# Synthesizing Scientific Knowledge:
# A Conceptual Basis for Non-Majors Science Education

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## Abstract

Using the evolution of the universe as an organizing conceptual framework allows for a natural synthesis of all scientific knowledge. With this concept as a foundation, I developed a curriculum that provides nonscience majors with a coherent scientific picture of our world. This synthesis addresses the basic need that all students have for reliable, coherent knowledge about their world.

## Introduction

> "When the inquiring [person] analyzes the facts as [they] find them, [they] have indeed made the beginning for a rational view of the world: but [they] have made only a beginning. Science analyzes experience, yes, but the analysis does not yet make a picture of the world. The analysis provides only the materials for the picture. The purpose of science, and of all rational thought, is to make a more ample and more coherent picture of the world, in which each experience holds together better and is more of a piece. This is a task of synthesis, not of analysis." (Bronowski, 1977, 253)

The beginning of the twenty-first century is a unique point in human history. Thanks to developments in cosmology and physics, it's now possible to build a coherent picture of the entire evolutionary history of the universe. I have taken advantage of this in developing a new non-majors science curriculum that uses the evolution of the universe as its conceptual framework. In this paper I explore the conceptual basis of this curriculum for teaching science to non-majors.

## A New Curriculum

Between 1997 and 2002, I developed and taught this new curriculum in an introductory course for nonscience majors at Western Washington University (WWU) in Bellingham, Washington (Alles, 2001). Over those 5 years, I taught 16 sections of the course to a total of 1300 students. Introductory non-majors science courses at WWU are a general education requirement for graduation. Despite pervasive apathy toward such courses, the assessment of my curriculum (based on student performance and student evaluations) has been positive.

The course maintained a reasonable amount of rigor with an overall class average of 79 percent and a median of 80 percent. As a measure of grade inflation (or lack thereof), approximately 16 percent of the students earned a grade of A– to A. By comparison, the national average in higher education for A– to A grades is estimated to be 26 percent (Levine & Cureton, 1998).

In addition, my students have given me hundreds of written evaluations, the great majority of which have been positive. Overall, on a 1 to 5 scale running from very poor to excellent, the course has consistently been rated a 4 (very good).

One concern I had in developing a new curriculum was whether it could be used by other instructors and other institutions. Because of circumstances at the time, I had complete academic freedom to choose what I taught, and was, therefore, free to innovate. But other instructors teaching non-majors science courses may not have the same degree of freedom. Many of them when first asked to teach a non-majors science course may find the curriculum already structured by the textbooks available or chosen by others.

One ray of hope for escaping the domination of textbooks over curriculum is that the Internet can make innovative curricular material readily available to all science instructors whether they teach in public high schools, community colleges, or universities. Most instructors should be able to obtain administrative approval for using such material off the web, if the conceptual justification for its use can be shown. What follows, then, is my conceptual justification and explanation of this new curriculum.

## Two Conceptual Issues

There are two issues, one from emerging science, the other from science education, that provide the central rationale for a new curriculum for non-majors science education. The first conceptual issue is from the study of causality in physics and astronomy. A modern scientific understanding of causality shows the universe to be an historical system with a beginning, cumulative change through time, and a potentially intelligible end; in a word, it has evolved. In this sense evolution describes a type of causal relationship just as random, determined, and chaotic describe other types of causal relationships (Dennett, 1995).

Many of the traditional disciplines of science study the evolution of historical systems through time. Biology's organizing concept is the evolution of living things; geology centers on the evolution of the planet Earth; and astronomy on the evolution of the universe (Lerner, 2000). The understanding that emerges from these organizing concepts is that the process of evolution is not confined to organic systems, rather, natural evolutionary algorithms are a fundamental characteristic of our universe (Alles, in press). The concept of the evolution of historical systems through time, therefore, provides a framework for a natural synthesis of all scientific knowledge.

The second issue is the relationship between public school science education and religion. The conceptual relationship between science and religion is a major issue in our world today. And it is clear, given the controversies surrounding the teaching of evolution in American public schools, that scientific knowledge impinges directly on beliefs and values (Pennock, 1999). We are, nonetheless, ethically and rationally compelled to provide reliable knowledge about the world to our students. If we do our jobs well as science educators, they should be able to obtain a clear picture of the physical reality of our world.

An ethical issue arises, however, when we do not provide students with reliable information about the physical world by avoiding unpopular subjects such as evolution. If we avoid these subjects, we are promoting ignorance over scientific knowledge. Whether or not students can understand this is a function of the mental baggage they bring with them to the classroom (NRC, 2000), for which we are not ethically responsible. But in either case, whether they understand the ethical issues involved or not, we must concern ourselves with the integrity of our teaching without regard to things beyond our control.

To the best of our abilities as science teachers, we must convey to all nonscience majors the broad outline of what science can reliably tell us about our world. The two issues above provide a conceptual basis for a curriculum that allows us to serve both the purpose of scientific knowledge (to make a more ample and more coherent picture of the world) and our ethical obligation as educated adults to better our world.

## Coherence and Consilience

By analyzing the fundamental assumptions of the scientific enterprise, it's possible to provide a conceptual justification for using the evolution of historical systems as the basis of a curriculum for non-majors science education. Epistemology, the systematic study of the origin, nature, methods, and limits of human knowledge, is an important part of the philosophy of science. One of the fundamental epistemological assumptions of science is that the goal of science is to understand the world of experience—the natural, physical world. Implicit in this goal is the assumption of realism—that there is an external, physical world that exists apart from our internal, mental existence.

Coherence is the epistemological condition that within science there must exist a logical consistency between the theoretical frameworks and conclusions of all the sub-disciplines of science. What lies behind coherence is the assumption that cause and effect are continuous in our universe, that all of nature is causally one event. Dividing science into separate disciplines is a product of reductionist methodology and the need for intense specialization by scientists (Greene, 1997). But it is not a reflection of reality. There is, in reality, only one body of scientific knowledge because there is only one natural world with which science can concern itself. Our practice of subdividing science is, in this respect, a matter of convenience that allows individual scientists to specialize.

Consilience is the characteristic that a scientific theory has when it provides a unifying explanation for many separate areas of study (Wilson, 1998). Some examples of consilient scientific theories are plate tectonics in geology, general relativity and quantum mechanics in physics, and evolution by natural selection in biology. Consilience presupposes the unity of knowledge that follows from the assumptions of realism. That is, if there is only one real world, then all true knowledge will be coherent and contribute jointly to understanding that world.

Consilience is the goal of science (NAS, 1998). But because of the intense need for scientists to specialize, it has fallen to science educators to provide the synthesis in building a more ample and more coherent picture of the world from the fruits of scientific analysis. Teaching a naturally integrated science curriculum, such as I have developed, is a step toward this goal.

## Curricular Organization

In developing the curriculum, it became clear that there were three distinct units of content that had a logical order of presentation. What follows is a brief description and explanation of the curriculum's organization.

The course I taught at WWU using this curriculum lasted ten weeks (one quarter) and included 28 lectures. Class size was typically a hundred or more students. A limitation on teaching such large classes is on any form of class discussion. I have had success, however, using a discussion format when teaching the course during the summer when class size is limited to thirty students.

In place of a textbook, I put the material I developed for teaching the course on my teaching web site for my students' use. Based on student comments and written evaluations, this is viewed as a real improvement to the course. I have since added additional curricular material for science instructors so that detailed information about the curriculum is available on the web.

Because its length can be easily adjusted, I have consistently used the term “curriculum” rather than “course” to refer to the program of study I developed. What I've already shown is that the curriculum can be successfully condensed into a ten week course. Doing the reverse, by developing the curriculum into a series of two or three courses for a full academic year, can be easily done by increasing the level of detail.

### *Unit One: The nature of science—Why is scientific knowledge credible?*

We can not assume that nonscience majors who take our science courses are either willing or able to accept scientific knowledge as credible. Numerous surveys have been conducted on the beliefs and attitudes of the general public toward science. For example, the Gallup Poll has conducted surveys on the public’s acceptance of evolution for twenty years. In March, 2001, Gallup named two theories and asked which one those surveyed believed in more—creationism or evolution. “Given this choice, more than half of Americans say they believe in or lean toward the ‘theory of creationism’ while far fewer believe in or lean toward the ‘theory of evolution’ (57% for creationism vs. 33% for evolution) and one out of 10 say they are unsure. The public has not notably changed its opinion on this question since Gallup started asking it in 1982.” (Gallup News Service, 2001, 2)

To find out if college students have the same beliefs as the general public, my WWU colleagues and I conducted a survey of 460 students taking introductory biology and physics courses for nonscience majors during the winter quarter of 2002. The results of this attitudinal survey, which used several of the same questions from the March 2001 Gallup poll, suggest that approximately 20 percent of WWU students who are nonscience majors reject evolution in general and human evolution in particular (Alles, unpublished data).

Given this state of affairs, and assuming that WWU does not have an unrepresentative student body, it is important that any non-majors science course begins with a unit on the history and philosophy of science to clarify why scientific knowledge is the most credible and reliable knowledge we have of the physical world (NAS, 1998). Unit One, which I cover in four lectures, contains three main topics devoted to defining what science is: the epistemological values of science, the origin of modern science, and science as a profession.

Presenting the nature of science at the beginning of a non-majors science curriculum allows for the presentation of the epistemological issues that surround the teaching of evolution, namely the nature of acceptable evidence. By showing students the contrast between what is acceptable evidence in science as opposed to what is acceptable evidence in theistic religions, specifically divine revelation and the word of authority, we set the stage for a non-confrontational presentation of evolutionary theory.

Presenting the origin of modern science serves to show when the rejection of the word of authority that led to modern science first began. Portraying how science operates as a profession shows how this epistemic value is maintained. This method of defining science focuses attention on the commitment of science to using only physical evidence in trying to understand the natural world.

### *Unit Two: The conceptual framework of science—How can we organize our knowledge of the natural world?*

In studying the evolutionary history of the universe it’s possible to identify natural hierarchical levels of organization in nature (Bronowski, 1977). These levels are characterized by their stability through time and can be identified by a unique scale in size, a new spontaneous self-organization of matter, and new emergent properties or processes. Examples of these natural levels are the quantum, subatomic, and atomic phases of the early universe (Silk, 2001). This natural hierarchy provides a logical mental framework for all scientific knowledge and reveals the following characteristics of our world.

- There is a chronological sequence in which the universe developed.
- Levels of stable phenomena are built upon other more basic levels.
- These levels of stable phenomena have accumulated through time.
- Life on Earth is one of these natural levels of stable phenomena.
- The natural algorithms of evolution (Dennett, 1995) can explain the development of all these levels of stability.

Using this conceptual framework, every aspect of the traditional non-majors science curriculum can be covered, but now in a logically coherent fashion that builds progressively on itself. The topics of Unit Two, which are covered in nine lectures, include cosmological evolution, natural levels of organization in the physical world, biological evolution, life as a chemical function (biochemistry and genetics), and the modern synthesis (Darwin and Mendel).

This portion of the curriculum is devoted to explaining the process of evolution. To do so, it's necessary to show the fundamental causal mechanisms that lead to evolutionary change. Cosmological evolution, as the most inclusive view of evolutionary change, provides the opportunity to explain the causal relationships behind evolution not only in biological systems but in the universe as a whole (Alles, in press). Presenting cosmological evolution also allows the introduction of the early history of the universe from the Big Bang, to the formation of the first stars and the nucleosynthesis of heavy elements. This sets the stage for the formation of our solar system and the planet Earth that is presented in Unit Three.

### *Unit Three: The history of nature—How can we integrate all of scientific knowledge into "a more ample and more coherent picture of the world?"*

Unit Three includes fifteen lectures and continues the chronological narrative of the evolutionary history of our universe from Unit Two. This unit includes the topics: the formation of our solar system and the planet Earth, geologic time, the origin of life, photosynthesis, aerobic respiration, endosymbiosis and eukaryotic cells, sexual reproduction, multicellularity, adaptive radiations and mass extinctions, vertebrate evolution, and human evolution.

In presenting the history of life on Earth, I've changed the emphasis from the traditional concentration on the Phanerozoic Eon in favor of the more fundamental events of the Precambrian. This allowed me to concentrate on prokaryotic evolution including such milestones as the evolution of photosynthesis, aerobic respiration, and the endosymbiotic evolution of eukaryotic cells, followed by the evolution of sexual cellular reproduction and the evolution of multicellularity in eukaryotes. This sequence emphasizes the major features of all of life on Earth.

At each of the major events in the history of life, such as the evolution of photosynthesis and aerobic respiration, I bring the subject to the present and relate it to living organisms and their interactions as a part of an ecological whole. By doing so I am able to tie an understanding of the evolution of life on Earth to an understanding of the intimate relationships of the living world today.

## Background and Resources

As novel as it may seem to use the evolutionary history of our world as the framework for teaching science, there has been a long standing recognition of the integrating power of presenting scientific knowledge in a holistic framework such as the evolution of the universe. The difference between these earlier attempts at synthesizing scientific knowledge and today, however, is both the quantity and quality of what we now know about the history of nature.

Natural history has been out of favor in science education for some time, but the evolutionary history of nature, as opposed to natural history, holds the key to understanding the world we live in. This may explain why astronomers, geologists, and paleontologists, all of whom study the evolution of historical systems through time, have been the leaders in integrating scientific knowledge for the general public.

Some examples include the astronomers Carl Sagan in his book *Cosmos* (Sagan, 1980) and Timothy Ferris in *Coming of Age in the Milky Way* (Ferris, 1988), Preston Cloud, a geologist, in his book *Cosmos, Earth, and Man: A Short History of the Universe* (Cloud, 1978), and the paleontologists Stephen Jay Gould in *The Book of Life* (Gould, 1993) and Richard Fortey in his book *Life: A Natural History of the First Four Billion Years* (Forty, 1998). An outstanding exception to this is the mathematician and philosopher of science, Jacob Bronowski. His BBC television series *The Ascent of Man* (Bronowski, 1973), first aired in 1973, set the standard for those who followed in synthesizing scientific knowledge and the nature of science for the general public. All of the books cited above were written for the interested general public. Together they serve as an accessible and intelligible resource for teaching this curriculum.

## Summary

Thanks to advances in science during the last 40 years, we now have available a scientific "story" of the universe in which all scientific knowledge can be synthesized into a coherent narrative. This both provides the proper format (historical narrative) and fulfills the purpose of scientific knowledge (to make a more ample and more coherent picture of the world).

The fundamental goal this story fulfills is to provide reliable knowledge that every individual needs to establish the context of their lives. This need for having an informed sense of time and place is expressed in our minds as we construct our worldview. As Bronowski put it, "When the inquiring [person] analyzes the facts as [they] find them,

[they] have indeed made the beginning for a rational view of the world..." (Bronowski, 1977, 253).

We must assume, in the absence of evidence to the contrary, that our students are inquiring persons who are beginning to build a rational view of the world, and that it is our responsibility as science educators to provide them, in as coherent a fashion as possible, the scientific knowledge about our world that is available to us today. The curriculum I developed provides this knowledge in a logically coherent and effective way. And hopefully, other science educators will also be able to use this curriculum to help their students build a rational worldview "in which each experience holds together better and is more of a piece."

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