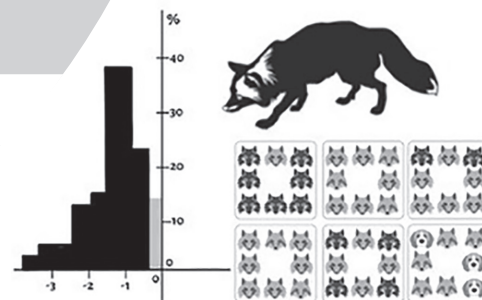# Inquiry-Based Activities for Teaching about Natural Selection: Dog Evolution & the Secret Ingredient of an Amazing Experiment

RECOMMENDED FOR *AP Biology*

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ABSTRACT

Teaching evolution is one of the most difficult tasks in biology education since there are a great variety of obstacles to its understanding. The inclusion of the nature of science and scientific inquiry, the connection with aspects of daily life, work based on scientific argumentation, and the use of empirical studies from current research have been identified as important aspects to include in teaching evolution. In this work, we present a series of three activities, which were developed after considering all the recommendations of the literature described above. The sequence begins with the example of the evolution of one of the species most loved by students: dogs. Through argumentation, students make their preconceptions explicit. After this, a long-term experiment about artificial selection in the silver fox (Vulpes vulpes) *is presented (see Glaze, 2018) as part of the reflection on the experimental evidence that supports evolution. Finally, students are asked to generate a hypothesis about how they think the domestication process of wolves occurred, eventually resulting in dogs. The outcomes of implementation in high school classrooms and biology teacher education are discussed.*

Key Words: *natural selection; nature of science; evolution of dogs; silver fox experiment.*

○ Introduction

In 1973, in this journal, Theodosius Dobzhansky developed an argument in favor of the validity of the theory of evolution as an explanation of the diversity and unity of life. Almost 50 years later, research in evolution education has shown that teaching effectively for this content is still a great challenge for several reasons. However, there are some strategies that can help biology teachers eventually overcome the intuitive explanations that students have about evolution (Harms & Reiss, 2019). A first approach seems to be including the nature of science (NOS), either before the teaching of evolution or integrated with it (Cofré et al.,

[We] present three examples of activities with different dynamics, where argumentation, the use of models, and the incorporation of the NOS are used in an inquiry-based strategy.

2018; Scharmann, 2018). The inclusion of NOS, or the understanding of how scientists work and how scientific knowledge is created, validated, and influenced (McComas, 2018), should serve mainly to show students that evolution is both a fact and a good scientific theory with solid empirical evidence and great explanatory power (McComas, 2018). This implies, then, that it might be useful to have students work with actual data and real examples of evolution (Lucci & Cooper 2019) to reflect on the theory of evolution and to fulfill the element of NOS, whereby science requires empirical evidence (McComas, 2018). Students must also understand that the evidence does not always come from experimental results (although there is such evidence) but also from geographic, taxonomic, and molecular comparisons; that is, science uses multiple methods (McComas, 2018). In addition, Glaze and Goldston (2015) established that student-centered teaching, which includes active learning, is an effective approach. For example, teaching using computational simulations, in which students can manipulate population variables of real species (e.g., snails, birds, lizards or fish), to investigate and not just to play, has been proposed as an effective strategy to achieve understanding of the process of natural selection (e.g., Hodgson 2019; Malone, et al., 2019). On the other hand, when evolution is related to aspects of students' daily lives, they are more likely to understand its relevance and are more motivated to work on developing an understanding of related content (Sinatra et al., 2008). This can be attained with laboratories where students must answer questions about how a population of bacteria can develop resistance to antibiotics (Williams, et al., 2018), or with the analysis of data on how humans have developed different adaptations (e.g., the evolution of skin color or the relationship between malaria and sickle-cell anemia) (Pobiner et al., 2018). Finally, argumentation, as a skill inherent to scientific activity, has been proposed as a propitious strategy to challenge the naive ways of thinking that students have about evolution (Osborne et al., 2017).

In this paper, we present a sequence of three activities for the teaching of natural selection within a context that motivates students due to familiarity: the evolutionary origin of dogs from an ancestral wolf population. Dogs are a phenotypically diverse group that consists of at least 400 genetically distinct breeds. Dogs (*Canis familiaris*) and Eurasian wolves (*Canis lupus*), as indicated by their species names, belong to the same genus. However, only dogs have been domesticated by humans. In the first activity, students are asked to argue about which of the three proposed hypotheses is the most correct; then, the hypothesis is contrasted with the empirical data of a study on the domestication of the silver fox (*Vulpes vulpes*), carried out by the Russian geneticist Dmitry K. Belyaev in 1959 (Trut & Dugartkin, 2017); the concluding activity is the development of a model of the evolution of dogs from wolves.

○ **Overview of Activities**

The three activities are considered to form a learning cycle like that proposed by Karplus (1977), with three phases: (1) exploration, (2) introduction, and (3) concept application. The first two activities are expected to bring students into a conceptual conflict situation, which can promote conceptual change (Nehm & Kampourakis, 2016). In Activity 1, planned for a 90-minute lesson, students are expected to reflect on their own knowledge regarding the familiar phenomenon of the presence of dogs in human life. Based on this familiar experience, students are encouraged to face the new experience of trying to explain how this species could have evolved from an ancestral species, such as wolves living today. To guide this discussion, groups are formed, and three possible explanations are presented to promote dialogic argumentation (Osborne et al., 2017). Figure 1 shows the worksheet that can be used with students. It is expected that this activity will make misconceptions about need or use and disuse emerge, which, in the first instance, should be challenged by the explanation of natural selection that some students can adopt. The misconception that "evolution is not something we see in our daily lives" is also addressed. At the end of the activity, teachers can include more information about the scientific evidence that supports the evolution of dogs as the first

species domesticated by humans, either through news (e.g., Funk, 2020; Pavlidis & Somel 2020) or by reading excerpts from scientific articles about dog evolution (e.g., Kaminski et al., 2019; Bergström, et al. 2020). For a summary of scientific information about dog evolution, see Appendix S1 (in the Supplemental Material available with the online version of this article). It is important to make students realize that scientists annually publish new evidence of dogs' evolution, and that sometimes there are controversies among them, but there is no controversy about whether the origin of dogs is by evolution, or if the process that explains it is natural and artificial selection.

If there are still doubts about the validity of the other possible explanations (the inheritance of acquired characteristics or intentionality), the teacher can propose that each group generate a prediction associated with the explanation they like the most. This proposal can be accompanied by the following question: How could we experimentally verify that the hypothesis of the evolution of the dog by natural selection is a good scientific explanation?

In Activity 2, the learning objective is to analyze and interpret data to provide evidence that changes in wild populations can be understood by studying examples of artificial selection that are analogous to natural selection. Students are expected to understand core ideas about natural selection after being exposed to experimental evidence of artificial selection, which is an analogy of the former. The preconception that "evolution acts on a single trait (gene) at a time" is addressed, as well as the preconception that "evolution only occurs after millions of years" (see the worksheet in Appendix S2, in the Supplemental Material available with the online version of this article). In this activity, students are confronted with the empirical data obtained through the artificial selection experiment carried out with the silver fox by Dmitry Belyaev and Lyudmila Trut (Belyaev 1979; Dugatkin, & Trut 2017; Trut & Dugatkin, 2017; see also Glaze, 2018). It is suggested that teachers begin by presenting the problem to be investigated to students for them to propose a hypothesis and an experimental design. Then, teachers present the Belyaev experiment, emphasizing elements that make this research an evolutionary experiment (the presence of a control group, experimental treatment, controlled variables, predictions, the results, and conclusions). It is expected that students will be able to build a better

Figure 1. Student worksheet to carry out Activity 1 on explanations of evolutionary change and argumentation. The structure of the guide and its version through the application Padlet for remote work are presented (https://padlet.com).

hypothesis about the origin of dogs, using this study as an example of artificial selection and allowing us to reveal characteristics of the nature of science and its importance to grasp how knowledge is built in science (e.g., the "empirical evidence is required" and "science uses multiple methods" elements of NOS, McComas 2018).

In Activity 3, the learning objective for students is to use the theory of evolution by natural selection and its postulates of variation, differential reproduction, and inheritance with the example of the origin of dogs from an ancestral population of wolves. The strategy of creating explanatory models is used, where it is expected that students can use the different concepts reviewed in the previous activities to generate a plausible scientific hypothesis about the origin of dogs. Because Activity 1 presents natural selection and Activity 2 presents artificial selection, students should wonder whether artificial, natural, or both processes are required. Appendix S3 (in the Supplemental Material available with the online version of this article) shows the activity worksheet. Students are expected to build an explanatory model using the concrete material found on the group worksheet. To represent the evolutionary process, a modified version of the dog evolution model presented in Kampourakis (2014) is used. The parts of the model can be offered to students on a cut-and-paste worksheet (if it is a face-to-face class) or on a digital whiteboard such as Jamboard (if the class is virtual). Figure 2 shows some models created by ninth-grade students. After creating a hypothesis for dog evolution, each group shares it with the class. At this stage, the teacher allows students to reflect on how the changes in their proposals occurred, where the elements of natural and/or artificial selection are found, and to observe that evolutionary changes occur in populations and not in individuals. Caution should be taken that

students reflect on the concept of the model and how the proposal is a simplification of the process that occurred (e.g., the process in the model is offered as a linear process, which is not necessarily correct).

○ Results

Teacher Reflection

The activities presented here were designed to be done in groups where students address previous ideas (see Table 1 for an example), thus creating an opportunity to reconstruct the scientific meaning of the phenomenon under study. For example, in Activity 1 at the beginning of the review of the topic of evolution, many of the students' explanations include need as a force of evolutionary change—or even hybridization—for the generation of a new species (dogs). Table 1 displays an excerpt from a discussion among ninth-grade students (14–15 years old) in which it is evident that some of the participants find it difficult to believe or understand that there is variation in the traits of a population, and rather see evolution as the change of every individual due to need.

When carrying out activities 2 and 3 with students, as pre-service and in-service biology teachers, we realized that it is very motivating to discuss and learn about the evolution and origin of a species as familiar as dogs (Figure 3). Sometimes it is also difficult for participants to identify the selective pressure; that is, what caused tame wolves to be selected during their interactions with humans. In the second activity, it is hard for participants to grasp that the evolution of certain traits can occur (as a change in the gene frequency of a gene in the population) as an epiphenomenon; that is, as a product of selection pressure on another trait (morphology vs. tameness). Finally, in activities 1 and 3, it is also difficult for students to see that a behavioral trait (tameness) can be an adaptation. They are more used to understanding adaptations as morphological traits. For all this, in all
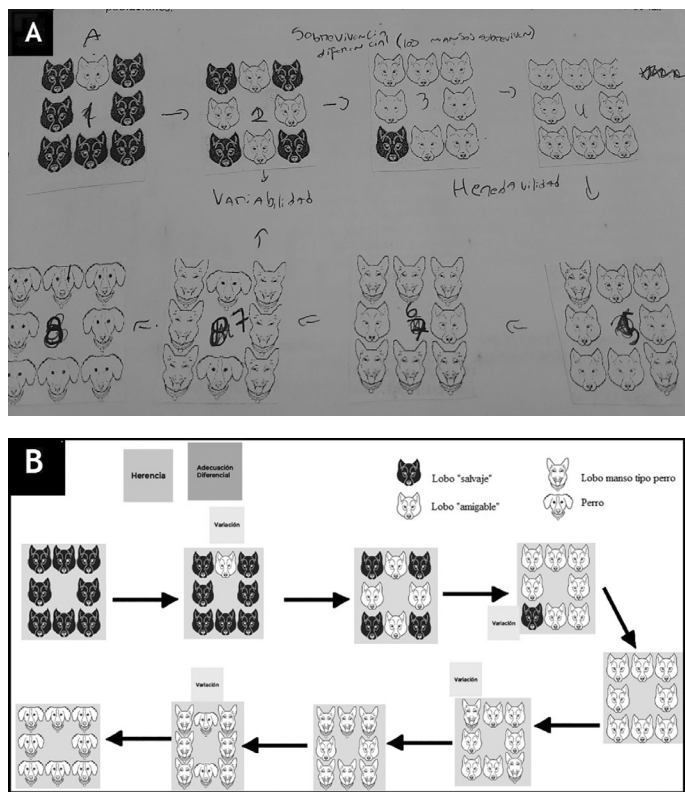

Figure 2. Example of a student worksheet to carry out Activity 3 about explanations of evolutionary change and argumentation in (**A**) face-to-face lessons and (**B**) virtual lessons using Jamboard.

Table 1. Excerpt from a discussion among three ninth-grade students in the context of Activity 1.

S1	The explanation was that they started looking for food. From then, the dogs that we know now were born. Explanation 2 is that there were some cute dogs and others that were angry. The cute ones went with the humans and reproduced.
S2	And the angry ones were left alone.
S1	The angry ones were left alone; they correspond to the current wolves and the other wolves are the dogs we know today. Explanation 3 says that the dogs were domesticated on their own and from then on, the dog developed.
S2	Which do you think is the best?
S3	I like number 2.
S1	I think 3 should be eliminated.
S2	Why do you have to get 3?
S1	No, we must get out explanation number 2.
S2	Delete number 2?
S1	I say that we must eliminate 2, because wolves, like dogs, act in packs, so if some of them go to a place, the whole pack will surely follow them. Therefore, I do not think there is a group of angry [wolves] and another [group] of nice [wolves].

Figure 3. (**A**) Student biology teachers working with the worksheet in the face-to-face version of Activity 3. (**B**) One of the authors (Pablo Castillo) and a group of ninth-grade students discussed the problem raised in Activity 1.

stages of the cycle (activities), an environment of trust must be fostered that fosters interactions between participants, and where errors are perceived as opportunities to learn (Vosniadou, 2019).

○ **Evaluation of Effectiveness**

Based on our findings, we found that most students learn about natural selection (Cofré et al., 2018; Parraguez et al.,

in press), through this inquiry-based approach. Using one question from the Assessment of Contextual Reasoning about Natural Selection (ACORNS) (Nehm et al., 2012), before and after activities 2 and 3 in one ninth-grade class, the number of misconceptions (mostly need-based and chimerical explanations) decreased after the activities. On the other hand, students' use of natural selection elements (mutation, variation, fitness, and selective pressure) increased from before to after the activities (Table 2).

Table 2. The numbers of scientific concepts and misconceptions before and after Activities 2 and 3 in a ninth-grade class (Parraguez et al., in press). Amechanistic responses explain evolutionary change only because of comparative evidence (fossil, genetic, or morphological, not by a mechanism). A chimeric explanation states that new species originate from the reproduction of two preexisting and different species.

Student	Scientific Concepts before Activities	Misconceptions before Activities	Scientific Concepts after Activities	Misconceptions after Activities
S1	0	0	1 (variation)	0
S2	0	0	3 (variation, inheritance, fitness)	0
S3	0	1 (amechanistic)	1 (variation)	1 (need-based)
S4	0	0	2 (variation, inheritance)	0
S5	0	1 (need-based)	1 (variation)	1 (need-based)
S6	0	1 (need-based)	0	1 (need-based)
S7	0	1 (chimerical)	2 (variation, fitness)	0
S8	0	1 (chimerical)	3 (variation, inheritance, fitness)	0
S9	0	1 (need-based)	1 (variation)	0
S10	0	1 (need-based)	1 (selective pressure)	1 (need-based)

Concluding Remarks

Teaching evolution effectively is not an easy task. However, there are several approaches and strategies that can help us to work through, and eventually overcome, the intuitive explanations that students may hold about evolution. A first approach to achieving this objective seems to be to include data and real examples of evolution, and reflecting with the students on this evidence (Cofré et al., 2017, 2018), as in the different activities presented here. Teaching strategies where students share their ideas with their peers and manage to build their own conclusions about certain evolutionary phenomena appears to be one of the best ways. This time, we focus on the case of the origin of dogs to present three examples of activities with different dynamics, where argumentation, the use of models, and the incorporation of the NOS are used in an inquiry-based strategy. We use artificial selection to help students understand natural selection, as Darwin himself did by making an analogy between the two. Bringing evolution closer to students' everyday lives, such as with cases of domestication or diseases that we suffer from today, is an effective way to promote their interest in, and ultimately to help them understand, the content involved.

Supplemental Material

The following appendices are available with the online version of this article:

- Appendix S1: Summary of scientific information about dog evolution.
- Appendix S2: Worksheet for Activity 2 in Spanish and English.
- Appendix S3: Worksheet for Activity 3 in Spanish and English.

Acknowledgments

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