

## **Evolution Education and the Nature of Science: Strategies for the Classroom**

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### **Abstract**

*There is a critical need for effective evolution education. This paper highlights some of the evidence that demonstrates that need and analyzes several aspects of the nature of science and how it can be illustrated during the course of evolution instruction. Biological evolution is a critical component to understanding the biodiversity of life on earth. Teachers and students of science alike, address the topic of evolution as a series of facts which tend to focus greatly on definitions and descriptions about life on earth while missing the underlying scientific methodology which was and is currently being used to explain how living things have evolved over time. The teaching of evolution coupled with an understanding of the nature of science (NOS) can provide teachers with a strong pedagogical tool to address important aspects in evolution education (Nickles, et al. 1996). Special emphasis is placed on the concept that science is testable; predictions and explanations about the natural world are based on empirical evidence; and knowledge and information about the natural world can be gathered through scientific experiments and data analysis. Finally, a variety of practical recommendations of effective methods for applying the approach of combining the topics of evolution and the nature of science are presented.*

**Keywords:** Biological evolution; Nature of science; Empirical evidence; Data analysis

### **1. Introduction**

Most biology teachers would agree that biological evolution represents a unifying theory and a common thread within the biological sciences and how the methodology of science is practiced. Unfortunately, the available evolution education literature provides little practical guidance on how to effectively blend evolution content with science process. As a result, the topic of evolution along with its various mechanisms such as mutation, gene flow, genetic drift, and natural selection, can assist students and teachers of science alike make sense of complex and diverse biological concepts, while at the same time providing students with an opportunity to engage in the scientific processes found within the boundaries of the nature of science (NOS) (Smith, et. al. 1995).

What is biological evolution? How does it work? What types of questions does evolution try to answer? What processes do scientists use to try and explain the variety of life on earth? These and numerous other questions regarding the (NOS) can serve as an ideal tool for students and teachers alike within courses such as biology, chemistry, physics, and the earth sciences. It is human nature to be curious and to ask questions about the world around us in order to better understand it. Biological evolution, along with its historical development, and the nature in which scientists collect and analyze empirical evidence can help students make sense of diverse concepts, such as mutation and genetic variation, Mendelian population genetics, selection and mutation, migration, genetic drift, non-random mating/inbreeding, and quantitative genetics.

One way of knowing or understanding our world is through the biological sciences. The biological sciences developed around a specific form of rationality which we know as inductive thought. Scientists were able to describe and explain the general principles or mechanisms involved in everyday observed natural phenomena through observation, experimentation, and collection of empirical evidence. As a result these nature of science principles formed the foundation of organized knowledge across the scientific disciplines such as biology, chemistry, physics, and earth science. As a result, the aforementioned scientific methodologies such as observation, hypothesis generation, experimentation, gathering of empirical evidence, and data analysis should also be associated with learning within the science classroom.

Yet there is an overwhelmingly heavy emphasis on learning scientific facts without a clear indication on how those facts were collected and analyzed. Thus, the student the student will memorize the content without learning the process of science.

## ***2. Science as a Way of Knowing***

The National Academy of Sciences (2008) defines science as “the use of evidence to construct testable explanations and predictions of natural phenomena, as well as the knowledge generated through this process” (pg 10). Science involves particular ways of knowing about the world (Moore, 1999). Scientific ways of knowing include: proposing a testable framework of questions and ideas based on observations; providing predictions and explanations about the natural world based on empirical evidence; and gathering information and knowledge by conducting experiments and/or through analyzing data (CDE, 1990).

Recent studies have indicated that accepting and comprehending evolution is related to understanding the nature of science (Lombrozo, et al. 2008). Numerous research articles and books have been published during the past decade concerning the curricular and pedagogical aspects of the NOS. Given the vast amount of research conducted by science educators during the past 20 years a consensus has emerged highlighting the fact that students tend not to learn science content meaningfully (Osborne, et al. 2003). As a result of the research, several core NOS ideas have emerged as well such as those highlighted above.

While delivering evolution content to students, teachers can examine the nature of science understanding, by referring to the Understanding Science website <http://undsci.berkeley.edu/>. This website provides teachers with a wealth of free resources that accurately communicates what science is and how it really works.

## ***3. Proposing Testable Questions through Observation***

The nature of science also refers to how science distinguishes itself from other bodies of knowledge along with the particular methodology it uses to collect data through the use of empirical standards, logical arguments, and skepticism, as scientists ‘compete’ for the best possible explanations about the natural world (NRC, 1996). Biology teachers have an opportunity to address both past and current evolution content, along with asking students inquiry-based questions such as “How do we know?” and “What does the data reveal?” One way in having students address these and other testable questions involves the use of observation. Though state and national science standards and the science education literature promote attention to the processes of science, and observation in particular, the research on student conceptions of the role and importance of observation within the study of science seems limited. Further reviews of the science education literature have revealed that when science process skills are emphasized in the classroom, student proficiency on individual skills increases, some transfer of skills to new situations is applied, and skills are retained over time (Padilla, 1990).

Charles Darwin conducted and recorded numerous observations during his five-year (1831-1836) voyage around the globe. Darwin’s data collections and meticulous record keeping included observations he made on the flora and fauna of the Galapagos Islands. Darwin later considered these observations as a critical component to this central argument for the mechanism evolution; natural selection. One such observational component included the Galapagos Marine Iguana, which he compared to the South American mainland iguana. In doing so, Darwin observed the differences and similarities of numerous related organisms found on the Galapagos Islands and the mainland of South America. Darwin also observed and described animal behavior as another line of observational evidence (NAS, 2001). Science teachers today can include Darwin’s observations along with a discussion of animal behavior as examples of observational evidence. The National Science Teachers Association (NSTA) in conjunction with the Smithsonian Institution developed a website entitled Galápagos Education: Resources for Teaching Evolution, which can be found at <http://www.nsta.org/publications/interactive/galapagos/resources/page1.html>

This web site supports teaching and learning about biology, ecology, geology, and the unifying concepts of science. It also provides teachers with material they can use in the classroom to help students develop testable questions and use direct and indirect observational data to help explain some of the mechanisms involved in biological evolution.

#### **4. Scientific Predictions and Explanations Are Based on Empirical Evidence, Data Analysis, and Experimentation**

In common usage, an explanation is a statement made to clarify something and make it understandable. In science, explanation means something more concrete. Scientific explanations consist of three specific parts: claims, evidence, and reasoning. A claim is an assertion or conclusion that answers the original question. Evidence is scientific data that supports the student's/scientist's claim. It must be appropriate and sufficient. It can come from a scientific investigation, or other sources such as observations, reading material, or archived data. Reasoning is the justification that links the claim and evidence. It shows why the data counts as evidence to support the claim, using appropriate scientific principles.

Science relies on and demands evidence collected from the natural world. Evolution in its simplest form can be described as change over time. Learning about the evolutionary processes and patterns of changes of the various mechanisms described in this article such as mutation, gene flow, genetic drift, and natural selection gives students an opportunity to predict and explain the various scientific concepts that have shaped the history of life on earth. Scientists regularly provide relevant data or evidence in support of evolution which include information from an array of scientific fields. Empirical data taken from the fossil record, developmental biology, biochemical and genetic relatedness among organisms, geologic and geographic distribution of organisms, comparative anatomy, embryology, and physiology all contribute to the vast amounts of evidence for evolution, biological diversity, and the history of life on Earth (Hoffman and Weber, 2003).

The various types of evidence described above not only provides scientists with vital data that establishes both the importance and reality of evolution itself, the data also provides support and validity of its mechanism; namely, natural selection. Here also teachers have another opportunity to point out a major theme in the NOS to their students, namely, that the various forms of evidence described above, do not all represent the same kind of scientific data. Students can also explore the various ways evolutionary biologists collect evidence which can include historical, observational, and experimental types of data. Today, scientists and science educators have continued to apply a wide range of critique, analysis, and techniques while at the same time providing a robust understanding of biological evolution.

There are numerous online resources which are freely available to science teachers that provide opportunities for students to analyze scientific data pertaining to topics which relate to biological evolution such as genetics and design their own online experiments. One such resource is VCISE (Virtual Courseware in Science Education) <http://www.sciencecourseware.org/vcise/>. VCISE is a collection of interactive, online simulations designed to enhance traditional middle and high school science curricula by providing supplements to experimental laboratory or field work. The inquiry-based activities emphasize the nature of science in general and scientific methodology in particular. Students develop testable questions, make observations, propose hypotheses, design experiments, collect and analyze data generated by the online simulation, and synthesize and communicate results through an electronic notebook and an online report.

#### **5. Science and the Natural World**

Science along with its methodology is limited to studying phenomena related to the natural world. In other words, science relies on data and empirical evidence which can be collected and experimented on. Those questions which relate to realms outside of the natural world are NOT scientific and cannot be put through the rigorous processes of scientific experimentation and evidence collection. Religion, questions of morality, ethics, cannot be tested in the scientific sense and thus are not and could not be included in science. Intelligent design, creationism, religion, and faith are considered super-natural and as a result they are not a part of the science.

Science and religion are two different ways of making sense of our world. Science relies solely on empirical evidence, including human observations of natural processes. As a result, inferences and explanations about natural phenomena are tentative and can change when new evidence or data becomes available. The key here is the idea of empirical evidence--not belief. The majority of scientists around the world agree that evolution occurs among organisms and that the mechanism for evolution, namely natural selection, is responsible for causing speciation (i.e., one species evolving into another). All organisms on Earth, from bacteria to *Homo sapiens* (humans), have undergone speciation, with natural selection being the primary cause.

However, scientists are still collecting data on the specific molecular and ecological mechanisms that drive natural selection, and have driven it in the past (Scott, 2004).

Scientists must work to provide evidence of natural occurrences that happened in the past, in the absence of witnesses. They do so by collecting as much evidence--both direct and indirect-- as possible (i.e., the fossil record, geological record, DNA analysis, etc.). Religious explanations are based on belief, not empirical evidence, and as a result are outside the realm of scientific understanding.

### **6. Implications for Teachers**

Biological evolution is most often presented as an infinite and fact oriented description of natural phenomena of seemingly unconnected content and activities. Uncovering the ideas behind the mechanisms of biological evolution can allow for the integration of the various nature of science themes described above. This in turn provides a further opportunity to reveal to students the interconnectedness of science content with process.

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