How to use dinosaurs to teach the scientific method, conservation and ethics

(A free teachers' guide with activity cards and evaluation tips, from the CR Open University)

Julián Monge-Nájera*

Received: 08-04-2016 **Accepted: 29-10-2016**

RESUMEN

Los dinosaurios tienen un gran potencial educativo porque fascinan por igual a las mentes jóvenes y al público general. Los antiguos chinos, griegos y romanos explicaron sus fósiles con hermosas leyendas; en el siglo XX *Parque Jurásico* y *Caminando con Dinosaurios* llevaron el tema de la ciencia de los dinosaurios a las grandes masas. Aquí se explica cómo hacer tres actividades económicas y sencillas: la primera es reconstruir la apariencia de un dinosaurio y su hábitat a partir de fósiles, enseñando los requisitos del Método Científico; puede realizarse con una computadora o manualmente. La segunda es una simple práctica de dibujo que nos enseña la imposibilidad de copiar fielmente una especie extinta ahora que se habla de la "des-extinción". Y la tercera consiste en una teatralización sobre ética en conflictos relacionados con fósiles. El artículo incluye materiales recortables para hacer las prácticas, así como el detalle de los pasos a seguir, cómo evaluarlas y consejos prácticos.

Palabras clave: Enseñanza del Método Científico, Extinción de especies, Ética en Ciencia.

ABSTRACT

Dinosaurs have great educational potential because they fascinate young minds and the general public. The ancient Chinese, Greeks and Romans explained their fossils with beautiful legends; in the Twentieth century, *Jurassic Park and Walking with Dinosaurs* brought dinosaur science to the masses. Here I explain how to make three inexpensive and simple activities: the first one teaches how to reconstruct the appearance of a dinosaur and its habitat from fossils and focuses on the requirements of the Scientific Method; it can be done with a computer or manually. The second is a simple drawing practice that teaches the impossibility of faithfully copying an extinct species (despite the current proposals for species "de-extinction"). The third activity is a dramatization about ethical conflicts related to fossils. The article includes activity cut-outs and detailed steps, how to evaluate and practical advice.

Key words: Teaching the Scientific Method, Species extinction, Ethics in Science.

* Laboratorio de Ecología Urbana, RECAS, Vicerrectoría de Investigación, Universidad Estatal a Distancia, 2050 San José, Costa Rica. julianmonge@gmail.com

INTRODUCTION

Those of us dedicated to teaching have always tried to avoid boredom and achieve −if not enthusiasm− at least the attention of the young minds that we educate. Fortunately for those of us who work with scarce funding, attracting those minds to science and ethics requires more imagination than money (e.g. Bierema & Rudge, 2014; Chudyk et al., 2014; Yerky & Wilczynski, 2014). However, even in a field as fascinating as science it may be possible to fall into soporific lessons, like the dinosaur show host in the film *Mrs. Doubtfire* (1993). The main character says something like "this guy used to put me to sleep when I was a kid!" and decides to do his own educational program combining music, puppets, and humor to educate about those ancient reptiles. Unfortunately, what I have seen in Iberoamerican educational TV looks more like the lessons of the boring teacher in *Mrs. Doubtfire* and I do not have much hope that it will improve. If we want better lessons, we have to make them ourselves, and we can follow the example of the great educational productions from Great Britain and the United States of America.

Excellent educational television, like the one people watch because they *want to* has a great example in the BBC show *Walking with Dinosaurs* (BBC, 1999). The same could be said about the not so recent but very influential American film *Jurassic Park* (1993), which reintroduced dinosaurs into popular culture at the end of the 20th century, touching on such topics as evolution, conservation and ethics.

I do not want to give the impression that blockbusters are needed to educate. Although we can now learn about dinosaurs thanks to Hollywood "hits", as a child I became fascinated with them when my mother bought me *Prehistoric Animals - Dinosaurs, Reptiles, and Mammals* by Lincoln Barnett and Jane W. Watson with the support of the excellent editorial team of *Life* (Simon and Schuster, New York: 1958, **Fig. 1**).

I don't believe better educational books have been written than those published by *Life*, being as fascinating now as they were half a century ago. A proof of this, and the reason why I still recommend these books to those dedicated to teaching even in these times of Wikipedia and Youtube, is the time that my son Andrés, after one of his trips, brought from a used book store in Mexico City several books from this series. Even though I had never talked to him about them, he chose the same books that I had chosen as a child 40 years earlier!

Thousands of years of education and imagination

Although movies and television are comparatively recent inventions, we have had excellent educational materials with us for centuries. If we go back to the beginning of the 20th century, the novel *The Lost World* by Scottish author Sir Arthur Conan Doyle (1912) also masterfully brought dinosaurs to readers, as did French author Jules Verne half a century before with other extinct reptiles in his *Journey to the Center of the Earth* (*Voyage au centre de la Terre*, 1864, which nevertheless did not include dinosaurs). Unlike some current

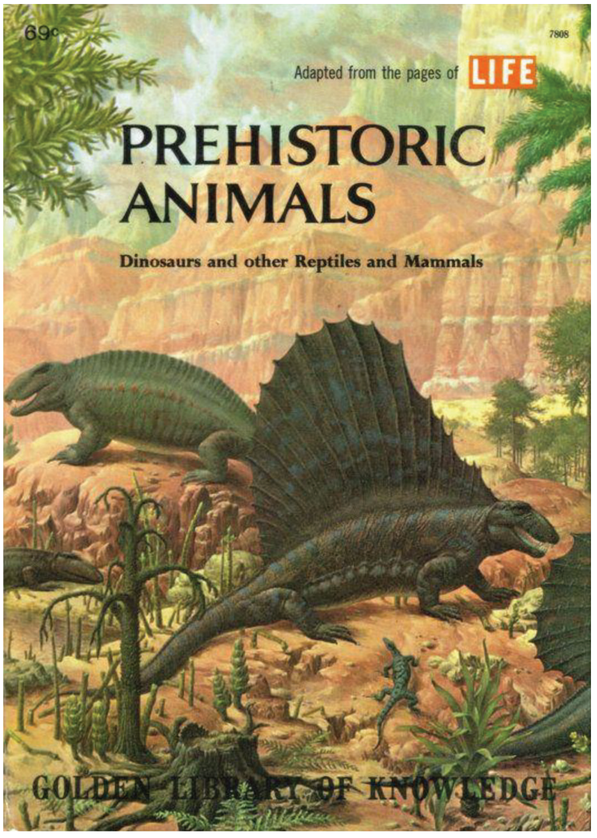


Figure 1. *Prehistoric Animals,* the gift from my mother that opened a wonderful world to me when I was a child.

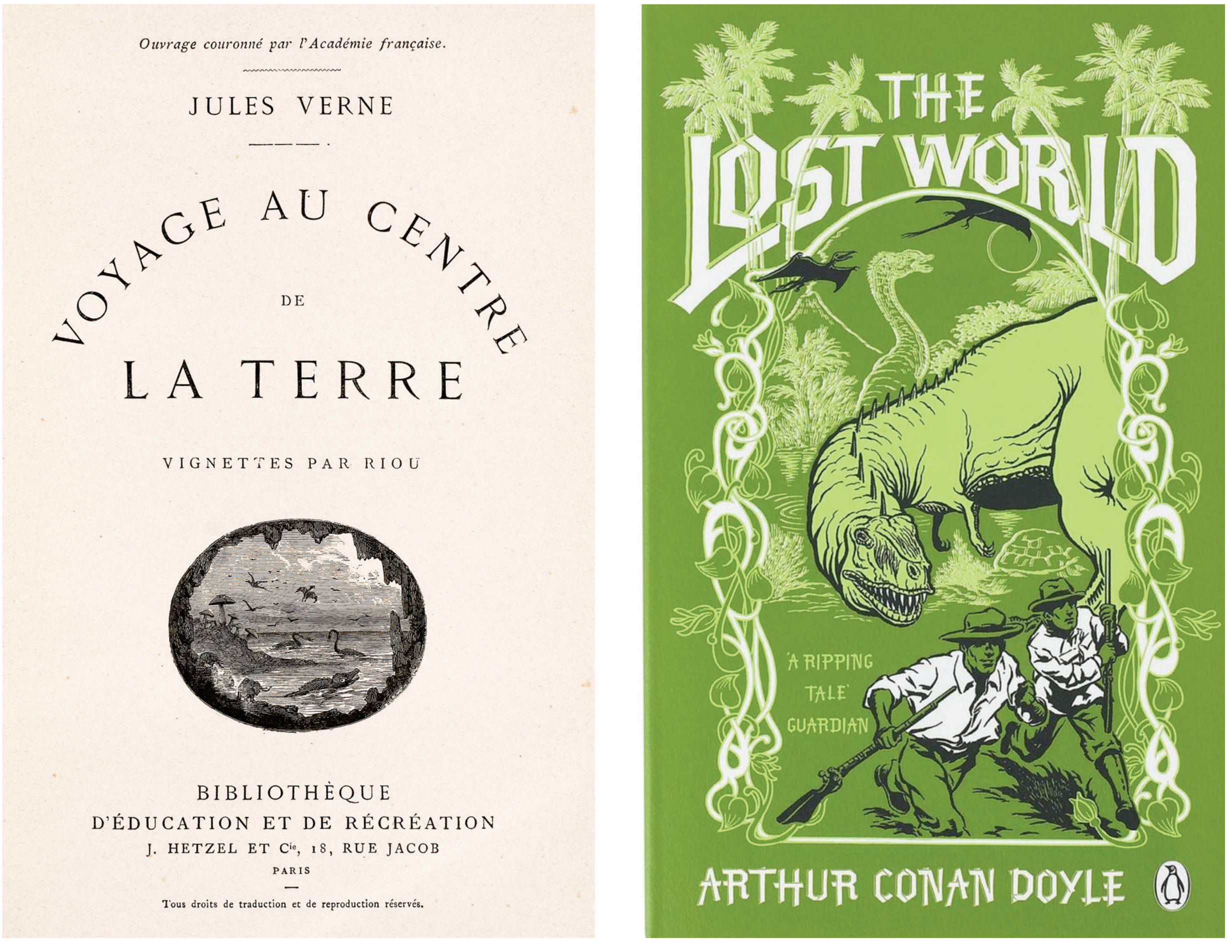


Figure 2. Jules Verne's *Journey to the Center of the Earth* was among the first to imagine a world populated by primitive reptiles, but it did not include dinosaurs. That was done shortly afterward by Arthur Conan Doyle in his Lost World. Image: Wikimedia.org

educational documentaries and texts, the books by Doyle and Verne revived the fossils of these "monstrous lizards" in a fascinating way, capturing the attention of several generations (**Fig. 2**).

However, Doyle and Verne were not the first ones to reconstruct and fascinate using the fossils of spectacular animals that do not inhabit our planet any longer. When Hernán Cortés invaded Mexico in 1519, he heard fascinating stories about ancient "giants" and saw their "bones", which were in fact fossils of Pleistocene mammals. There are even more ancient examples: for thousands of years the Chinese have shown the remains of legendary "dragons" to an amazed audience. Such remains were pulverized for medicines, destroying unknown quantities of valuable fossils in the immensity of the Chinese Empire (Mayor, 2000 **Fig. 3**).

Almost as old, but more creative, was what the Greeks and Romans did a couple of millennia ago. American folklorist Adrienne Mayor said that, thanks to fossils, ancient people understood that their land had been previously inhabited by different creatures (Mayor, 2000). Although other cultures explained fossils as remains of animals that were too large to fit on Noah's Ark, or as divine traps to test the faith of Christians, in ancient Greece Aristotle correctly interpreted fossils as remains of extinct organisms.

Figure 3. The ancient Chinese believed that dinosaur fossils were the skeletons of dragons. Image: Wikimedia.org

Figure 4. The folklorist Adrienne Mayor suggested that the legend of the Griffin originated in the fossils of Protoceratops. Image: Wikimedia.org

The gryphon myth, the Eagle-beaked lion that nests underground and guards a treasure could have arisen, according to Mayor, from the Scythian miners who found *Protoceratops* fossils on their way to the gold mines (Gobi desert, **Fig. 4**). Although experts doubt it, the idea is appealing. Another example is the monster of Troy, represented in a Corinthian vase with what, according to Mayor, could be the fossil skull of a giraffe of the genus *Samotherium* (Mayor, 2000, **Fig. 5**).

Other Greeks thought that fossils were remains of legendary heroes and mythological creatures and took the time to excavate them, place them in luxurious coffins and - in some cases - even tried to reconstruct the bodies, behavior, and habitats of giant “battle animals” (Mayor, 2000).

With these examples from Greece and China, we can teach the concept of the scientific method by comparing scientific components such as the desire to explain something (the giant fossilized bone that someone found); and the difference between the mind that freely imagines an explanation (a “giant warrior”) and the investigating mind that uses the scientific method.

Figure 5. The Trojan Monster, which appears in a vessel and could be inspired by a fossil, according to Adrienne Mayor. Image: Wikimedia.org

The scientific method seeks natural explanations (in this case, hypotheses about fossils) and tries to rule them out one by one, to end up with the most probable explanation according to proven evidence. The basis of the scientific method is honesty: communicate what you find even if it goes against your beliefs.

FIRST CONCEPT: How can we practice the relationship between evidence and conclusion, characteristic of the scientific method, by reconstructing a dinosaur in our classroom

In order to teach how the bodies and lives of dinosaurs are reconstructed and how the scientific method involves, first and foremost, rigor and honesty, we can use the example of "paleo-artistic" work that has been vital in the history of Paleontology.

Our students can learn that scientific rigor is necessary even in art because, without the proper collaboration between painters, zoologists, ecologists and other experts, artists could do incorrect reconstructions. Errors have been found in some older reconstructions in terms of proportion, posture, the way of walking and even behavior and habitat where those organisms once lived. However, these errors are identified and corrected as new fossils are found and as our methods and interpretations improve.

A good example is the *Brontosaurus*, now *Apatosaurus*. At the beginning of the 20th century, it was represented as a giant dinosaur that dragged its tail and lived in water to alleviate the effects of its enormous weight. It became popular thanks to the animated film *Gertie the Dinosaur* (1914, youtube.com/watch?v=TGXC8gXOPoU), as well as the silent film *The Lost World* (1925; youtube.com/watch?v=9UXqL0LTPX8), and especially the classic *King Kong* (1933), in which the reconstruction is more accurate because it shows the animal moving rapidly on dry land (Monge-Nájera, 2016a).

Interestingly, many years passed before special effects artists correctly reconstructed the *Apatosaurus* in *King Kong*. Scientists also improve reconstructions thanks to the discovery of new fossils and better methods. The new reconstruction shows an animal that lived on land and did not drag its tail; on the contrary, computer models suggest that the tail could have been used as a whip, and, when young, this dinosaur could run on two legs! We must emphasize to our students that a paleo-artistic error does not imply that *all* scientific interpretations were wrong; for instance, the basic body reconstruction and how they lived in swampy lowlands have withstood the test of time (Fig. 6a). This is an important lesson because anti-evolution fans often use any small error that scientists themselves discover to deny the validity of the entire scientific method.

The herbivorous dinosaur *Iguanodon* is famous for being one of the first dinosaurs used for a life-size reconstruction. The reconstruction was sculpted from cement in England in the 19th century. In 1853, scientist Benjamin W. Hawkins offered a dinner party inside the mold that included mock turtle soup; cod and oyster sauce; turbot a l'Hollandaise (Dutch-style turbot); roast turkey; ham; raised pigeon pie; boiled chicken and celery sauce; French entrees (such as Cotolettes de Moutonaux Tomatoes [mutton chops], currie de laperaux au riz [curried rice with rabbit], salmi de perdrix [partridge stew], mayonnaise de filets de sole [sole fillets with mayonnaise]); game meats (pheasants, snipes); sweets (macedoine jelly, orange jelly, Bavaroise [Bavarian cream], Charlotte Russe [Bavarian custard with gelatine], Nougat a la Chantilly, Buisson de Meringue); and for dessert, grapes, apples, pears, almonds, raisins, French plums, pine nuts, hazelnuts and walnuts. All of this was accompanied by the wine of their choice (Sherry, Port, Madeira, Marsala, or Claret). I have always thought that my ideal lesson would be one where I would serve this same menu while talking about dinosaurs. Dinner was spectacular, but the dinosaur was reconstructed incorrectly in aspects as serious as placing the hind legs in the front (Fig. 6b).

Another example of correct and incorrect dinosaur reconstruction is a species that became famous for appearing in *Jurassic Park*, under the informal name of "raptor". I would like to use this

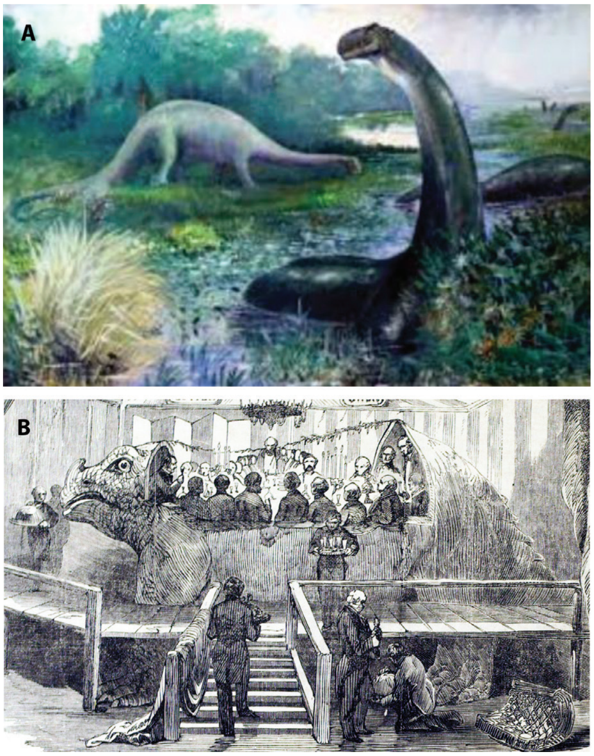


Figure 6. A. Ancient reconstruction of Apatosaurus as an aquatic dinosaur. Although details like the tail touching the ground have been corrected, most of the reconstruction has withstood a century of scientific advances. B. Victorians dining inside a cement dinosaur. Image: Wikimedia.org

case to make an original contribution. So far, the most common reconstruction of the *Velociraptor mongoliensis* Osborn, 1924 (Theropoda: Dromaeosauridae) has been like the one in Fig. 7.

However, that reconstruction is inaccurate because it is based on older, less complete fossils. In our case, we will practice a reconstruction in class in accordance with the most complete fossils and genetic studies of the latest generation (see *Activities*).

The scientific basis of the reconstruction we will perform here can be found in recent studies that corroborate the genetic closeness of the ostrich, *Struthio camelus* Linnaeus, 1758 (Struthioniformes: Struthionidae) with dinosaurs (Dzemski & Christian, 2007; Huang, Zhang, Wei, Wang, Sun, Hu, Ren..., & Zhao, 2012). The end result of our practice will be the alternative reconstruction of a feathered *V. mongoliensis*.

Our reconstruction meets the following requirements: habitat justified by fossil evidence, in this case, arid zone (Jerzykiewicz & Russell, 1991); proportions based on real skeleton (Norell & Makovicky, 1999); feather covering (Turner, Makovicky & Norell, 2007) and posture similar to the one of a known relative (Balanoff, Bever & Norell, 2014).

Figure 7. Reconstruction of the Velociraptor when it was not known that it had feathers. Image: M.A. Rumbo, Wikia.com

This reconstruction also coincides with the recent hypothesis that the forelegs (wings) at most helped this small predatory dinosaur to maintain balance during the attack, as some modern birds do (Fowler, Freedman, Scannella & Kambic, 2011).

In the future it would be good to reconstruct its behavior and examine the hypothesis that it did not use its enlarged claw to strike, but rather to hold prey animals while biting them (Fowler, Freedman, Scannella & Kambic, 2011).

ACTIVITIES

The goal of the activities described here is to let students apply scientific principles to evolutionary reconstruction, and to discuss ethical problems associated with extinction and with the study of fossils. The activities produce the following outcomes:

- The students learn that even if we cannot go to the field and see the dinosaurs that became extinct, we can use the scientific method to reconstruct their bodies and behaviors, as long as imagination is limited by fossil evidence and principles known from extant species.
- Students conclude that it is very difficult to make a good copy of something as simple as a drawing, and thus it is impossible to faithfully copy something as complex as a dinosaur; in other words, extinct species cannot really be brought back to life in their full constitution.

Students exercise critical thinking to form an ethical opinion about how to proceed when fossils are found, taking into account the perspectives of commercial collectors, amateurs and professional paleontologists.

ACTIVITY 1

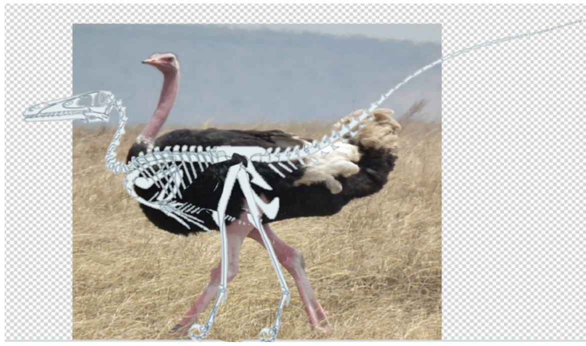
Reconstruct a Dinosaur

Materials:

- Image of a bipedal dinosaur skeleton (for example: https://goo.gl/bJIZPS)
- Image of an ostrich (available here: https://goo.gl/jytWkM)
- Computer with imaging software, for example Gimp (freeware: gimp.com)

Activities:

- **Step 1:** Place the skeleton and ostrich in different layers:



- **Step 2:** Add a habitat layer, stretch the ostrich to conform to the proportions of the skeleton (not the other way around) and add details as needed:

- **Step 3:** Merge the layers and polish details to produce an image like this one:

- **Step 4:** Organize students in groups to answer the questions listed below. According to class characteristics, decide if answers are presented in written or discussed in front of the class.

Evaluation:

- The evaluation can be based on a questionnaire that at least includes these questions:
- What was the most difficult part of the reconstruction?
- Why?
- What are the main differences with the traditional reconstruction? (available here: jurassicparck.wikia.com)
- How different would the behavior be?
- How different would the habitat be?
- How can your previous experience of dinosaurs reconstructed as large lizards affect your acceptance of this new image that is scientifically reasonable but less familiar?
- What could still be wrong with this reconstruction?

Tips:

- The objective is not to produce a professional quality reconstruction, but to assess how well the student limited the reconstruction to the correct skeletal proportions and other evidence: I recommend individual evaluation of the final image.
- You may need to assist students not familiar with the software.
- If for some reason you cannot use a computer, you can adapt this activity to be done by hand. Early paleo-artists did the reconstructions with traditional media such as pencils, pens and watercolors and so can you.

SECOND CONCEPT: Resurrection of species is possible, but imperfect

The second concept that we can teach with dinosaurs in the classroom (whether real or virtual) is the irreversibility of extinction. *Jurassic Park* introduced the idea that we can resurrect extinct species, but they would actually be somewhat different (Monge-Nájera, 2016b).

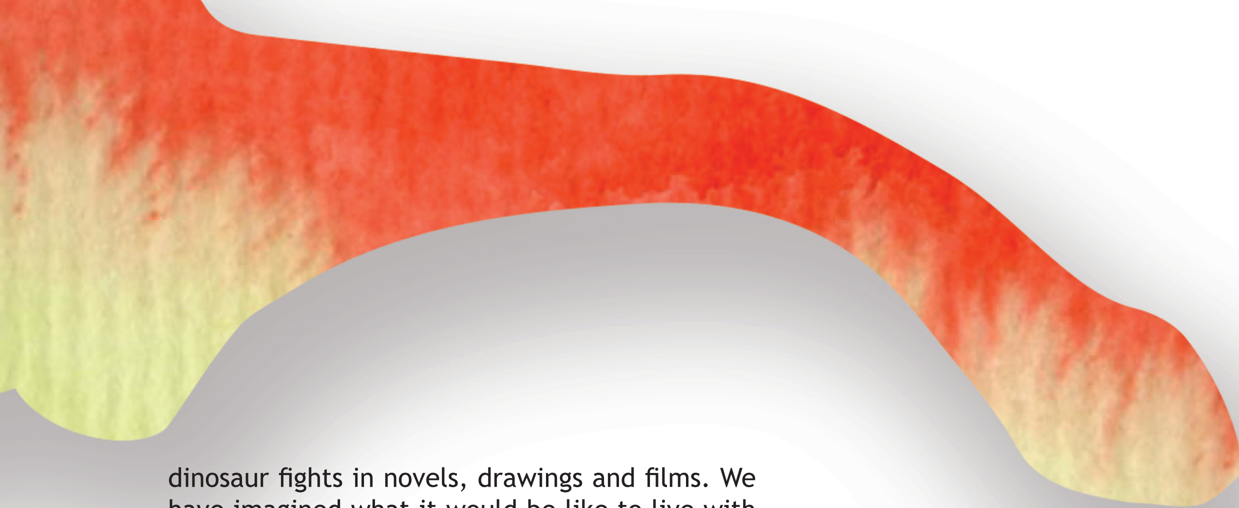
No one knows what caused the extinction of dinosaurs; many scientists doubt that it was a comet, and fossils indicate that they had a long decline until they completely disappeared, perhaps with that final blow from space. Whatever it was, the key lesson here is that *they are extinct and we cannot rebuild any extinct species*.

It is a shame to have lost such wonderful animals, of which, it is believed, there were thousands of species (we have only identified approximately 700). They were as small as a cat (*Epidexipteryx*) and as large as a five-story building (the 80 ton *Brachiosaurus* was 23 m long and 12 m high). These giants came of unexpectedly small eggs, which, depending on the species, ranged from 3 to 30 cm in diameter.

At the moment, the oldest dinosaur formally described is the *Eoraptor* that lived 230 million years ago; the last dinosaur to leave fossils is the *Triceratops* from Hell Creek, Montana, USA, 65 million years ago. It is believed that certain sauropods migrated up to 1400 km. Some were slow, but the *Dromiceiomimus* could reach up to 60 kilometers per hour, and the *Troodon* had a brain proportionately as large as a mammal, as well as stereoscopic vision and skillful hands (being candidate for "the most human like" dinosaur).

For sure their behavior was fascinating, with displays of threat, courtship, and fighting using sounds and colors. I have heard the computer simulation of *Corythosaurus* and *Parasaurolophus* sounds and they remind me of a ship siren. Quite possibly some dinosaurs, like the *Maiasaurus*, cared for their young in the nest and lived many years (up to 30 and 80 years in the cases of the *Tyrannosaurus* and the *Diplodocus*). At least two fossilized dinosaurs that died during a fight have been found; in 1971 a *Velociraptor mongoliensis* was found with its claws dug into the body of a *Protoceratops andrewsi* (its poor prey tried to defend itself by biting the *Velociraptor*'s wing, Fig. 8). A *Nanotyrannus lancensis* found in the United States fighting with a *triceratops* has also been mentioned by some authors.

Long before these fossils of real fights were found, the human mind had already imagined



dinosaur fights in novels, drawings and films. We have imagined what it would be like to live with them at least since the magazine *Punch* commented that, having lived at the same time, the *Iguanodon* would have eaten B.W. Hawkins and his group (they did not know that *Iguanodon* was herbivorous). That fascination of placing people and dinosaurs together inspired films with such contrasting budgets as *Jurassic Park* (1993) by Steven Spielberg and *Dinosaur Valley Girls* by Donald Glut (1996). Glut combines both species in his unusual House-Museum (donglutsdinosaurs.com).

Figure 8. Fossil of *Velociraptor* in apparent struggle with a *Protoceratops*. Image: Wikimedia.org

But, are dinosaurs really extinct? The answer is that surprisingly *not all of them are extinct*. In 1980s the phrase “extinction is forever” was in vogue; however, after the publication in 1990 of the novel *Jurassic Park* by American writer John Michael Crichton, the idea that extinction was not forever became acceptable and the possibility of reconstructing extinct species was born.

In real life it is very unlikely that dinosaur DNA will be found inside insects trapped in amber, as in the novel, but “luckily” modern birds are direct descendants of dinosaurs, and their DNA has dinosaur sequences. The proof of such sequences is that they have already been used to produce chickens with teeth (Harris, Hasso, Ferguson & Fallon, 2006). It is also true that the South American Hoatzin (*Opisthocomus hoazin*) has claws on its wings! In fact, I have always thought that if we could see a live archaeopteryx (*Archaeopteryx lithographica)* it would look much like the Hoatzin (Fig. 9). In summary, both the extinct archaeopteryx and the Hoatzin share the genes that produced front claws in extinct dinosaurs (see Mayr, Alvarenga, & Mourer-Chauviré, 2011).

I present here the concept that we cannot completely reconstruct extinct species, although we can get close to this ideal goal.

Figure 9. The “Venezuelan Stinkbird”, an extanct animals that looks much like I imagine the extinct *Archeopteryx*. Image: Wikimedia.org

ACTIVITY 2

Can we Really Bring Extinct Dinosaurs Back to Life?
(De-Extinction or Resurrection)

Materials:

- Pencil drawing of a dinosaur (projected for the class or printed for each student). One is available here: https://goo.gl/04KhFC
- Pencil
- Paper

Fuente: https://goo.gl/04KhFC

Activities:

- **Step 1:** Each student copies the dinosaur by drawing it with the pencil.
- **Step 2:** Ask students to organize in three groups and to choose -within their group- the drawing that looks more like the original.
- **Step 3:** The whole class compares the three chosen drawings with the original and discuss the strong and weak aspects of the drawings.

Evaluation:

You can ask questions such as these:

- What is the most difficult part of producing a faithful copy?
- Is any of the drawings indistinguishable from the original?
- Consider the case of superb hand-painted copies of the Mona Lisa. They actually exist but are worth little in comparison with the original. Why do you think this is so?
- Apply your previous answer to the imaginary rebuilt dinosaur: what is your conclusion?

Tips:

- Students with poor drawing skills may feel uneasy about the practice. The grid guide is helpful but you should reassure them: the goal is not to produce a professional illustration.
- If you have students who do not wish to do the drawings ask to propose other activities where they can copy something but feel more confident. This is fine as long as they learn the final lesson: *perfect copies are impossible*.

THIRD CONCEPT. Ethics in relation to fossils

The subject of dinosaurs also allows us to teach ethics. Let's consider an actual case: the robbery of Mongolian specimens. In 2010 an American dealer sold for a million dollars a nearly complete skeleton of a *Tyrannosaurus bataar*, found in the Gobi desert and illegally removed from Mongolia. The skeleton was returned to its country thanks to the actions by the Minister of Culture of Mongolia, (BBC, May 7, 2013).

We can also teach ethics with findings of dinosaurs in places like Argentina and Africa, where foreign scientists get the specimens and take to their countries both the fossils and the fame. It is true that specimens should be rescued from countries where cultural treasures can be destroyed (as it has happened recently in some Islamic countries: Coles, Isabel & Hameed, 2015); however, in democratic countries with a long scientific tradition such as Argentina, specimens should stay there and be described by local researchers, who are perfectly trained for this purpose. Furthermore, institutions in rich countries should prohibit photographing fossils, as suggested by Andrew Farke, who criticizes this practice that unsuccessfully seeks to generate money by "kidnapping" fossils belonging to humanity's heritage (Farke, December 5, 2013).

Another example of immoral approach to fossils relates to *Archaeopteryx lithographica*, which was falsely accused by physicist R.S. Watkins and others of being "manufactured" (Watkins, Hoyle, Wickramasinghe, Watkins, Rabilizirov & Spetner, 1985). Although their article was not published in a scientific journal, it served as ammunition for evolution deniers, and shows the damage that calumny can do (Feo, Field & Prum, 2015).

Activity 3 includes an exercise on fossils and ethics.

ACTIVITY 3

What is the Right Thing to Do? Ethics in the Study of Dinosaurs and other Fossils

Materials:

- Hand-outs with the fossils (Appendix)
- Cards with identity information (Appendix)
- Optional: access to a free blog site such as Blogger or Wordpress.

Activities:

- **Step 1:** Ask the students to organize in five groups to play roles or write a blog. Give each group a different fossil card. All groups must have students playing the three roles but otherwise they can organize freely.
- **Step 2:** To begin the activity, the student playing the role of fossil dealer prepares an add offering a fossil for sale. If the students are playing the roles, read the add aloud; if they choose the blog option, the add is published on Internet and deleted as soon as the activity is finished.
- **Step 3:** The student playing the role of museum paleontologist criticizes the offer and the commercial extraction of fossils, and the amateur collector moderates the developing debate and -at the end- prepares a brief report for the teacher.
- **Step 4:** The teacher compares the outcomes of the five groups and discusses them with the class.

Evaluation:

You can grade how well students presented the arguments for their own position and how they identified the significant differences among cases, because the ethical outcomes cannot be the same considering the differences among cases.

You can also ask questions such as these:

- What are the main differences among the five cases, from the point of view of public interest?
- When does public interest matter less than individual interest?
- Did you expect all groups to reach the same conclusion? Why?

Tips:

- Student groups differ greatly in what they like: let them choose if they want to act the roles or write blogs.
- You can finish the activity by discussing a real case, the stolen Mongolian dinosaur (J. Hecht. 2014. Save the Dinosaurs; http://goo.gl/DtwKwe).

Hand-outs with the fossil examples (Appendix)

CONCLUSION

The evolution of dinosaurs is a fascinating and useful topic to help students learn how science, conservation, and ethics work, and all this basic knowledge has an important effect on our future (Carter, Infanti, and Wiles, 2015).

There are many ways to take advantage of dinosaurs. For example, Eliyahu (2014) used paper cuttings and comic strips to learn about meiosis with a fictional reptile, and May (2014) designed activities equally ingenious and inexpensive to calculate the speed of a dinosaur, simply using paper footprints.

Other teachers have developed interesting activities to study evolution, even with students biased against science because they come from anti-scientific environments (Saunders & Taylor, 2014; Schauer, Cotner, & Moore, 2014).

Based on your knowledge of each group of students, you can decide which activities to use and the order in which they will be more successful. Computers are more attractive for students inclined to technical activities (Activity 1), while more extroverted or artistic students may prefer Activities 2 and 3.

What is important is that these activities are flexible because they combine individual work with group interactions: I suggest letting students choose, while you focus on *motivating them*.

Motivation becomes easy with dinosaurs and other fossils because some of them had fantastic features appealing to young minds; for instance, the *Spinosaurus aegyptiacus* was apparently semi-aquatic (my daughter has a real *Spinosaurus* tooth that she values highly), and the incredible *Microraptor zhaoianus* had *four* wings!

As recommended by Krupa (2014), narrative is a good way to motivate the class, so you may start by telling your students how one of the most extraordinary fossils found in the last thousand years, a hadrosaurus with richly fossilized skin, was not discovered by a famous scientist, but by Tyler Lyson, a high school student! I can't think of a better example to motivate young minds about their enormous potential in the world of science.

ACKNOWLEDGMENT

I thank Zaidett Barrientos for inspiring this article with her comments on errors in dinosaur reconstruction; and Sally Horn (University of Tennessee, Knoxville) and S. R. May for valuable suggestions to improve the manuscript. I also thank Mariana Rodríguez for her support with the text and Sergio Aguilar for help with figures and cards.

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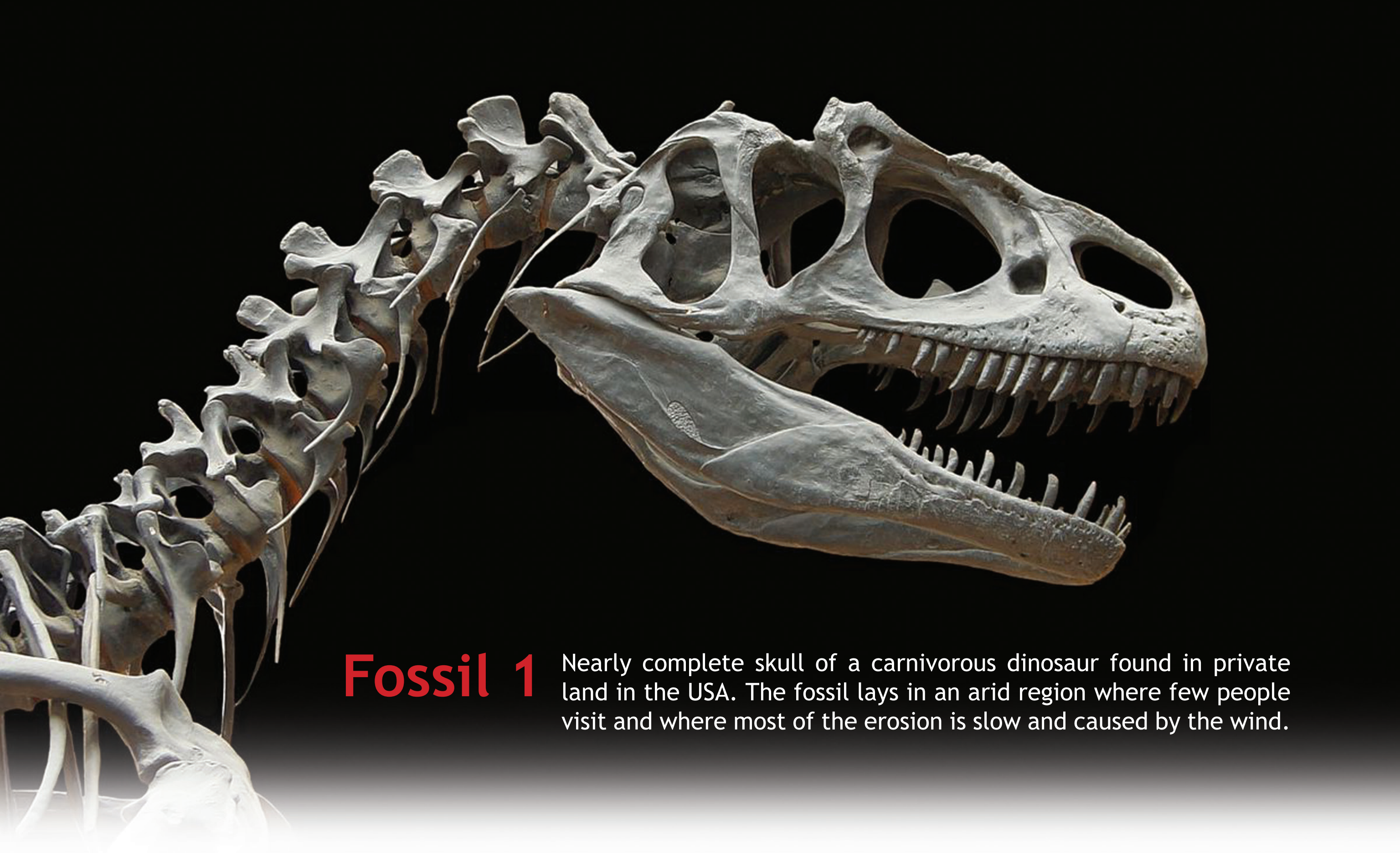
APPENDIX

Cut Cards



Fossil 1

Nearly complete skull of a carnivorous dinosaur found in private land in the USA. The fossil lays in an arid region where few people visit and where most of the erosion is slow and caused by the wind.

Fossil 2

Small, half complete dinosaur from Brazil, judging from the size it may be an immature specimen and it looks like nothing that has previously been found. It was exposed by the waves in the base of a cliff where rock falls are a frequent problem.

Fossil 3

Large herbivore dinosaur found in the Sahara desert in northern Africa. It was found in a region plagued by crime and civil unrest where a small local museum was recently destroyed by rebels.

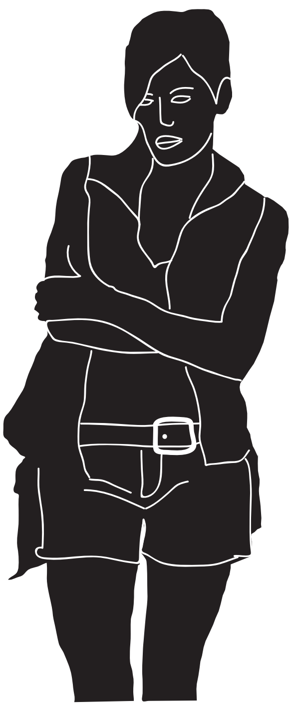
Fossil 4

Feathered dinosaur from eastern China, incomplete but the feather impressions show great detail. It was found by a poor farmer when preparing his land to plant sorghum. Fossils smuggling carries extremely heavy penalties in the country and China has world-class scientists.

Fossil 5

Complete dinosaur with large eye sockets found in Antarctica in an area that was briefly exposed by melting during the summer.

Cards with identity information (Appendix)

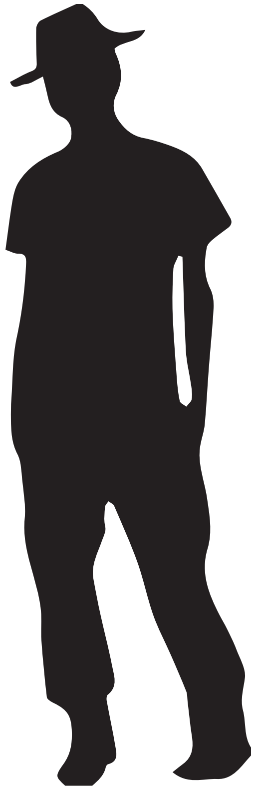


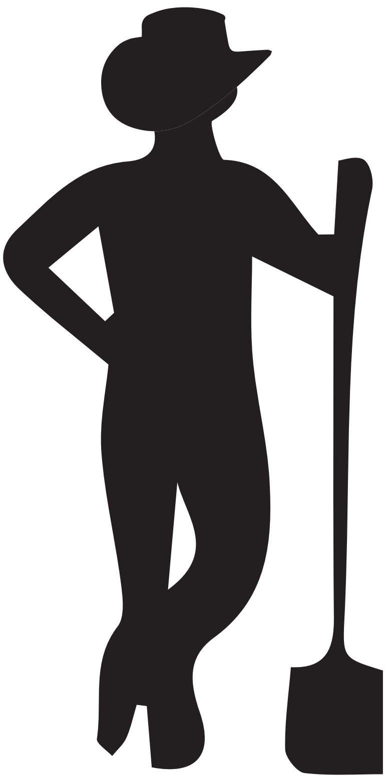
Amateur collector

You have always been interested in the fossils and know that if you find one, and sell it in the illegal market, you can get paid the same amount of money that you make for five years of work in your normal job; and that for a couple hours work! But if you are discovered, you can spend years in jail and perhaps even not come back alive. Your heart is divided.

Fossil dealer

You know that fossils extracted without scientific procedures lose valuable information but your position is that institutional researchers are insufficient to extract and preserve the vast number of fossils lying on the ground, so that dealers help society by providing fossils to amateurs and researchers alike. Your motto is “honesty, knowledge and experience”.





Museum paleontologist

You are a professional paleontologist with a museum job that you love. You were fascinated by fossils since childhood and now believe that fossils must only be extracted using a scientifically valid procedure. Otherwise they have little, if any, scientific value because you cannot know when and where these animals lived, what others species shared their ecosystem and what their habitats looked like.