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Research Article

Metacognitive Regulation of Essentialism in the Teaching of Evolution

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ABSTRACT

Essentialism is a way of reasoning that implies assuming that the members of a group share an immutable essence, and that the variation among the members of the group is negligible. Although this way of reasoning is useful for people in their everyday lives, it may pose difficulties in the learning of scientific models, particularly those of evolutionary biology. Essentialism, understood as an epistemological obstacle, requires some didactic work encouraging the development of metacognitive vigilance, in other words, the awareness and regulation of this way of thinking. In this article, we will characterize the processes of metacognitive regulation of essentialism that took place during a didactic sequence to teach evolution. The sequence was implemented in a secondary school in Argentina with 80 students. We will present some of the possibilities and difficulties of carrying out metacognitive regulation of essentialism in biology classrooms. From the use of thematic analysis, we have found that students seem to regulate essentialism in an implicit way during discussions with their classmates, at both the individual and social levels. Moreover, in the case of evolution learning, we distinguished two types of specific regulations: the regulation of 'typologism' and that of 'noise'. In this sense, we consider that essentialism is not regulated as a whole, but instead through some of its assumptions. This work will allow further thinking about the possibilities of promoting the metacognitive regulation of epistemological obstacles in biology classes.

Keywords: essentialism, metacognition, epistemological obstacle, metacognitive vigilance, teaching of evolution

INTRODUCTION

Different researchers agree on how important it is for students to understand the basic models of evolutionary biology (Anderson et al., 2002; Harms & Reiss, 2019; Kampourakis, 2014). This consensus rests, among other issues, on the fact that evolutionary biology models can help people to understand and make decisions about their everyday lives, such as those regarding self-medication, biodiversity conservation, racism, etc. (Dennett, 1995; Futuyma, 2009; Stamos, 2008). Nevertheless, an extensive bibliography exposes the difficulties experienced by students to understand these models (Gregory, 2009; Nehm & Reilly, 2007; Smith, 2010; Thagard & Findlay, 2010). Among such difficulties are the misconceptions and, more specifically, certain ways of reasoning that influence the learning of evolution, such as teleology and essentialism (González Galli et al., 2020; Kampourakis, 2014; Ronfard et al., 2021; Rosengren et al., 2012; Wingert & Hale, 2021; Wingert et al., 2022). In the present work, we will deal with the latter, which is a way of reasoning that assumes the members of a group share an immutable essence, and that variations among them are insignificant. Moreover, the analysis derived from essentialist reasoning are focused on the individual level, and based on a prototypical individual. This type of analysis is problematic for understanding the population character of evolutionary processes as well as the importance of variability in them (Gelman & Legare, 2011; Gelman & Rhodes, 2012).

The theory of evolution by natural selection was originally proposed by Darwin (1859) and involves population thinking in the sense that the recognition of the existence and importance of inter-individual variability within the population constitutes one of the pillars of this theory. The uniqueness of each individual is central to Darwin's (1859) theory. In this regard, and of special importance for the subject of our work, Mayr (2004) has argued that population thinking is opposed to typological thinking (which is another way of calling essentialist thinking). This is also expressed in the notion of variational evolution as opposed to transformational evolution (Levins & Lewontin, 1985; Mayr, 1997), of which Lamarck's theory would be an example. According to Mayr

(1997), population thinking would be one of the most original and revolutionary aspects of Darwin's (1859) proposal.

Essentialism can be understood as an epistemological obstacle (Astolfi, 2002; Astolfi & Peterfalvi, 1997). Epistemological obstacles correspond to ways of reasoning that are functional for students in their everyday lives, but conflictive at the moment of understanding scientific models. In this theoretical framework, didactic work on epistemological obstacles would require students to develop 'metacognitive vigilance': in other words, to become aware of these ways of reasoning and be capable of regulating them when constructing scientific models at school. This approach has been tested in the case of teleology, and good results were obtained in the learning achieved by students (Wingert & Hale, 2021; Wingert et al., 2022).

The purpose of the present work is to characterize the processes of metacognitive regulation of essentialism that took place during a didactic sequence based on the development of 'metacognitive vigilance' over epistemological obstacles, in a public secondary school in Argentina. Knowing how students perform metacognitive regulations on essentialism will improve our understanding of the processes by which evolutionary models are constructed, and this, as we mentioned, is of great relevance for any citizen in daily decision-making.

First, we will introduce the theoretical framework in which the epistemological obstacles, as well as the didactic work based on them, will be defined. We will then focus on essentialism as one of the epistemological obstacles that influence evolutionary biology learning. We will also present the methodological aspects taken into account when this research work was conducted, followed by the analysis that allowed us to characterize the ways of regulating essentialism, as well as other evidence of regulation. Lastly, we will draw conclusions and discuss some implications for the teaching of biology.

THEORETICAL FRAMEWORK

Conceptions, Epistemological Obstacles, and Associated Didactic Strategies

The analysis of students' misconceptions has allowed researchers to identify a considerable number of ideas which are supported by people from different fields of knowledge and tend to persist despite education (Gregory, 2009; Smith, 2010; Thagard & Findlay, 2010). As the knowledge of these conceptions increased, a line of investigation was established to infer the ways of reasoning that underlie these ideas. French science education researchers (Astolfi, 1994, 2002; Peterfalvi, 1997) named these ways of reasoning 'epistemological obstacles', a notion originally proposed by the French philosopher Gaston Bachelard.

Returning to Astolfi's (1994) research, in previous works about the teaching of evolution (González Galli & Meinardi, 2017; González Galli et al., 2020) we have characterized epistemological obstacles as ways of reasoning which present the following traits:

1. **Transversality:** Obstacles have a certain degree of generality regarding the phenomena they allow to explain. This way, they underlie the conceptions belonging to different knowledge domains.
2. **Functionality:** Obstacles are ways of thinking that fulfill an explanatory function, as they generate a network of concepts with which people describe, explain, and predict the world they live in.
3. **Conflictivity:** Obstacles may hinder the knowledge and/or acceptance of the scientific model to be taught, as they explain the same phenomena as the scientific models of reference.

Epistemological obstacles have a certain degree of ambiguity, as they prove useful to think about some aspects of the world, but may in turn hinder the learning of scientific models. Therefore, contrary to what the term 'obstacle' suggests, its cognitive function is not purely negative, in accordance with cognitive psychology studies proposing that certain ways of reasoning are part of people's intuitive psychology (Inagaki & Hatano, 2006). In this line, an approach from the conceptual change models (Cho et al., 2011; Evans, 2008) may be useful to treat certain misconceptions; however, it would not be appropriate for the treatment of epistemological obstacles, as the possibility of eliminating or radically modifying these ways of reasoning is limited due to their usefulness in people's everyday life. For this reason, a possible way of addressing epistemological obstacles in the science classroom will require that students consciously reflect on them, what is called 'metacognitive vigilance' (Astolfi & Peterfalvi, 1997; González Galli et al., 2020.; Peterfalvi, 1997; Wingert et al., 2022).

This proposal is framed within the constructivist perspective of learning (Driver & Oldham, 1986; Duity Odlham, 1998), according to which learning is the result of a constructive process performed by the subject, and implies that the subject relates new information and ideas to those that were already present in his or her cognitive structure. In this process, both the previous cognitive structure and the new notions incorporated are modified, so that the final result is to some extent idiosyncratic to each individual. Thus, for constructivism, the conceptions that are already present significantly condition the learning process. For this reason, learning a theory, especially when the theory in question is counter-intuitive (as is the case with scientific theories), involves becoming aware of previous conceptions related to the subject under study and, in certain cases, abandoning them. However, when it is not possible or desirable to eliminate such prior conceptions, it is necessary for the subject to develop a high degree of conscious regulation over them. It is in this framework that the 'metacognitive vigilance' of which we speak occupies a central role in the learning of the theory of evolution.

This 'vigilance' relates to two dimensions of metacognition: metacognitive knowledge and metacognitive regulation (Anderson & Nashon, 2006; Avargil et al., 2018; Schraw & Gutierrez, 2015; Zohar & Barzilai, 2013). On the one hand, students are expected to develop metacognitive knowledge about epistemological obstacles, which implies acknowledging their existence, being aware of these thinking frameworks when constructing or applying a scientific model, and understanding that these obstacles may appear in different situations. On the other hand, students are also expected to become capable of regulating epistemological obstacles during the construction or use of the scientific model of interest, through processes such as planning, monitoring, and assessment of their own work.

The aim of this proposal is not that students abandon such ways of reasoning, but rather that they can consciously regulate them. One possible way to regulate would correspond to the inhibition of intuitive reasoning when learning or using the scientific model (Ronfard et al., 2021). In addition, this regulation would imply that students use the scientific model as a tool to assess in which cases the expressions based on epistemological obstacles are acceptable (for further reading on the foundations of this proposal, see González Galli et al., 2020).

It should be noted that, although metacognitive processes were traditionally understood as individual processes, in recent years a large amount of research has suggested the existence of social metacognitive processes. These investigations refer to interpersonal regulatory processes, in which students can regulate their peers' actions (Iiskala et al., 2011; Saab, 2012; Volet et al., 2009). This way of conceiving regulations is appropriate to analyze the social and collaborative processes that take place in science classes.

Essentialism as an Epistemological Obstacle, and Its Relationship with the Models of Evolutionary Biology

Different investigations have shown that people reason in an essentialist manner (Atran et al., 2001; Gelman & Legare, 2011; Waxman et al., 2007). No consensus has been reached on what this way of reasoning implies, but in order to consider the difficulties that students face when learning evolutionary models, the characterization made by researchers Susan Gelman and Rhodes (2012) is useful. For these authors, essentialist reasoning encompasses five assumptions, each of which would hinder the understanding and/or acceptance of a particular aspect of evolutionary models.

The first of these assumptions implies that the categories people construct are based on the idea of a stable, immutable essence. Although members of the same category may change in appearance, this variation is superficial, since the underlying essence remains intact. The immutability of a category is incompatible with the evolutionary theory, given that evolutionism is based on the idea that species change across generations. While it is true that many adults can accept that species change, they often understand that such change conserves something important, essential, which remains immutable. In this sense, the essentialist bias can be compatible with a notion of evolutionary change which is limited, teleological, and progressive (González Galli & Meinardi, 2017; González Galli et al., 2020; Kampourakis, 2014).

The second assumption these authors mention is connected with the idea of intensified limits. It is often assumed that the boundaries between categories are strict and impervious. In evolutionary biology, this postulate does not allow us to understand categories as constructions (for example, that there are different concepts of species) or the possibility of intermediate categories. In addition, conceiving strict limits prevents students from thinking in terms of continuous variation, and therefore from understanding that one species can give rise to another (Gelman & Rhodes, 2012).

The third assumption involves the notions of variability as noise. Categories are homogeneously represented in terms of a prototypical structure. Thinking that a category is based on an ideal 'type' is contrary to thinking in terms of a population, which is one of the foundations of the evolutionary theory. Moreover, ignoring variability in the comprehension of evolution poses two problems: firstly, because variability is necessary for evolution to occur, and secondly, because an essentialist perspective may accept variability, but tend to consider it superficial compared to the underlying immutable essence.

The fourth assumption mentioned by the authors postulates there is something internal (substance, part, quality) which causes individuals to have their particular traits and behavior. This 'essence' is what all the members of the category have in common, and it works as an individual causal force. This is problematic for the comprehension of evolution, as the analysis of causes is performed at the individual–and not the populational–level. When the individual is the unit of analysis, change is assumed as an individual process rather than a populational one, and alludes to individual effort or necessity rather than to the selection pressures affecting the population.

Finally, the fifth assumption is associated with the platonic notion of idea. The essence is regarded as an ideal which is impossible to achieve in the real world. According to the authors, this postulate underlies the idea of progressive evolution, of improvement towards a possible ideal that is never achieved (Gelman & Rhodes, 2012).

Given the ambiguous nature of epistemological obstacles, it is worth considering that although essentialist reasoning hampers the understanding of evolutionary models, different authors mention its various advantages (Gelman et al., 1994; Pinker, 2002; Wilkins, 2013). For instance, essentialist reasoning could be at the root of our capacity to classify and make inferences on these categories. This way, when we are talked about something we may have already categorized, this categorization ability reduces the amount of information we need to process in order to reply. Without categories, nothing could be generalized or learned, any experience would be new and unpredictable. Without classifications, we would be incapable of distinguishing edible objects from toxic ones, friends from enemies, dangerous situations from harmless ones, etc.

Moreover, essentialist reasoning appears in multiple cultures and social contexts. What dramatically varies among them and through time is the intuition about what the essence is. Studies about this issue have been conducted in different cultures (Atran et al., 2006; Waxman et al., 2007).

Furthermore, essentialism is a study topic in different knowledge domains. This way of reasoning seems to be a general form of thought, which transcends domains. For example, essentialization can also be found in social categories (social class, race, gender, and even 'human nature'). Individuals tend to consider belonging to a social category as the reflection of a unique, real identity. In these cases, the immutability of the category as well as the inheritability of the essence also hold (Dar-Nimrod & Heine, 2011; Del Río & Strasser, 2007; Hirschfeld, 1994; Pinker, 2002).

Within the area of science teaching, essentialist reasoning is related to different disciplines such as biology (Coley & Tanner, 2012; Donovan & Nehm, 2020; Emmons & Kelemen, 2015) and chemistry (Talanquer, 2006). In biology we can find essentialist expressions not only in common sense evolutionary explanations but also in other areas such as ecology ("if left alone, a wetland ecosystem will remain a wetland indefinitely") or molecular biology ("because different cells in an organism have different morphological characteristics, they must contain different DNA", "changing a single gene in an organism results in a new kind of organism") (Coley & Tanner, 2012).

For the above-mentioned reasons, we can characterize essentialism as an epistemological obstacle (due to its functionality, transversality, and conflictivity), and therefore expect to encourage the students' metacognitive vigilance over it. However, investigations on the didactic treatment of essentialism in the learning of evolutionary models are mainly restricted to the characterization of the misconceptions students derive from an essentialist framework (González Galli et al., 2018; Samarapungavan & Wiers, 1997; Shtulman & Schulz, 2008; Stern et al., 2018). These authors point out that students (of different ages) provide essentialist explanations with a high degree of coherence. Only a few articles propose a didactic treatment of essentialism in classroom contexts (see, for example, Donovan & Nehm, 2020). In contrast, research has been conducted, within the theoretical framework we adopted, for another epistemological obstacle such as teleology (González Galli, 2011; González Galli et al., 2020).

METHODS

Research Design

The purpose of this work is to characterize the processes of metacognitive regulation of essentialism that took place during a didactic sequence based on the development of 'metacognitive vigilance' in a public school in the city of Buenos Aires, Argentina.

To achieve this objective, a qualitative-interpretative research design was adopted (Creswell, 2012). In particular, we have employed thematic analysis (Braun & Clarke, 2006, 2013; Neuendorf, 2019) with the purpose of systematically organizing the data set, by identifying meaning patterns. This way, the aims of this work were achieved through the construction of categories. In this type of design, it is necessary to bear in mind that contexts, such as the classroom, are in constant social, cultural and historical transformation. For this reason, we do not mean to extrapolate the constructed categories to other contexts. This implies that it is not the intention of this work to 'discover universal laws' that regulate the teaching of evolutionary biology. However, it is not merely intended to understand a particular and unique situation. From this perspective, we aim to compare–and not directly extrapolate–results, so they serve as a useful guide for research in other groups (Creswell, 2012; Flick, 2018).

Participants

In Argentina, the educational system involves twelve years of compulsory schooling, where the last five correspond to the level of secondary education. In particular, this work was carried out with students in level 3 (upper secondary education) according to the International Standard Classification of Education (ISCED).

Eighty students between fourteen and sixteen years old who attend a public school in the city of Buenos Aires, Argentina, participated in this study. They were recruited through convenience sampling. In previous biology classes, the students had worked on notions of cell biology, nutrition and genetics (e.g., Mendel's laws), among other topics. We worked with three different class groups from the same year, which contained between twenty-three and twenty-nine students.

The students and their families provided informed consent two months before the onset of research in the classroom. The importance of research in didactics in actual schools was made explicit in that consent, which also explained the study would be part of the PhD thesis of the first author of this article.

Data Collection

Two data collection instruments were employed, as follows:

1. a didactic sequence designed to develop metacognitive vigilance and oriented to the construction of two models: the model of evolution through natural selection and the model of allopatric speciation and
2. a semi-structured interview after the implementation of the didactic sequence, which allowed to collect the meanings students gave to the processes of metacognitive regulation.

The goal of the implemented didactic sequence was for the students to build two basic models of evolutionary biology, as well as to develop metacognitive vigilance on two epistemological obstacles: teleology and essentialism. The proposal was built based on a modeling approach (Clement & Rea-Ramirez, 2008; Passmore et al., 2014), from the perspective of semantic epistemology (Giere, 1999, 2004), and emphasizing the development of metacognition, particularly metacognitive vigilance on the aforementioned epistemological obstacles. The overall duration of the didactic sequence was three months and two weeks, and the instructor for these lessons was the first author of the paper. The didactic proposal consisted of 21 activities which are synthesized in **Table 1**.

It is worth mentioning that the present work will focus on the activities aimed at encouraging metacognitive vigilance over essentialism. The complete foundations of the didactic sequence can be read in Pérez et al. (2018).

Different activities were planned and performed in order to promote the regulation of essentialism. In the first stage of the didactic sequence, the idea of variability within the population was constructed from the discussion of audiovisual material (activity 4) as well as from the analogy between natural and

Table 4. Activities

No	Description of the activity	Goals (according to the students' role)
1	Explanation of a case about the evolution of arctic wolves.	Explicitly state their starting models on change in populations over time.
2	Introduction to the lessons using a video about different populations of wolves.	Know the question to be answered throughout the lessons as well as the learning goals. Explicitly pose their questions about evolution and state their feelings about learning this topic.
3	Analysis of advertisements containing the word 'evolution'.	Explicitly state their conceptions about the meanings of the word 'evolution' in everyday life.
4	Construction of the concepts of variability and inheritability from a video about a population of wolves.	Acknowledge the existence of inter-individual variability among the organisms that comprise a population. Understand that some traits are inheritable.
5	Construction of the relationship between the environment and the survival of wolves based on the resolution of a problem about food availability.	Understand that the environment includes factors that limit the survival and breeding of organisms.
6 †	Construction of the concept of differential reproduction by working with images.	Understand that the probability of breeding and surviving in a certain environment depends on the interaction between the characteristics of the individual and those of the environment.
7 †	Assessment of the analogy between artificial selection and natural selection.	Construct a first approach to the model of natural selection.
8	Metacognitive reflection based on the revision of answers to activity 1.	Reflect metacognitively on the finalist conceptions that appear in their initial expressions.
9	Elaboration of a guide for a Darwinian explanation.	Agree on the criteria for a good Darwinian explanation, which will be taken as a reference for the rest of the lessons.
10	Part A: Construction of a first approach to the model of allopatric speciation	Understand that populations that are reproductively isolated by a physical barrier follow divergent evolutionary paths until they eventually become different species.
	Part B: Explicit discussion about the functional and conflictive nature of essentialism from the reading of a text by Jorge Luis Borges.	Understand the biological definition of species, its significance and limitations. Reflect metacognitively on essentialism in an explicit way.
11 †	Explicit discussion about the transversal character of essentialism in popular phrases (sexist, racist).	Reflect metacognitively on the essentialist obstacle.
12	Creation of cards with learning strategies.	Reflect metacognitively on the learning strategies.
13	Analysis of their own difficulties in the application of evolution models to concrete cases.	Apply the constructed methods to two particular cases and reflect metacognitively on the difficulties in their application.
14 †	Application of the constructed models to the resolution of concrete cases.	Apply the constructed models to particular cases.
15	Peer assessment of conceptual maps made by students.	Assess their peers' conceptual maps.
16 †	Analysis of the representations of evolutionary trees.	Understand the representation of evolutionary trees in biology. Reflect metacognitively on the idea of progress.
17	Creation of a card for the analogy-based learning strategy.	Reflect in a metacognitive manner on the use of analogies as a learning strategy.
18	Application of the constructed models to different increasingly-complex situations.	Apply the constructed models to the resolution of different problematic situations. Reflect metacognitively on other epistemological obstacles not explicitly addressed in the sequence.
19	Metacognitive reflection based on the revision of answers to activity 3.	Reflect metacognitively on their knowledge in relation to evolution and apply it to the critical assessment of images and advertisements.
20	Metacognitive reflection on the learning process.	Reflect metacognitively on their own learning process throughout the entire sequence.
21	Resolution of cases based on the constructed models.	Explicitly state their models on evolutionary phenomena.

artificial selection (activity 7). The latter activity represented a first approach towards the model of evolution through natural selection. Essentialism was addressed in an explicit manner in activities 10 and 11. Its functionality was discussed from the reading of the short story *'Funes, el memorioso'* by Borges (1944), where the usefulness of essentialism was examined in terms of the classifications we perform in everyday life. The transversal character of essentialism was then considered by analyzing popular phrases. Finally, the conflictivity of this way of reasoning with evolutionary biology was addressed, going back to the ideas previously presented. Moreover, a consensus was sought with the class-group over a label to refer to this epistemological obstacle. This term was expressed in a poster, which was hung up in the classroom to facilitate reference to this way of reasoning during the rest of the work in class.

Throughout the lessons, a collaborative activity named 'regulatory activity' was carried out in different moments of the didactic sequence (marked with † in **Table 1**), with the aim of creating a space where students could examine the notions constructed up to that moment, as well as their initial ideas regarding the evolution of arctic wolves (activity 1).

Overall, there were written records for each student of ten individual activities (including the pre-instructional and post-instructional activities), two activities in pairs, and six group activities (one for each regulatory activity). The latter involved the audio-recording of three teams per group-class for approximately eighteen hours.

Lastly, fourteen randomly-chosen individuals were interviewed with a semi-structured protocol, which lasted approximately twenty minutes. These interviews were based on a question guide that aimed at deepening the students' reflections on what had happened during the didactic sequence, understanding the emotions that were put into play and inquiring about the meanings they gave to the metacognitive regulation of the epistemological obstacles. The script of questions was elaborated based on information obtained during the sequence, and of which we sought to deepen our understanding. For example, in the interview, each student was asked to look back at the conceptual schemes built in the regulatory activity and inquired about what they learned with them, the difficulties they had, ways of regulating their thinking, among others.

Data Analysis

As previously mentioned, in the present work categories were constructed by using thematic analysis (Braun & Clarke, 2006, 2013; Neuendorf, 2019). Next, we will characterize the different phases of the analysis.

The first phase involved the generation of codes. Codification is a task that implies classifying the information registered during fieldwork, so as to structure data analysis. Through codification, every unit of transcribed text, as well as every drawing made by students, were assigned a code that allowed to summarize the information collected in the register. We used a combination of coding strategies using a priori codes based on the theoretical framework of the research, and open coding based on an inductive process. This initial list of codes was refined as different types of data were codified, by adding, suppressing, or redefining such codes. In a first stage, the definition of each code was close to the empirical material and, in some cases, arose from the meanings given by students. However, codes were also related to the theoretical frameworks and the research questions.

The second phase involved categorization. This process consisted in the identification of similarities among codes, by collapsing or creating code clusters that described a pattern in the data. These patterns, themes, or categories contain a meaning, such as, in our case, categories related to metacognitive regulation. In the construction of such categories, the theoretical framework served to orientate fieldwork, only in terms of general concepts. This way of conceiving theory allowed for the gradual rise of questions and concepts from categories close to the empirical material to a high level of abstraction. The passage from the categories more closely related to the empirical data to the more abstract ones was possible because the construction involved a spiraling movement – from the empirical material to theory and vice versa. Since the list of codes is very extensive, only the constructed categories or themes will appear in the analysis.

The third and last phase corresponded to the revision and validation of the categorization. This phase served to assess the quality of categories and refine them. Categories were regrouped, divided, added, or discarded, and it was in this process that researcher triangulation and data triangulation occurred (Flick, 2018). Three independent researchers, who reviewed the collected data and the constructed categories, participated in this triangulation. Based on this process, some pre-assembled categories in which there was no agreement among the three researchers were discarded.

FINDINGS

In this section, we will present some of the findings of our research on essentialism regulation. We will only provide some empirical examples not to exceed the length of the manuscript; however, many other examples can be found in Pérez (2021). To understand regulatory processes, we will first introduce the students' essentialist explanations in the pre-instructional activity. We will continue to focus on two modes of regulation of essentialism that were performed by the students during the didactic sequence. Each mode of regulation is understood as a category that was constructed from the methods described before. We will define these categories and illustrate them with some examples. Subsequently, taking the two categories defined before into consideration, we will describe the analysis performed of the explanations constructed by the students in the post-instructional activity. Next, we will present two categories that emerged from the interviews and serve as further evidence that allows us to infer the processes of essentialism regulation performed by the students.

Essentialist Answers in the Pre-Instructional Activity

In previous works (Pérez, 2021; Pérez et al. 2021), we analyzed these first responses and found that students conceive of evolution as a change that pursues a purpose, generally related to survival, and appeal to intentionality. Furthermore, students are often deterministic in their explanations, as they assume that the type of trait an organism have determines its fate. For example, white fur wolves will survive while dark fur wolves will die.

In this work, we will focus on those productions that we interpreted as expressions of essentialism, which appeared during the pre-instructional activity. Following are some examples:

> "From the beginning, I think that with time they may change pretty much, but there will be some important trait that doesn't change" (Julia).

> "I believe that for them to stop being wolves what should happen is that they should be tamed. Perhaps the physical traits shouldn't change, as should instinct and wild personality" (Natalia).

Julia indicates that although wolves may change, some important traits will not be modified. We interpret that this important trait which is conserved would correspond to the immutable essence. In other words, a wolf will never cease to

Figure 1. Clara's drawing representing the evolution of arctic wolves in the pre-instructional activity. English translation from left to right: They're wolves. The wolf's fur evolved through time

Table 2. Examples of activity 9

Highlighted phrase	Correction
'The wolves' ancestors were all sparsely furred'	They are not all equal. They are all different. (Aldana)
'Nowadays all the wolves in that region have thick fur'	Not all have thick fur but surely those with thicker fur can survive (Daniel)

be a wolf even if those traits which are '*important*' for the student change. Turning to Natalia, although she assumes a change may occur, she indicates that for them to stop being wolves some traits should change: not the physical ones, which are superficial, but those which are somewhat more profound, like *'instinct and wild personality'*. In this case, we can infer that physical traits would be no more than negligible 'noise' (as indicated by Gelman & Rhodes (2012) in the third assumption about the essentialist reasoning they propose), and that the last characteristics mentioned by the student are the expression of an underlying essence in wolves.

Finally, we deem Clara's drawing (**Figure 1**) representing the evolution of arctic wolves as an expression of essentialism, as it explains populational change from a 'prototypical' wolf, this is, the change in the species or population is represented by a single individual, ignoring the variability that could exist within that population. According to Gelman and Rhodes (2012), reasoning in essentialist terms produces 'type'-based explanations, that is, individual-level explanations which are contrary to the populational-level explanations characteristic of evolutionary models, in which intra-populational variability is of great importance.

Two Modes of Regulation of Essentialist Thinking That Emerged During the Didactic Sequence: Regulation of 'Typologism' and Regulation of 'Noise'

To promote the regulation of essentialism, different activities (mentioned before) were planned and carried out. To begin, we will present what happened during activity 9, in which students were asked to correct the explanation given by a fictional student about the evolution of the arctic wolves' fur. The explanation was as follows:

> "The wolves' ancestors were all sparsely furred. Due to the cold weather, all of the wolves grew thicker fur. They improved in order to survive to the cold weather. Nowadays, all the wolves in that region have thick fur and those wolves with sparse fur could not survive and died."

Students undertook the correction task by highlighting phrases and then rewriting them. **Table 2** shows two examples.

With regards to the phrase written by the fictional student, Aldana points out that the wolves in the population *'are not all equal'*. In this case, her correction alludes to populational variability, but fails to connect it with its importance in the process of natural selection.

On the other hand, regarding another phrase by the fictional student, Daniel remarks that *'not all have thick fur'*. This type of remarks can be considered a call for attention about essentialism, of an implicit type since it is not being referred to as a way of reasoning. In his alternative explanation, the student mentions that those wolves with thicker fur will be able to survive. Unlike Aldana, we infer that Daniel does associate the idea of variability with differential reproduction. These first cases let us realize how students construct certain remarks (such as 'not all are equal') which will be useful for the posterior development of metacognitive regulation.

To advance in the analysis of essentialism regulation, we will present a discussion students maintained during the construction of a collaborative explanation after activity 11, where essentialist thinking had been explicitly addressed. Unlike the previous case, in which students had to analyze an explanation constructed by others, here they had to agree on a collective explanation for the example of the wolves. The transcribed discussion took place during one of the regulatory activities (group-class 2°3°-team 3-regulatory activity 3).

> Liliana: How could you explain that today's wolves have white fur if their ancestors didn't have white fur?
>
> Alexis: You tell me and I'll draw.
>
> Liliana: They mate with another species of wolf. Well, we should draw it. Let's see…
>
> Miguel: A white wolf and a black wolf. Of any color.
>
> […]

Liliana: Well… Ehm… What were the little wolves I once made like?

Alexis: There was one with long legs, another one with short legs. Another one with long legs. Another one with medium-length legs. Because we need to draw many of them, make the differences show.

Emma: Now, very long legs. Very. [She indicates to Alexis, who is the one that is drawing].

Liliana: And now this one, very tiny. Tiny. Tiny. Tiny. But… [Laughter] Well, now on this side. We need to find (a) brown (pencil), guys. Now, this wolf has one foot that's long and another one that isn't.

Miguel: That one came out … Deformed.

Alexis: Ears change as well.

Miguel: One with long legs.

Liliana: Very bow-legged. We make them all brown, right? Or any of them black?

Miguel: One of lighter color.

From the rubric, students start discussing the construction of the drawing they have to make. Alexis suggests drawing differences among the individuals, indicating that '*we need to draw many of them, make the differences show*'. The student's suggestion does not implicitly relate variability to differential reproduction, at least for the moment. The same occurs in the rest of the discussion, where the students talk about populational variability but not the advantages and disadvantages of each of the variants in that particular environment, or how this influences the change in proportions over time. In this line, the differences they discuss refer to any trait, but color, which is the main feature to explain in this problem, only appears at the end. In our view, this indicates students are attentive to variability in general terms, but fail to relate it to this particular problem. It would be possible to think that being attentive to variability is a consequence of regulating essentialism, in particular the notion of an ideal "type" (Gelman & Rhodes, 2012).

In the following transcript (class-group 2°3°-team 3-regulatory activity 3), which shows what happened a few minutes after the previous one, the discussion on the importance of variability in the construction of an explanation based on the natural selection model becomes explicit when the teacher takes part in it.

Liliana: I'm drawing bow-legged wolves as well.

Alexis: Fine. So the difference shows. Make it show that they're all different.

Liliana: Anyway, we draw like there's only one [at the beginning]… And then more. How come by chance they all mutate? It doesn't make sense […] Yes. Like this one had offspring. Because if it's a mutation, they're all not going to change at once. So…

Teacher: Why are there more white wolves than brown ones [at the bottom of the drawing]?

Alexis: Because of the environment they live in.

Emma: And because years have passed.

Liliana: Maybe because of the offspring… Or some other mutation, which through the generations could happen…

Teacher: There are three things you're saying: because of the environment, because there was a mutation or because years have passed.

Alexis: And the mutation. Now, Liliana, you have to decide.

Emma: Because of the offspring, Liliana said.

Teacher: Because of the offspring. Fine. And why are there more white cubs than brown ones?

[…]

Liliana: But, maybe, it depends on the environment, where they lived the white ones had a higher chance to survive than the brown ones…

At the beginning of this transcript, students still discuss inter-individual differences. Alexis insists that differences should be made evident. We infer that this points out at essentialism in an implicit way, without directly alluding to the epistemological obstacle. We will delve further into this later.

When comparing the initial and the final populations, Liliana believes it does not make sense to think that all the individuals mutated. However, her classmates do not offer any alternative explanations. The teacher approaches the group and asks for an oral explanation about the change in the wolves' fur over time. The students select three elements to explain it: time (Emma), the environment (Alexis), and differential survival (Liliana). While for Liliana the concept of variability finds another dimension in relation to its importance for the selection process, in the other explanations there may not be any variability and therefore the explanation could still be sustained. We consider that in the case of Emma and Alexis, these students still regard variability as 'noise', or as a detail they should bear in mind because they have been working with it, but not to construct an explanation about the evolution of wolves. This leads us to believe that these students are in a transition process regarding the concept of variability and its relevance for selection.

The concept of mutation as a source of variability also emerges from this discussion. Although this is an important concept, the explanation constructed by the students (except from Liliana) holds at the individual level. In the drawing made by the group (**Figure 2**), the following two types of explanation also appear as alternatives: on the one hand, the mutation-based explanation (at the individual level) and, on the other hand, an explanation according to which white wolves have a

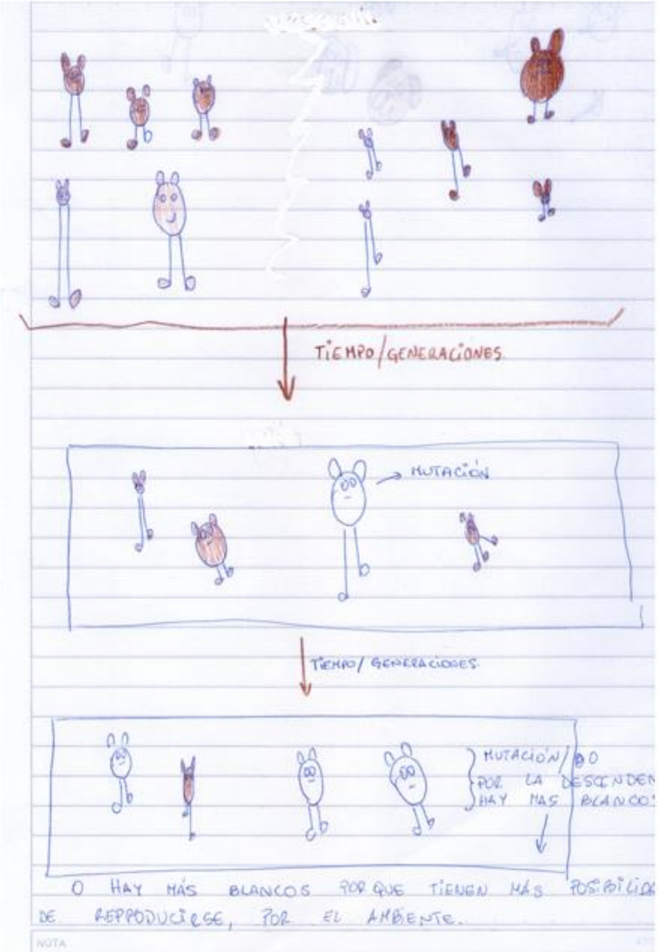

Figure 2. Drawing made by the students during the regulatory activity to explain the change in wolves through time. English translation from top to bottom: Time/generations. Mutation. Time/generations. Mutation or because of the offspring there are more white ones. Or there are more white ones because they have more possibilities of reproducing, due to the environment

higher chance to breed; in other words, an explanation of populational change.

Based on the previous examples (and other examples that can be found in Pérez, 2021), we constructed two categories that allow us to think about the regulations of essentialism performed by the students. These regulations correspond to two different assumptions of essentialism:

1. **Regulation of ‘typologism’:** Here students point out the necessity of thinking in terms of inter-individual variability within the population. However, in the alternative explanations they construct, this variability does not relate to differential reproduction, or to the change in proportions of the variants through time. The alternative explanation remains at the individual level of organization. In this case, it is the assumption of prototypical structure that would be undergoing regulation.
2. **Regulation of ‘noise’:** Here students, apart from indicating the necessity of thinking in the population, construct alternative explanations in which variants are the raw material for selection. This is to say, in which variants are connected to differential reproduction. In this case, it is the assumption of variability as ‘noise’ that would be undergoing regulation.

We believe the regulation of ‘typologism’ is less complex than that of ‘noise’, as the alternative explanations constructed for the latter require more elements from the natural selection model. For instance, such explanations allude to the fact that organisms belonging to the same population differ among them, but also include the issue of differential reproduction. In this sense, the regulation of ‘noise’ is more powerful in terms of metacognitive vigilance development.

The regulations we presented could be described as implicit in the sense that students make remarks that directly refer to essentialism, but not in an explicit way. We consider that awareness of essentialist reasoning was achieved in these cases, as such remarks correspond to this epistemological obstacle that has been a focus of attention at different moments of the didactic sequence. In this sense, these statements would not just be random expressions, but would rather account for a regulation of essentialism. Later on, we will provide further evidence in support of this interpretation.

Regulations of Essentialism in the Post-Instructional Activity

Taking into account the two categories constructed with regards to the ways of regulating essentialism in the previous section, we will present examples from the post-instructional activity. In this task, students were asked to construct explanations for evolutionary change which resulted in an increased length in the cheetahs’ legs over time, and also for complex cases such as the evolution of burn pain in human beings from an ancestral condition of low sensitivity to intense heat. Although we understand the last example may result strange in the light of the theory (as the pain reaction is probably older), it arose from an inquiry made by the students, which we adjusted to potentiate the work. The first example corresponds to an explanation about the evolution of pain and the other two, to the evolutionary change in cheetahs.

> “Pain as a defense mechanism didn’t always exist. Before you would get burned to a greater extent because you didn’t realize it. Until one individual began to feel pain when he got burned (not intentionally, but it was still considered an advantageous trait). Until today, when by natural selection all of us, or almost all of us, have a not-so-high tolerance to pain” (Carla).

> “The ancestors of the cheetahs were different among themselves, there were some with short legs, others with a lighter color coat, etc. The vast majority had short legs, but because of a random mutation, a cheetah was born with longer legs, this cheetah was faster and more resistant than the others, because of having an advantageous trait the long-legged cheetah could reproduce more than the cheetahs with short legs, and as generations and years passed, the population changed so that now there are more cheetahs with long

> legs (not all of them). This trait gives them an advantage to survive" (Natalia).
>
> "In a population a random mutation appeared in a living being, in this case, a cheetah, which had longer legs than the others, therefore allowing it to hunt and escape from other animals. This one had an advantageous trait, therefore it could reproduce more than those which didn't have that characteristic. Over time it reproduced until it formed a population with this advantageous trait, without all being the same, of course" (Simón).

In the first example, Carla points to the fact that one of the individuals was different from the rest, thus using the idea of inter-individual variability, and in turn is attentive to the essentialist obstacle when at the end she indicates *"until today, when by natural selection all of us, or almost all of us, have a not-so-high tolerance to pain."* We infer that the phrase 'almost all of us' accounts for an idea of variability underlying her explanation. In this explanation, the regulation is that of 'typologism', since the variability mentioned by the student is not associated to its importance in terms of differential reproduction. This way, Carla explains the change in the population from an individual change ("*until one individual began to feel pain when he got burned*").

In the second example, Natalia deals with essentialism in an implicit way. She indicates the change in the population implied that '*the population changed so that now there are more cheetahs with long legs'* and adds '*not all of them*', as a typical remark that implicitly points to essentialism. We infer that Simón does the same thing when he points out, at the end of his explanation, '*without them being all equal, of course'*. Unlike Carla's explanation, in the latter two cases the constructed explanations use the idea of inter-individual variability as an important element in the selection of individuals, and mention these variants in relation to differential reproduction, for which we consider them a regulation of 'noise'.

With these examples taken from the post-instructional activity, we intend to demonstrate that the different students managed to construct different ways of regulating essentialism. As we have mentioned, the regulation of 'noise' is more complex than that of 'typologism', so with students like Carla it will be necessary to continue working towards making their ways of regulating more complex.

Since all the regulations mentioned so far are of an implicit type, the question arises as to what extent students could effectively be regulating certain aspects of essentialism. To further delve into this question, next we will present the perceptions that the students made explicit during the interview, concerning the process of regulating epistemological obstacles.

Categories Constructed Based on the Interviews: Awareness of the Epistemological Obstacles and Their Regulation

In this section, we will analyze some patterns that emerged in the interviews, which will serve as further evidence allowing us to infer the regulation of essentialism performed by the students. We will present two categories and illustrate them with examples.

Metacognitive knowledge over epistemological obstacles

This category includes all the verbalizations about the students' conscious knowledge regarding their own or other people's ways of thinking, understood as epistemological obstacles. Such knowledge was constructed throughout the didactic sequence. Following is an example from Liliana's interview:

> Researcher: As we worked, we named some ways of thinking that we all have. 'Necessity thinking', 'Generalization thinking'. Do you think it was important to do so: putting those names and hanging up the poster in the classroom? Or not? Why?
>
> Liliana: It did help me. But, for example, my group sometimes asked what it meant. They didn't remember.
>
> Researcher: Well, and why did it help you?
>
> Liliana: Well, because sometimes I wanted... At the beginning I wanted to write something and it was misinterpreted, so it seemed something of 'necessity'. So every time I wrote a phrase I always made sure the opposite wasn't understood.
>
> Researcher: So you tell me it was useful for your individual work, and in the group work, was it of any help?
>
> Liliana: Yes. Because as we wrote sometimes I said something, and they either corrected me or we would always make one another remember.

In the interview, students were asked to reflect upon the activities performed. In the previous example, Liliana mentions that working on epistemological obstacles from labels in posters helped her with her work. She is not only able to mention the obstacles but also to think about them (for example, 'necessity thinking' refers to teleology). In particular, we consider that Liliana is aware of the obstacles when she points out that *'every time I wrote a phrase I always made sure the opposite wasn't understood'*. In turn, this usefulness is not only observed at the level of her own regulations, but was also part of teamwork as a way of social regulation.

It is worth mentioning that a trait of this metacognitive knowledge the students elaborate is that the obstacles are understood as mistakes to avoid in the learning process and that as such, it is important to be aware of them. This situation is far from the spirit of the theoretical frame, according to which obstacles do not represent an intrinsically negative aspect of cognition, this being the reason why metacognitive vigilance consists in regulating rather than eliminating such ways of reasoning. We will analyze this issue further.

Awareness of the regulation of epistemological obstacles

This category includes all those verbalizations in which students demonstrate they consciously regulate epistemological obstacles in various ways during the construction of individual and group explanations. Following is the transcription of an excerpt from Natalia's interview:

> Researcher: Were those posters helpful to you when you did the activities?
>
> Natalia: Yes, they were very helpful.
>
> Researcher: Why?
>
> Natalia: Because I was writing, then all of a sudden looked up, and if I got stuck I looked at the poster and say 'Oh! What I'm doing is wrong' or 'I'm making a mistake here' and it helped me to see where I was wrong specifically.
>
> Researcher: And in the group activities, were they helpful?
>
> Natalia: Yes, when we discussed them. Maybe one of us got lost and started talking, started thinking in the individual and it was like, 'No! You're thinking in the individual, we have to think in the community'.

In her interview, Natalia states that posters, where the labels previously agreed upon by the class-group could be found, were useful to regulate the obstacle. On the one hand, during the construction of the explanations, the poster would work as an alert, which made the student re-examine her explanation. In this sense, the poster allowed the student to identify which way of thinking she did not have to resort to in her explanation, and from there to search which way of reasoning she did have to employ. We consider this situation could be understood by using the concept of 'recovery paths' by Salomon (1993). The author proposes that, if we understand the classroom as a distributed cognition system, a certain element within the classroom could help stimulate, incite, guide or reorientate thinking in another way. In this case, we believe that posters work as this element that helps them recall that *'they shouldn't think that way'*. In our view, this situation recaps what was worked on in different instances of the didactic sequence, assuming the obstacle as a mistake to avoid. As mentioned before, in the Discussion we will analyze this issue further.

Natalia is also aware of the fact that during the group tasks proposed in the sequence there were moments when regulation was made based on what a fellow student thought. In other words, she is conscious that regulation was not reduced to her own regulation, but that others could also be regulated. This is an interesting point for us, since the student realizes that learning to reflect on her own ways of thinking can also be useful to identify them in other students.

DISCUSSION

In the first explanations provided by students we detected some expressions of essentialism, regarding not only the assumption of the immutable essence, but also the analyses carried out at the prototypical individual level. During the didactic sequence, the students performed different processes of metacognitive regulation of essentialism that have different features. On the one hand, the regulations observed can be characterized as implicit. In this type of regulation, students make some kind of remarks that we can interpret as an implicit reference to essentialism. These clarifications serve as a way of pointing out the epistemological obstacle. These remarks appear constantly in the class discourse.

On the other hand, we found that the regulation of essentialism can be made at two levels: individual and social. For example, the group discussion transcripts that we presented show regulation of a social type, in which students regulate essentialism during the collaborative construction of the drawing, by appealing to the importance of depicting variability in the representation. However, in the examples from the post-instructional activity the regulation is of an individual type, in the sense that it is exerted on the students' own explanations. Given that most of the traditional research on metacognition only emphasized its individual aspects, we believe it is of great importance to value the framework of social metacognition (Iiskala et al., 2011; Saab, 2012) as it allows us to focus on another type of processes that occur during the regulation of essentialism in real classroom situations, such as the social ones. Emphasizing only the individual aspect would not allow us to characterize the regulations that occur, for example, in the construction of collaborative explanations.

A deeper analysis of the regulation of essentialism, and concerning the different assumptions that comprise this way of thinking, allows us to propose that two ways of regulation may occur: the regulation of 'typologism' and the regulation of 'noise'. Each of them addresses the regulation of a particular assumption of essentialism reasoning (Gelman & Rhodes, 2012). We regard the regulation of 'typologism' as less complex than that of 'noise', as the alternative explanations constructed for the second case require more elements from the scientific model of reference. For instance, according to these explanations organisms of the same population are different and, in turn, such differences are associated with different chances of breeding and surviving in a given environment.

Regarding what happened in the classroom, explicit regulations of essentialism never appeared, for example, when using the labels agreed upon with the class-group (one such label was 'generalization thinking'). Based on the examples shown, a possible interpretation is that students understand some assumptions of essentialism and manage to regulate them, but fail to make them explicit. The reasons behind this may be diverse. On the one hand, we can suppose that the label agreed upon by the students comprises different assumptions of essentialism, but that only some of them are detected and regulated by students (like 'typologism' and 'noise'). This may be the reason why students did not find the label helpful, as they could not associate that some of these components belonged to a more complex way of reasoning like essentialism. On the other hand, some authors mention the difficulty to make metacognition explicit in a school context (Astolfi, 1994; Saldaña & Aguilera, 2003), particularly in a science classroom where students are not used to making their way of thinking visible (Ritchhart et al., 2011; Pozo, 2016). In particular, students do not see the necessity of making their reasoning explicit during the activity, unless the activity requires them to do so (Saldaña & Aguilera, 2003; Volet et al., 2009). Although the didactic sequence contained various tasks inviting students to make their way of thinking explicit, they are not expected to do it constantly, as it would involve a high cognitive demand (Pintrich et al., 2000). In this line, we can assume that using verbalizations as data has its limitations, particularly because the regulatory capacity is undervalued in students with low levels of introspection and/or poor oral expression. Therefore, it is worth considering that there will be different degrees of metacognitive domain in a classroom (Saldaña & Aguilera, 2003).

Based on what has been mentioned above, we consider that the implicit regulations of essentialism that students performed account for metacognitive processes for three reasons. The first one is that we have demonstrated that students are–to a certain extent–aware of epistemological obstacles and their regulation during the interviews. The second one is that the remarks they make correspond to the epistemological obstacles that have been a focus of attention at different moments of the didactic sequence in which they were dealt with. In this sense, they would not be random expressions, but could rather account for a regulation of essentialism.

The remarks made by students in their explanations could even be eliminated without affecting the coherence of the constructed explanation. For instance, if we take Simón's explanation of the cheetah problem, the remark he makes (*without them all being equal, of course*) could not appear, and the explanation would still be coherent. The third one is that other authors (Ronfard et al., 2021) did not find an explicit inhibition of reasoning in the learning of evolutionary biology, but inferred it from the analysis of their data.

Finally, it is worth mentioning that the regulation students perform is driven by the need to understand the epistemological obstacle as a mistake. This is typical of traditional school classes which pretend to avoid and conceal mistakes. Students follow these rules in an implicit manner (Astolfi, 2002; Astolfi & Peterfalvi, 1997), which could lead to trying to avoid epistemological obstacles.

However, this status of mistake is far from the spirit of the didactic model adopted in the present work, as is from the goals of the didactic intervention. Based on the theoretical framework, epistemological obstacles should be understood as ways of reasoning which are not mistaken or wrong in themselves, but are rather functional in some specific contexts.

This difference between the students' actual construction and what they were expected to construct could emerge from multiple factors, such as the language employed at school to talk about the way of thinking or the traditional manner in which mistakes are penalized in science classes with the purpose of replacing them with erudite, correct knowledge (Astolfi, 2002; Ritchhart et al., 2011; Sawyer, 2006). We could deduce from this analysis that explicitly discussing with the students about the status of error in learning could be favorable in the understanding of the epistemological obstacle concept.

CONCLUSION AND IMPLICATIONS FOR BIOLOGY EDUCATION

In this work, our objective was to characterize the processes of metacognitive regulation of essentialist thinking in secondary school students that took place during a didactic sequence based on the development of 'metacognitive vigilance'. We believe that the regulation of essentialism occurred, to a certain extent, at the individual and social levels, and that in both cases it was only in an implicit manner. We particularly distinguished two types of specific regulations of essentialist thinking in relation to evolution learning: the regulation of 'typologism' and the regulation of 'noise'.

Based on these two types of regulations, it could be considered that essentialism is not regulated as a whole, but through the regulation of some of its assumptions in a relatively independent manner. In this regard, we believe it is important that teachers identify which assumptions of the epistemological obstacles could be conflictive in relation to the scientific model to be taught, in order to take them into account when planning concrete activities.

We believe it would be important, in a first stage, to work locally on the different assumptions in the classroom. For instance, by encouraging metacognitive regulation over 'typologism' or 'noise' to allow a posterior transition towards more complex forms of regulation, involving the passage from the regulation of assumptions to the regulation of essentialism as a whole. This task will imply that students identify that certain ways of regulation, such as 'typologism' and 'noise', correspond to the same epistemological obstacle. We believe this proposal leads to further emphasizing the need to teach metacognitive regulation strategies in the different school subjects, as an indissoluble part of teaching (Gaskins & Elliot, 1991; Jorba & Sanmartí, 1996).

Returning to the work done by French science education researchers (Astolfi, 1994, 1999; Astolfi & Peterfalvi, 1997), a label for each of the assumptions of the obstacle could be agreed upon with students. One of the reasons for proposing this orientation is that, in our case, no regulations were used the labels to indicate essentialism, which could be due to the fact that the constructed label includes many of the assumptions of essentialism, but only some of them are recognized and regulated by students. As far as labeling is concerned, we deem relevant the use of semiotic supports, such as posters or conceptual maps, which help to perform metacognitive regulation. In the interviews, the students have shown or mentioned the potential of these supports in their own learning.

We believe that a good starting point to think about the different assumptions of the epistemological obstacle related to the model to be learned, are the students' spontaneous remarks. These typical clarifications or recurring phrases allow us to pay attention to certain aspects of the obstacles before explicitly dealing with them. An example of a recurring phrase in the classroom was 'not all are equal', which may serve as a tool to teach how to regulate.

On the other hand, we support the importance of the spaces of collaborative construction of explanations, where regulations of a social nature can take place. These spaces of collaborative construction may serve to test regulations or to learn about other ways of doing them. In this sense, the regulation that occurs within a group can feedback into individual regulations. Other investigations have shown evidence of the positive influence social metacognition has on individual performance (Janssen et al., 2012; Malmberg et al., 2015).

The findings exposed in this work illustrate some of the possibilities and difficulties of performing metacognitive regulation processes in science classrooms. As other authors point out (Schraw & Gutierrez, 2015; Veenman, 2012; Zohar & Barzilai, 2013), developing students' metacognition is important for multiple reasons: it generates better learning of scientific models, allows the development of abilities to reflect on the ways of thinking, allows the learning of meta-strategies (analyze causality, analyze a text critically) which can be transferred to other situations, among others.

Our analyses agree with those recently reported by Ronfard et al. (2021), who state the importance of intuitive reasoning inhibition in the learning of evolutionary biology models. However, their results differ from ours in two ways. On the one hand, these authors do not show qualitative data revealing the inhibition process, while in the present work we show some empirical examples that could be interpreted as expressions of this process. On the other hand, these authors mention the relevance of inhibition skills in learning but do not explicitly promote them in teaching. In contrast, our theoretical framework of teaching favors specific instances of explicit metacognition.

The observations we have presented open new questions concerning research on biology didactics. In particular, we consider important to deepen our knowledge of the existing relationship between critical thinking and regulation of epistemological obstacles. Many authors agree that thinking critically implies self-correction, involves thinking about our way of thinking and generating actions to improve it (Facione, 2020; Weissinger, 2004). In the same way that epistemological obstacles influence the learning of biology models, they can be expressed in other topics of social relevance. For instance, essentialism often appears in hegemonic discourses about sexism or racism (Dawkins, 2017; Donovan et al., 2019; Stamos, 2008). In this context, the regulation of epistemological obstacles will be influenced by political, social, moral, or cultural issues, and may prove useful to encourage a critical view of these speeches. Such critical look could involve biology models as useful tools to construct other explanations as alternatives to those based on epistemological obstacles. We are aware of the fact that there are many sides to the topics mentioned before, and that biology models as well as metacognitive reflection over the obstacles are just part of the issue. However, we value its importance and therefore wonder how to teach that, in certain decision-making contexts, epistemological obstacles cut across the political decisions we make, both as individuals and as a society, and that biology can help us think about alternatives, and to what extent this reflection can help develop critical thinking.

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