Introducing Evolution to Non-Biology Majors via the Fossil Record: A Case Study from the Israeli High School System

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In a much-repeated quote (first stated in the pages of this very journal), Theodosius Dobzhansky (1973), one of the framers of the Neo-Darwinian evolutionary synthesis wrote, "Nothing in biology makes sense, except in the light of evolution." Yet, the core theory of biology has proven to be very difficult to teach to students, both in high school and university. The reasons for this difficulty include perceived conflict with religious doctrine, lack of practical laboratory experiments, and the belief in "alternative" theories to Neo-Darwinian evolution (Ron, 1995).

However, the greatest difficulty would seem to be student inability to comprehend natural selection – a fundamental element of evolutionary theory and the most emphasized topic of evolution in most biological curricula. Research indicates that even after instruction, students in both high school and university often reject natural selection for a different understanding of evolution, including Lamarck's theory of the "inheritance of acquired characteristics," anthropomorphism, or teleology (Bishop & Anderson, 1990; Brumby, 1984; Demastes, Settlage & Good, 1995; Demastes, Good & Peebles, 1995, 1996; Jensen & Finley, 1995, 1996; Jimenez, 1992; Lawson & Thompson, 1988; Settlage, 1994; and Tamir & Zohar, 1991).

Natural selection can be difficult to understand because it is dependent upon understanding processes (such as mutation or genetic drift) that are not easily visualized and are therefore abstract to the student. Fensham (1985) has shown that the majority of students have difficulty with abstract thinking. However, research also shows that concrete, hands-on learning experiences can mediate such difficulties (Novak, 1976;

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Orion, 1993; Piaget, 1970). With regards to evolution, a primary source of concrete evidence lies in the fossil record. Thus, we suggest that fossil materials might provide these all-important hands-on learning experiences, bridging the gap between the concrete evidence of the geological record and the abstract mechanisms of natural selection.

Indeed, we argue that one of the difficulties with teaching evolution is that because it often focuses on abstract processes such as mutation, the student is often unable to believe and thus accept the possibility of evolution. Scheffler (1965) argues persuasively that believing a concept is at least one of the stages in learning that concept. In ignoring or downplaying the fossil record, educators might be losing an opportunity to convince students of the validity of evolutionary theory. This is even more important when attempting to introduce such a subject to a group of students with little conceptual background in biology, as is the case with this study.

A second advantage of using the fossil record in introducing evolution is that it emphasizes that this process largely occurs in geologic time. Indeed, many educators and scientists list geologic time as one of the fundamental concepts in developing an understanding of evolution (Trowbridge, 1992; Keown, 1988; Wicander & Monroe, 1993). Thus, the *National Science Education Standards* (NRC, 1996) have made the understanding of "deep time" a major component of the middle school standards, wherein students first encounter learning materials focusing on the origins of the solar system, the Earth, and life on Earth.

Yet, in most biological programs where evolution is taught, this critical element is largely ignored in favor of the genetic component of evolution. To address this problem, Dodick and Orion (2000a) designed a curriculum "From Dinosaurs to Darwin" that emphasizes the temporally influenced evolutionary changes that have affected the Earth's biota.

In this paper, the authors discuss both the curriculum (its design as well as learning strategies) as well as a short case study focusing on an implementation cycle in a single high school class. The class participating in this program consisted of 22 earth sciences students in an urban high school in Israel, with little or no background in biology. Indeed, in this characteristic, it was typical of the 15 classes of students that have so far participated in this implementation. The program "From Dinosaurs to Darwin" contributed the fourth point of their five-point matriculation in the earth sciences.

This class was chosen for implementation because the subject material of the program expanded on a required element of their earth sciences program, "History of the Earth," which focuses on the physical and biotic changes affecting the development of the Earth. Concurrently, it provided the researchers with a chance to test this (new) program in evolutionary biology on a population of students that was not taking (and thus not affected by) the Israeli matriculation program in biology.

In presenting this case study, the authors considered the following questions:

1. After exposure to the program, can students reconstruct the fossil environment based both on geological and biological (evolution) principles?
2. Do students understand the concept of geological time and its relationship to evolutionary biology?
3. Did the students enjoy learning the program?
4. Which learning strategies were the most effective for teaching the program?

The Program

Curriculum

"From Dinosaurs to Darwin" starts from the understanding that the fossil record is (possibly) the best concrete evidence for evolution. Based on this understanding, it was decided that the program would emphasize reconstructing the evolutionary changes that have affected the Earth's biota in deep time, rather than on the evolutionary mechanisms that are the usual focus of Israel's high school biology program. Thus, it was designed to complement the traditional biological program, which emphasizes the genetic component of evolution.

The program can be divided into three units.

INTRODUCTION

As the basis for the entire unit, it has two primary foci: defining the basic materials of a fossil investigation, and understanding the temporal relations between such materials so it is possible to reconstruct their environmental and evolutionary relationships. It consists of two chapters:

What Is a Fossil?

This chapter provides basic definitions on how fossils (the organic record of the past) and rocks (the inorganic record of the past) are defined and classified as scientific information. Emphasizing the historical development of "paleontology," this chapter's structure is based upon Rudwick's (1985) book, *The Meaning of Fossils.*

Matter & Time

This chapter focuses on the understanding that the relationship between fossil and strata is key to understanding evolutionary and environmental change in time. To build this understanding, this chapter focuses on a field exercise that tests the students' ability to reconstruct an ancient marine environment. The learning strategies are based on the model of Orion (1993) and Orion and Hofstein (1989, 1994) for integrating field trips in a high school earth science class. This consists of three stages:

1. A preparatory unit in which students participate in concrete learning activities associated with the specific field site.
2. A field trip, in which the students participate in structured activities in the field (rather than passively listening to a field guide as is the case with many field trips). The field trip consisted of an excursion to Mahktesh Hatira, a natural crater-like feature in the central Negev region of Israel. As this field trip required an entire day (with a total travel time of 4-5 hours on a rented school bus), it was necessary to receive cooperation from both the teachers and administration, so that the students could take time off from their other classes to participate in this activity.
3. A summary unit taught in the classroom that focuses on the complex, abstract questions that arise from the field trip.

EVOLUTION & THE FOSSIL RECORD

Armed with a better understanding of the distribution of fossils in geological time, the students can tackle macroevolutionary problems. This unit consists of three chapters:

The Dinosaurs – A Hot Debate Over Cold Blood

This chapter is based on an ongoing controversy, how to reconstruct the thermal physiology of the dinosaurs. On a more general level, it demonstrates how scientists might reconstruct the adaptive patterns of any group of extinct organisms.

Central Features of the Fossil Record

In this chapter, students encounter the evolutionary changes that circumscribe the fossil record. Its structure is influenced by Gould's (1988, 1997) critique of the standard textbook representation of evolution as a time line populated by a series of organisms marching in a straight line with man in the lead. Such a representation of evolution is often incorrectly interpreted as a linear series of appearance, extinction, and replacement by the next life form. Thus, in a series of activities, students learn that evolution in geological time might better be represented by a phylogenetic tree emphasizing temporal scale.

Macroevolution

As its name implies, macroevolution is concerned with large-scale changes in evolution, such as the development of new body plans (for example, the transition from non-flying to flying animals) or the evolution of any new group of animals at, or above the level of species. Macroevolutionary change generally occurs on the scale of geological time, with fossils as its primary evidence. This unit focuses on the ongoing debate concerning the rates of evolution as well as the physical causes of catastrophic extinction.

INDEPENDENT INVESTIGATION

This unit consists of in-depth research projects concentrating on macroevolutionary change as witnessed in the fossil record. These projects are a continuation and incorporate elements of the materials that the students learned in the unit on Evolution and the Fossil Record.

Sample topics include: the evolution of birds, mass extinction, and modeling geological time. The format of such projects was flexible and included (traditional) written papers, posters, class or multimedia presentations.

Organizing Activities

Organizing activities were designed so as to help students integrate the knowledge that they had learned during the program. In Table 1, the authors outline the types of activities that were designed for this program and where they were implemented.

Evaluation

As part of the development process two questionnaires were distributed to the students both prior to and following the learning of the program: a geological time assessment test (GeoTAT) containing a series of cognitive puzzles testing the students' ability to understand the temporal relationship between strata and the fossils that they contain (see Dodick & Orion, 2000b) for a full description of this tool), and; a knowledge questionnaire which tested the students' understanding of (macro)

Table 1.
Organizing activities for the curriculum "From Dinosaurs to Darwin: Evolution from the Perspective of Geological Time."

CHAPTER	ORGANIZING ACTIVITY	DESCRIPTION
Chapter 1 What Is a Fossil? Chapter 2 Matter and Time	Field work assignment	Students survey the Mahktesh Hatira fossil site in southern Israel. In their final reports, the students reconstruct the biological and geological factors that transformed the environment of the Mahktesh between the Late Jurassic and Early Cretaceous periods. This activity is based on the tripartite field study model suggested by Orion (1993) and Orion and Hofstein (1989; 1994).
Chapter 3 The Dinosaurs – A Hot Debate over Cold Blood	Class debate	In small groups, the students research an element of the dinosaurs' life habits (for example, locomotion) to see how it influences science's understanding of their physiology. The students use such evidence in a group debate concerning the thermal physiology of the dinosaurs. In essence, this activity mimics on a small-scale how scientists critically evaluate an issue in science.
Chapter 4 Major Features of the Fossil Record	Class presentations	Students build a phylogenetic tree of evolution based on research about the major features of the fossil record (for example, the development of terrestrial life). The tree is built in a jigsaw-like fashion via small group oral presentations, based on the format of MacDonald (1989).
Chapter 5 Macroevolution	Class debate	Using case studies from the literature, students participate in a class debate evaluating the gradual and punctuated models of speciation.

evolution. In addition, a third questionnaire, that tested the students' attitudes towards the learning program, was distributed post program. The first author was present in the classroom to observe and participate in both the implementation and evaluation of this program.

Outcomes

Evaluation of the unit showed overall improvement both in the students' cognitive understanding of geological time, as well as evolutionary phenomena. In fact, in almost all of the questions tested in the GeoTAT and knowledge questionnaires, the students improved their performance. Not surprisingly, the geology students were more successful in those questions stressing a connection to the earth sciences, but there was still an overall improvement in their understanding of biological evolution. This is reflected both in the post questionnaire results, as well as the final projects, which were routinely quite sophisticated in their description of evolutionary phenomena.

Breaking down the results of the individual questionnaires reveals a number of important trends in student understanding; in addition, it permits us to identify which learning activities and strategies were most effective.

Cognitively, the students found it easier dealing with temporally ordering fossil layers than reconstructing their biological and depositional history. The relative ordering of geological layers is a more concrete skill in which all of the evidence (the layers) is present. Indeed Ault (1981) found that, at its most basic level, children as young as five have the ability to perform basic tasks such as superposition. Thus, there was a large improvement in the students' understanding of fossil correlation (i.e., temporally ordering fossils from different localities based on their relative position in different stratigraphic layers).

In contrast, reconstructing transformations in time involves a more abstract level of thought because it relies on visualizing what is not presently observed. Given the proper knowledge base, children as young as 11 can successfully represent such transformations (Montagnero, 1996). Such a knowledge base allows a child to reconstruct the unobservable stages of a transformation. In this program, simulations and (**especially**) fieldwork were utilized to improve the students' ability to reconstruct events.

Indeed, the authors stress that fieldwork is the integral element in this process. This assertion is corroborated by the research of Dodick and Orion (2000b). When comparing grade 11 and 12 earth science majors with non-earth science majors, the researchers found that the geology majors were significantly superior in representing transformations in time. We also suggest that such fieldwork is a key element in understanding evolutionary transformations in time. It might be added that the students themselves also recognized the value of the fieldwork exercise; on the attitudes questionnaire they gave it the highest rating in both the categories of "the activity which contributed to my learning" (4.27, on a scale of 1-5) and "most enjoyable activity" (4.27).

In terms of changes in knowledge of evolution (as represented in the fossil record), the students showed a strong improvement in explaining (macro) evolutionary transitions. For example, when asked about the development of flowers in plants prior to the program, students would suggest that "they acted as a food source for the plants or animals." Post program, the majority of the students knew that "flowers attract insects, permitting the plant to multiply and survive." Although many misconceptions remained, for an introductory program in evolution, this represents substantial improvement.

This change was all the more impressive as it was based on the strategy of using small group oral presentations, a learning strategy that is quite unfamiliar to Israeli students. Nonetheless, the students demonstrated that they were able to learn from their classmates' presentations. Moreover, based on results culled from the attitudes' questionnaire, the students recognized the importance of this strategy, rating it above average (3.46 on a scale of 1-5) in the category of "the activity which contributed to my learning."

More problematic for the students was conceptualizing the temporal scale of evolutionary time. Although the students improved their ability to assign absolute dates to such events, they had greater difficulty in understanding that the majority of these events are confined to the last 11% of geological time. This lack of correlation between absolute age and scale indicates that for students, long expanses of time remain an abstraction that might be remembered as information to be recalled, without a corresponding meaning. Difficulties with proportional thinking, overestimation, and sheer size of numbers were all connected to this problem.

Although the students did not accurately locate the event time, they were closer to the correct temporal figures post program. In other words, they had reduced their overestimation of the chronology. This suggests that the strategy of building an association between evolutionary events (represented by concrete fossil materials) and their chronology is fundamentally sound in theory. Moreover, individual students were more successful in understanding the chronology of events they had researched in their group projects. Still, to be successful, students need time so that they assimilate the relationship between chronology and event.

Conclusions

Research has shown that students of all ages have difficulty learning evolution. The program "From Dinosaurs to Darwin" based on the concrete evidence of the fossil record was an effective tool for introducing the concept of evolution to non-biology majors. By the end of the program, the students were able to describe and explain sophisticated macroevolutionary events. Moreover, the students better understood the concept of geological time and how science defines it.

We suggest that implementing a unit that integrates the fossil record (macroevolution) and the genetic mechanisms of evolution might alleviate many of the problems that students have in understanding this complex topic. If non-biology majors benefit from this exposure, there is good reason to think that biology students will also benefit from it.

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