to the Chemistry component contributed to my development as a human being” presents only favorable and divergent positions, which present respectively, 90% (adding 4 and 5) and 10%. We believe that the indicated percentages result from the understanding of the

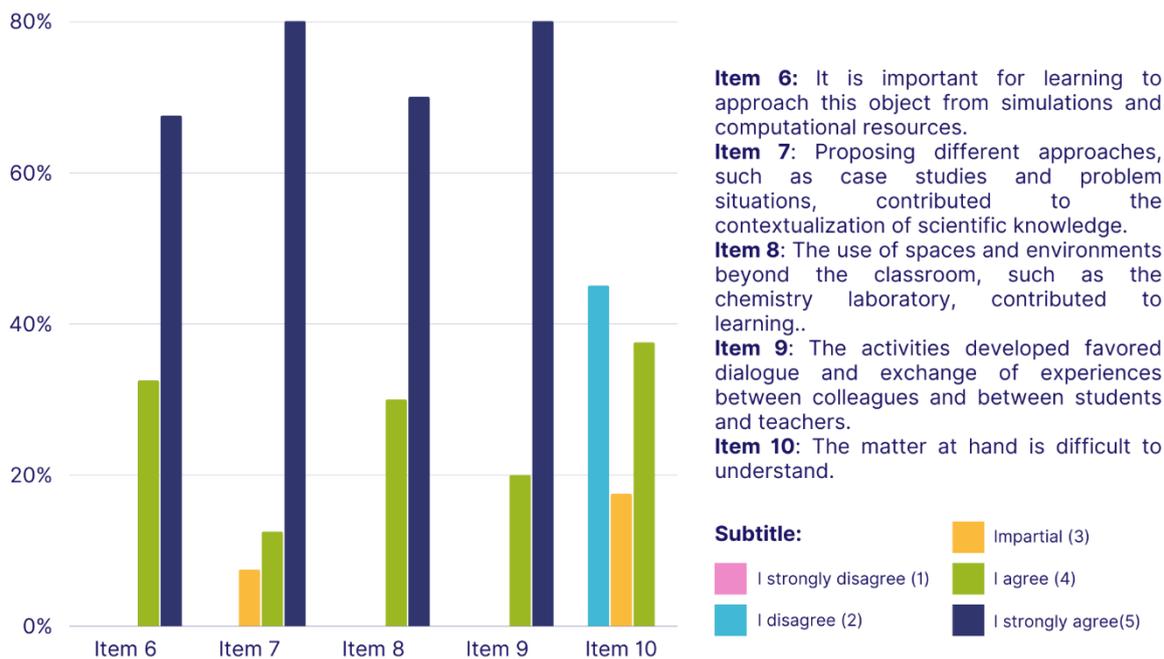
objectives and premises of the area for the participants' formation, i.e., through the appropriation of such knowledge and assuming that Science is in constant development, it contributes to a more critical reading of the world. Furthermore, during the development of the didactic sequence, the reading and analysis of scientific research and the discussion and socialization of the works developed were encouraged, which requested the student to structure argumentative discourses. In the same way, the production of media resources was instigated through the use of different features and programs.

In summary, such actions may have contributed to a more critical reading of the world by students, since the process of reading and analyzing scientific research requires the student to master better the structuring scientific elements, which also improves the argumentative process that derives from socialization. In other words, the research-socialize-argument movement not only demands from the student skills and competencies related to the cognitive field but also requires socio-emotional attitudes and values. This aspect is also observed in item 4: "understanding this object of knowledge contributed to my scientific formation," where 95% of the participants agree with the statement, of which 65% indicated grade 5 and the remaining 30% checked grade 4. Also, a simple percentage equivalent to 5% was identified in item 3, with an intermediate percentage on the statement.

Regarding the fifth question: "it is important to approach, together with specific knowledge of Chemistry, issues related to daily life and information conveyed in information and communication media," we identify a consensus since the group, as a whole, claims to agree or totally agree with the statement. This result aligns with the need to approach specific knowledge in a contextualized way, in the sense that the student perceives the applicability of such knowledge in their daily life.

Figure 11 shows the percentages attributed to the other questions on the form. Regarding item 6, which reiterates the importance of "approaching this object of knowledge through simulations and computational resources" for learning, we highlight a percentage of 100% agreement distributed between grades 4 and 5.

Figure 11: Group perceptions form.



Source: Research Data, 2022.

Still alluding to Figure 11, in particular item 7, where we read: “The proposition of different approaches, such as case studies and problem situations, contributed to the contextualization of scientific knowledge,” we see that only 7.5% of the participants were not for or against the statement. The percentages observed in item 7 are in accordance with the research by Carbo et al. (2019), as they give the class a dynamic, interactive, and interesting character, corroborating students’ interest and involvement during the activity. Consequently, it encourages the engagement of subjects beyond the actions carried out in formal teaching spaces, thus searching for pages, series, texts, and reports on the subject, contributing to the understanding of the topic, as can be observed in the reports of the participants of the search:

Lithium: we really liked the activities developed because despite the atomic models being difficult due to the amount of information, we managed to understand the topic well, especially how each model was proposed and in what historical scenario it was developed — Excerpts from students’ registers.

Items 8 and 9, which refer to the “use of spaces and environments beyond the classroom, such as the chemistry laboratory, contributed to learning” and “the activities developed favored dialogue and the exchange of experiences between colleagues and between students and teacher,” respectively, also present a high percentage of favorable answers, since the data from both questions only indicate checking in items 4 and 5, that is, a degree of agreement of 100%.

Regarding the practical classes, for example, the students performed the flame test. They placed atoms of different chemical elements under the flame to excite the electrons, so they change to other levels of higher energy; therefore, according to the atomic model proposed by Niels Bohr, when electrons return, they tend to release energy in the form of light (MELLO; MICARONI; CUNHA, 2018). According to the authors, experimental activities are fundamental for understanding and deepening the objects of knowledge addressed, constituting a possibility of a more concrete approach to this field of knowledge.

The last question on the form, item 10, reiterated that “the evolution of the atomic models is difficult to understand.” Thus, nobody checked grades 1 and 5, extreme points of the Likert. The markings were distributed among scores 2, 3, and 4 with percentages of 45%, 17.5%, and 37.5%, respectively. The item under analysis also meets Lithium’s statements since the object of study presents a significant degree of complexity. As Del Pino (2006) reiterates, materials such as textbooks do not explore the construction process of scientific knowledge, focusing, above all, on discoveries and scientists’ birth and death dates, among other specific statements.

In short, we believe that, considering all the elements, strategies, and resources present in the didactic sequence, the activity enabled students to mobilize different skills and develop multiple ones. These meetings not only helped sharpen students’ interest and curiosity but also provided them with a movement to analyze, interpret, and organize texts, going through a process of decoding ideas in maps and stanzas, researching, publicizing, and arguing about scientific elements that emerged from the History of Science. In this sense, Chart 1, briefly based on the meetings, aims to illustrate the skills and competencies mobilized.

Table 1: Competencies and skills mobilized in each meeting

Meeting	Actions	Skills
1	<i>Creation of an acrostic for the definition of Chemistry and of a word cloud.</i>	EM13CNT201 EM13CNT301
2	Moment of the exposition of the theme and instructions for the activity to be developed on atomic models.	EM13CNT101 EM13CNT303 EM13CNT207
3	Presentation of works on atomic models.	EM13CNT305 EM13CNT302 EM13CNT103
4	Development of prototypes of atomic models.	EM13CNT302

5	Learning activity by stations.	EM13CNT205
6	Assessment and form on the students' perception of the activities developed.	EM13CNT101

Source: The authors (2022)

In summary, the implementation of this pedagogical action to discuss the History of Science and atomic models sought to encourage the development of the mentioned skills to ensure that during basic general education, the student experience and understand beyond the systematization of conceptual knowledge characteristic of the area and perceive the role of scientific knowledge in different organizations, such as social and cultural ones. Nevertheless, the investigation dimension was emphasized throughout the didactic sequence so that the characteristic procedures of scientific research could be understood, as well as the language, codes, symbologies, and nomenclatures characteristic of the CNT.

4 Final Considerations

Given the considerations made throughout the text, we can conclude and validate the didactic sequence developed as fruitful for building scientific knowledge about atomic models, in the sense of understanding it as a strategy that facilitates the learning of that object of study. Likewise, activities of this nature are fundamental to students' scientific education, in the sense of understanding the History of Science beyond mentioning memorable dates and names, i.e., focusing especially on the understanding of the constructive process of scientific knowledge, which is strongly influenced by historical, political, and economic conditions.

As for the approach proposed for the discussion on the evolution of models from a historical perspective, we emphasize that it aimed to deal with the theme to highlight its construction process in a complex way and as something essential for the development of society. Thus, we reiterate that such discussions are recommended at this teaching stage to deepen and expand discussions and reflections on the contexts of construction and application of scientific knowledge in individuals' daily lives, as proposed by the BNCC.

Furthermore, through plural planning, which encompasses a set of diversified activities, such as the use of games, simulations, and experimental practices, we expect to have fostered the interest and involvement of students in carrying out the proposed activities, enabling them to promote and mobilize different competencies and

abilities. In other words, we sought to engage students in building scientific knowledge to support a more solid scientific education rooted in the conceptions of the History of Science. Such actions aimed to explore the relationships between students to develop in them a critical conscience for acting with responsibility for the construction of a more just and egalitarian society.

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