

# Paleontology as a didactic tool to learn about environmental change

## A PALEONTOLOGIA COMO FERRAMENTA DIDÁTICA PARA ENSINAR SOBRE MUDANÇA CLIMÁTICA

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**Abstract: Introduction and Objective.** This paper describes a workshop on historical climate change for teachers at the University of Buenos Aires, Argentina. **Methodology.** In this workshop, teachers analyzed hypothetical evidence of fossil records to relate them to climate and environmental change. **Results.** This work describes the subsequent analysis of the proposed activity. Teachers' prior knowledge about these concepts and their cognitive-linguistic abilities are also described. **Conclusion.** The workshop provided teachers with a didactic tool for teaching fossil records, climate change, and geological time within Earth Science.

**Resumo: Introdução e Objetivo.** Este artigo descreve um workshop para professores sobre mudanças climáticas históricas, realizado na Universidade de Buenos Aires, Argentina. **Metodologia.** Neste workshop, os professores analisaram evidências fósseis hipotéticas para relacionar com as alterações climáticas e ambientais. **Resultados.** Este trabalho descreve uma análise posterior da atividade proposta. Da mesma forma, são descritos os conhecimentos prévios dos professores sobre os conceitos e as habilidades cognitivo-linguísticas que entram em jogo. **Conclusão.** Este workshop fornece aos professores uma ferramenta de ensino para ensinar o registro fóssil, as mudanças climáticas e o tempo geológico no âmbito das Ciências da Terra.

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## Introduction

The events and processes studied in Geology and Paleontology encompass such long periods that they are challenging to comprehend and explain. Geological time is difficult to understand because it involves many interlinked concepts, including time as a magnitude, historicity, and an unfolding of events (Sequeiros et al, 1996). In addition, there are the concepts of geological change, facies lithology, causal succession, duration, and chronology (Pedrinaci, 1993). Didactic studies have identified these aspects of time as one of the main obstacles to understanding geology and paleontology (Sequeiros et al, 1996). Since the nineties, time has been considered the most critical structuring concept within the Earth Sciences

(García Cruz, 1998). Pedrinaci (1993) reported several epistemological hindrances and their consequences for studying geological time. He highlighted the importance of the imaginative barrier, which, from a human static perspective, inhibits us from understanding the considerable number of events that have taken place on Earth over thousands of millions of years. The spatial scale poses another tremendous difficulty; for instance, a minor tectonic fault can stretch thousands of kilometers. García Cruz (1998) also defines the idea of globality as another significant epistemological obstacle, that is, understanding how any phenomenon or geological process identified on the local scale integrates into the global functioning of the planet.

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The difficulty of experimentally testing many geological events and processes and directly observing them poses a significant obstacle to teaching about these phenomena. Immutability is usually observed, except for particular situations, such as earthquakes or volcanic eruptions. This feeling of fixity is detrimental to understanding the concept of geological time, where change plays a preponderant role (García Cruz, 1998). In this context, paleontology can provide a friendlier way to approach this concept. Since it is a popular science, its interest in children and teenagers facilitates the introduction of complex concepts such as geological time. Furthermore, reconstructing stories from the tracks left by fossils is especially attractive for students (Sequeiros, 1996).

Another subject that is related to geological time and is of growing interest and concern amongst the non-scientific community is climate change. Nosty (2009) describes how the media exploit climate change stories to boost their readership but seldom provide holistic explanations that explain how past events relate to present-day climate change. Paleoclimatology is the discipline concerned with the qualitative and quantitative study of climate change through geological time. As such, stratigraphy is essential to interpret the chronological sequence and extent of inferred climate changes.

From a constructivist perspective, it is necessary to consider the knowledge that the student already possesses since it is that knowledge that the student will use to interpret the activities and new knowledge that will arise (Driver, 1985). Therefore, these ideas may act as obstacles that impede learning. However, these are a good starting point for the collective construction of knowledge in a reflective, participative, and motivating way. On the other hand, formulating productive questions intended to guide the student's thinking is also extremely important. This way, the teacher can provide students with the path to build their knowledge based on necessary support. These questions should not follow a particular order, allowing to build the scaffold while observing what happens to the students (Lee Martens, 1999). Lee Martens (1999) claims that the strategic application of this type of question keeps students motivated. In this way, students shall actively and responsibly participate in the task.

This paper describes a workshop that aimed to provide teachers with an innovative method for

teaching the concepts of geological time and climate/environmental change, using paleontology as a motivating didactic tool. Providing teachers with fictional evidence of fossil records in the province of Buenos Aires and, through abductive reasoning, were asked to develop a hypothesis explaining the environmental change of the region and to extend their findings by making inferences about global climate change in the past. While completing this task, they practiced essential science competencies such as observation, description, comparison, identification patterns, classification, and formulating questions and hypotheses, explanations, and arguments (Adúriz-Bravo et al., 2005, Hernández, 2005, Ma, 2019).

The workshop on climate change and environmental evolution took into consideration that in order to achieve meaningful learning, a didactic strategy different from the transmissive one is necessary (Khalaf, 2018). This way, it sought to guide the teachers to achieve a less expository approach, relying on abductive reasoning, which offers the possibility of formulating hypotheses based on the evidential description of an event (Adúriz-Bravo, 2002). The study relied on the description of indirect observations, *i.e.*, through an image of a fact that represents reality.

## Objectives

Understanding climate change as a globally distributed socio-environmental problem in Argentina, within the framework of the law for the implementation of comprehensive environmental education (Law 27621), environmental problems must be addressed in a transversal and particular manner at all levels and modalities of the national educational system. However, beyond the interest, there are difficulties in addressing these issues in the school environment, despite being present in the school curriculum, possibly caused by the use of traditional methodologies centered on the teacher, which are not ideal tools for meaningful learning.

A workshop was devised with the goal of meeting all these needs, taking into account all of the difficulties associated with the understanding of geological time, the public's curiosity about climate change, the popularity of paleontology, the teachers' need for assistance in teaching geosciences, and the need to advocate learner-centered teaching methodologies.

## Method

The didactic proposal was presented in a 150-minute workshop to 23 teachers and students of biology, chemistry, geography, and physics. The workshop was part of a week-long series of outreach activities related to the teaching of science carried out in July 2017 by the School of Exact and Natural Sciences of the University of Buenos Aires.

### Didactic Proposal: Fossils, Climate Change and Environment Evolution.

#### How to understand climate change from the fossil record

The sequence begins with a dramatization in which “subway workers” enter carrying a saber-toothed tiger skull (replica) that they have found during their working shift. The reason for their visit is to find out about their strange discovery. In addition, they brought along a sketch of what they found during the excavation. This sketch represents an idealized stratigraphic profile, where there are no exceptions to the original horizontality law or succession law. In the sketch, fossils of marine and continental environments are interleaved, forming a three-strata sequence. The first stratum, from bottom to top, contains the fossil remains of a saber-toothed tiger, the second one (which is recognized by a slight change in color) includes shell fragments and whale bones, and the last one presents another saber-toothed tiger beneath urban trash (Fig. 1). After that, students are asked to produce a hypothesis to explain this stratigraphic sequence, thus helping the unexpected visitors.

The participants are provided with the sketch and asked to answer the following questions:

“a) How would you explain these findings? Write or draw a possible explanation.”

Once this first activity is finished, the main consequences of global warming are mentioned: the melting down of glacial ice and its relationship with the climate at that time and the flooding of the coast. Additionally, a brief explanation regarding the widespread presence of immense ice caps during the last ice age is also given. In order to deduce the possible consequences of current climate change and infer what might have happened in the past, the participants address the following questions: What is a glaciation? How many ice ages have there

been? Are we heading into a new ice age? Do you know what a glacier is? How much ice does a glacier contain? What is the height of a cap glacier? Where does the ice of glaciers come from? How long does it take for snow to form a glacier? How much does the sea level drop due to the influence of continental ice? What percent of Earth is water? These questions are intended to guide the participants to conclude the link between sea level rise and temperature change.

Overall, the goal of this part of the sequence is to relate the megafauna with the ice ages and understand the relationship between the continental ice and the fall in the sea level.

After making groups, participants are given a set of cards with fossil findings (summary of journalistic notes), which describe what type of organism they were, the region where they were found, and the relative age of the fossil (Fig. 2). The cards depict some odd findings, in which land animals are found in aquatic environments and vice versa throughout Buenos Aires.

Firstly, they are asked to construct a timeline with these cards according to the age of the featured fossil. Subsequently, every group shares its

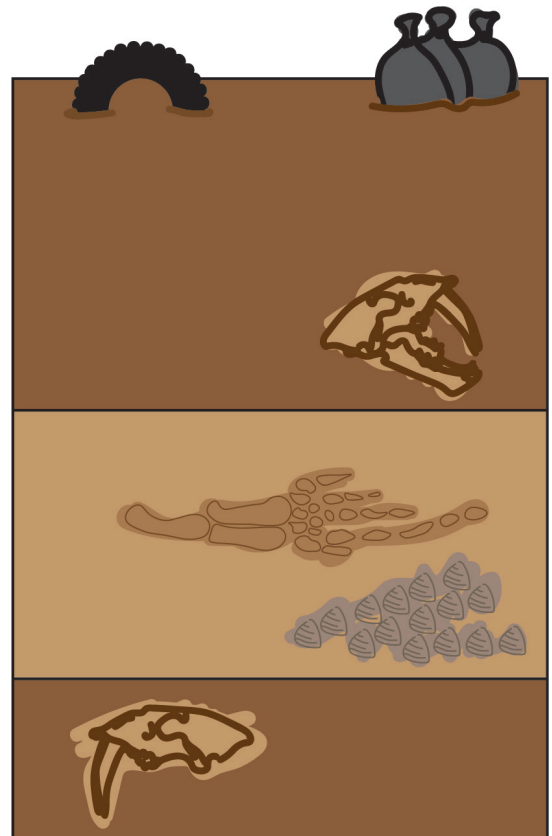


Figure 1. Sketch of what was found in the excavation of the subway (Martín et al., 2017)

work, showing and explaining the way the cards were sorted. They are guided through productive questions to correct the timelines in cases where they have not been made to scale. Then, it is explained that paleontologists do not work with a complete record and that they use fossils of similar age. After that, they are asked to group the findings with similar ages.

For the next activity, participants received some blank maps of the province of Buenos Aires and another one with the positions where the fossils featured in the cards were found. Participants are asked to use a map for each group that they made in the previous activity and point out the findings on it. Then, they are required to differentiate between land and marine animals.

The following questions are posed, considering all the information already discussed: *Do you notice anything strange? What can you infer from the maps and the characteristics of the fossil species? What does it mean that certain places were inhabited by marine animals when nowadays they are dry land?* These questions are intended to guide the participants toward the realization that the presence of land fossils in areas covered by the sea at present, and *vice versa*, implies a change in the

environment as we know it today. Finally, participants drew a new coastline for Buenos Aires according to the area the continent could have occupied in the past due to the rise and drop of the sea level, as indicated by the fossil findings in their maps.

As a plenary, a timeline is made on the blackboard, where the temperature is plotted based on it, thus relating their observations of fossil findings to the change in sea level attributed to climatic variations.

To conclude, participants are asked to reformulate their theories about the stratigraphic registry scheme discovered by subway workers through a metacognitive process to incorporate their new vision and discover their expertise when using the concepts worked on.

### Didactic aspects of the proposed activity

A second part of the workshop was devoted to reflecting upon the didactic aspects of the proposal. Firstly, the concepts and skills involved in the activity were enumerated as follows: geological time, stratification, fossil findings, climate change, paleoclimatology, and stratigraphy, on the one hand, and the cognitive-linguistic abilities as explain, justify, compare, classify, analyze, hypothesize and plotting, on the other.

It was explained that the proposal is based on a constructivist perspective. That means that the spotlight is set on the student, and it is expected that they actively build their knowledge in a dynamic, interactive, and participatory process. In this way, learning is facilitated by peer interaction and meaningful knowledge is acquired. Thus, understanding that learners are not devoid of preliminary knowledge, participants' previous ideas and preconceptions on the subject were addressed during the activities. By the end of the workshop, it was assessed whether these thoughts remained or whether participants had indeed changed their point of view, and now they could explain the sketch with all the factors involved in the picture and the concepts worked in the workshop.

The importance of productive questions to build knowledge within this framework was highlighted (Lee Martens, 1999), particularly encouraging the application of scientific competencies, both in science workshops and in everyday teaching.

Following Hernández (2005), we consider that the acquisition of science-related competencies at school is vital for the development of a critical



Figure 2. Image of one of the cards with fossil findings presented (Martín et al., 2017)

frame of mind, allowing a better understanding of the environment and active participation in relevant social decisions during later life.

Additionally, the inductive, deductive, and abductive reasoning methodologies were discussed, relating the latter with the didactic proposal of the workshop and highlighting its potential use in science classes to induce students to hypothesize. Abductive reasoning functions as a formal analog of the modeling process, prototypical of scientific research (Adúriz-Bravo, 2002, Rapanta, 2018).

Finally, an anonymous survey was conducted individually and among the participants in order to obtain their feedback on the workshop, along with suggestions for improvement.

## Results

By the time the timeline exercise was concluded, only two out of eight groups of teachers had ordered the cards correctly. The other six placed them equidistantly and did not group them according to the discrete chronological groupings they indicated.

In other respects, the didactic proposal unfolded as intended, and the guided dynamics of the workshop allowed a fluent analysis of the inferred past environments and the respective climate that they indicated.

The final activity allowed us to assess whether participants indeed acquired new knowledge after completion of the assigned task. It must be taken into account that, in order to ascertain this correctly, it would be necessary to evaluate if participants can make inferences in relation to the subject on the basis of other pieces of evidence.

A descriptive statistic analysis was made with the answers from the sketch of the stratigraphic record (collected at the initial phase of the workshop). Firstly, two answers were excluded from the following analysis, defining them as lacking a reasonable connection to the subject. The total sample shows that only 62% of the teachers made an explanation, while the rest just wrote a description. Of those who gave a possible explanation for the stratigraphic record, 23% explained the findings by an accumulation of sediments, while a change in sea level was proposed by 70% of participants. Of this group, only two-thirds mentioned causes for the change in the sea level, with 50% explaining it as a consequence of seawater evaporation, 25% referring to climate change, and 25% proposing a geological cause (Fig. 3).

## Causes of change in the paleontological record

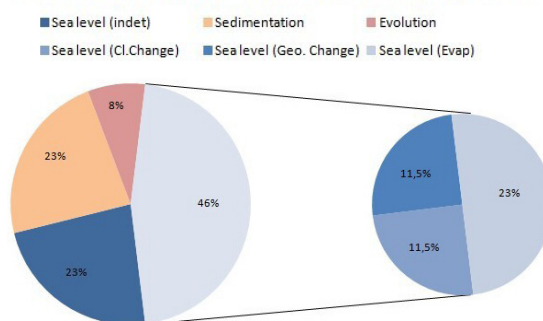


Figure 3. Relative frequency of proposed explanations for the observed stratigraphy

Among those who did not explain the formation of strata, 8% interpreted the faunistic succession in terms of evolutionary processes. Approximately 70% of teachers applied the principle of stratigraphic overlap, defining the lower strata as the oldest.

As for the arguing itself, we noted a startling similarity between teachers and students regarding the way they expressed their ideas and justified their answers (Martín et al., 2017). A generalized lack of argumentative competencies and the distinction between the concept of “explanation” and “description” was observed in both cases. There was a lack of explicit texts, no distinction of paragraphs, excess of lists and sentences without meaning.

## Conclusions

The fact that the participants ordered the cards equidistantly was observed in equal proportions among the groups of teachers in this workshop and groups of secondary school, which would indicate a lack of practice in quantitative plotting of data (Martín et al., 2017). Moreover, during the analysis of the findings, there were some non-grouped fossils in terms of chronological time; these facts generated significant conflicts in the analysis of most of the teachers. In terms of the outlier data point, none of the teachers managed to identify it, and much less had notions of how to deal with it, which could reveal a lack of notions about data processing and statistics.

The lack of cognitive-linguistic abilities reflected by this series of exercises, including the confusion between explanations and descriptions evidenced in 38% of the teachers, was considered alarming. On the other hand, it was evidenced that the participants had little knowledge of the causes

of past sea level change, such as climatic change and tectonic activity, or the relevance of these phenomena to plausible future scenarios for coastal dwelling human populations. In light of these results, we consider that the number and quality of teacher training courses related to the field of earth sciences in the region should be increased.

The proposed activity could be carried out in secondary schools. In Argentina, Buenos Aires City and the homonymous province follow different curricula; this proposal falls within the scope of the so-called Earth and Life History thematic line in the former district and the field of Earth Sciences (for secondary schools with orientation in Natural Sciences) in the latter. Furthermore, this proposal could be carried out elsewhere since it deals with current global climate change. While the activities were planned for a regional context, featuring maps of Argentina and local fossil faunas, they could easily be adapted to be more appropriate for other regions.

As for survey results, we highlight that the teachers were both entertained by and interested in the proposal, which they deemed pretty helpful. One of them mentioned that the issue of climate change could be a complex subject to deal with in

the classroom or be considered by students of little interest, but that when well presented, it could prove more engaging. Another teacher said that the proposal could help correct previous misconceptions. The highlighted features of the activity were the resources used (the use of cards), the teamwork dynamic, the didactic gameplay, the interaction, the participation, the linking of concepts, the interactivity, the use of data to frame hypotheses, and the use of guidance questions to build knowledge. Finally, the participants, who considered that the proposal could be applicable to the classroom and motivating for the students, requested the necessary didactic materials to carry out the activity in their workplace.

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