KNOWING THE NATURAL WORLD: THE CONSTRUCTION OF KNOWLEDGE ABOUT EVOLUTION IN AND OUT OF THE CLASSROOM

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KNOWING THE NATURAL WORLD: THE CONSTRUCTION OF KNOWLEDGE

ABOUT EVOLUTION IN AND OUT OF THE CLASSROOM

By

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Evolution is a central underlying concept to a significant number of discourses in civilized society, but the complexity of understanding basic tenets of this important theory is just now coming to light. Knowledge about evolution is constructed from both formal and “free-choice” opportunities, like television. Nature programs are commonly considered “educational” by definition, but research indicates the narratives often promote creationist ideas about this important process in biology. I explored how nature programs influenced knowledge construction about evolutionary theory using a combination of qualitative and quantitative approaches. Because misconceptions about evolution are common, I examined how students’ conceptual ecologies changed in response to information presented in an example of a particularly poor nature film narrative. Students’ held a diversity of misconceptions, proximate conceptions, and evolutionary conceptions simultaneously, and many of their responses were direct reflections of the nature program. As a result, I incorporated the same nature program into an experiment designed to examine the effects of narrative and imagery on evolution understanding. After completing an extensive pre-assessment that addressed attitudes and beliefs about science knowledge, students viewed one of four versions of the nature program that varied in the quality of science and imagery presented. The effect of watching different versions was only vaguely apparent in students with a moderate understanding of evolution. The relationship was much more complex among students with a poor understanding of evolution but suggested a negative effect that was more influenced by public discourses about this “controversial” subject than conceptual understanding. The relationships warranted examining learning from the perspective of the consumers of these programs. I surveyed audience beliefs about the educational value of nature programs and found that an overwhelming majority believed the programs were “educational” and designed to teach about nature. The results were particularly alarming because beliefs about the educational value may strongly impact learning outcomes. An informal survey of nature programs aired during a “sweeps” month indicated that poor presentation of science, and specifically evolutionary theory, was indeed the norm. Indeed, nature programs may be contributing to the “deconstruction” of knowledge about evolution both in and out of the classroom.
Acknowledgments

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CHAPTER 1.
INTRODUCTION

Antibiotic resistance, gene therapy, disease, food production, environmental quality, and biotechnology are all areas of active biological research that address issues of public concern. Indeed, all of these are issues where being an informed citizen requires an understanding of evolution. Yet many Americans hold serious misconceptions about evolution and the process of science (Nelson, 2000; Rudolph & Stewart, 1998; Southerland, Abrams, Cummins, & Anzelmo, 2001; National Science Foundation, 2006). The form of misconceptions can range from misunderstandings about terminology (e.g., “adaptation” and “fitness”; Alters & Nelson, 2002; Bishop & Anderson, 1990) to misunderstandings about the process (e.g., the sources and causes of change – focusing on individuals rather than populations; Bishop and Anderson 1990; Greene, 1990). These misconceptions can have far-reaching effects. Indeed, proponents of intelligent design take advantage of these types of misconceptions, held so commonly by the general public, to foster consideration of their “alternative theory” in education. School boards from Darby, Montana, to Dover, Pennsylvania, have voted to include, or are seriously considering adding, intelligent design or creationism as part of the science curriculum in their schools. Less than half of the American population accepts the theory of evolution (National Science Foundation 2006), and the issue of whether and how evolution is taught in public schools remains highly contentious. Science classes taught without evolution will not only impact future citizenship but a future workforce in biological research as well. Nevertheless, most adults are removed from formal education settings,
and they must rely on other educational opportunities at the interface of science and society to learn. Therefore, to counter these alarming trends, evolutionary biologists and ecologists must look to all learning opportunities, both formal and free-choice/informal, to educate the general public about one of the most fundamental concepts in biology. My research explores how nature programming produced for television interacts with viewers’ knowledge and understanding to ultimately affect their understanding of evolution.

Exploring the contributions of learning that takes place outside of school is a complex task, and theories about the nature of learning in these environments draw on a variety of disciplines. Lucas (1991) suggests several issues that need to be addressed to examine the impact and utility of informal sources of science learning. For example, how do people process the information presented to them, and do authority and source affect processing? And what should we expect of these informal sources given that often they are intended to be both entertaining and educational (Lucas 1991)? Recently, researchers have started incorporating theories about how people learn science in school to learning in museums and other informal environments (Anderson, Lucas, & Ginns, 2003). Indeed, this approach strongly supports a view of learning that recognizes that the concepts held by individuals are the result of more than just the formal explanations learned in school. Learning involves a complex combination of school experiences, as well as culture, language, and personal experiences and observations (Wandersee, Mintzes, & Novak, 1994). In fact, the role of the individual in knowledge construction is reflected in the use of “free choice” terminology: “free-choice” science education implies
some intrinsic motivation of the learner, “informal” refers to the setting of the learning event, i.e., outside the formal school setting (Falk, 2001).

Television is one source of free-choice science education, and it can be a powerful tool for mass communication. More than 280 million television sets are in use in the U.S., and these sets are turned on 5 hours/day on average (Nielson Company, 2009). These viewing habitats suggest that most people will spend more of their lives watching television than they will in school. Moreover, broadcasted programs are available 24 hours per day, and channel diversity is increasing. Indeed, over half of the general public (51%) considers television their leading source of science news and information (National Science Foundation 2006). Recently, cable and satellite markets have expanded to include stations with science-based programming within an entertainment context; The Learning Channel, Discovery Channel, and Animal Planet broadcast programs with considerable science content. Along with the trend for internet videos, the conversion to digital television will increase the number of channels even more. As a result, the likelihood that individuals will be exposed to science programming that will affect their understanding of ecological sciences is high.

The accuracy with which nature programs actually represent nature has received much attention recently. Both Bousé (2000) and Mitman (1999) clearly endorse embracing a highly skeptical view of the reality presented in wildlife films, warning that this genre is driven by the need for compelling story lines rather than scientific accuracy. In fact, the most beautiful and engaging nature films often include narratives that endorse creationist accounts of life on earth (Dingwall & Aldridge, 2006). As part of the narrative, many wildlife films individualize the “struggle for existence”; they humanize
the dramas (e.g., the orphan that struggles to survive and returns victorious to breed) that can mislead viewers to teleological and Lamarckian misconceptions about evolution. Indeed, Aldridge and Dingwall (2003) and Dingwall and Aldridge (2006) show that references to evolution in nature programs are often teleological – that is, they imply evolution is driven by some purpose. These authors conclude that the narratives in this genre actually increase the differences in understanding of evolution between the general public and biological scientists (Dingwall & Aldridge, 2006). They note “it is highly questionable whether wildlife and nature programming is making an appropriate contribution to the preparedness of civil society to deal with key issues in biological and environmental sciences” (p. 148).

Indeed, the video images so important to a well-crafted program may interact with the narrative and become powerful “virtual witnessing” events (Kirby 2003, see also Graber, 1990). The “plausibility” of pictorial images can have extensive impacts. For example, scientific reconstructions of bat-winged pterosaurs were so influenced by early artistic interpretations that Padian (1987) notes, “a picture is not only worth a thousand words; however inaccurate, it may be worth a wealth of well-documented evidence to the contrary” (p. 76). Clearly, virtual witnessing can result in an epistemological impact difficult to overcome, especially with socially controversial topics such as evolution. Research into the effects on learning from one beautifully crafted nature film suggests that the misconceptions presented in the narration do indeed affect undergraduate students’ understanding of evolution (Bright, Brewer, Snetsinger, & Perkins, 2003).

The essence of the problem, then, is that people continue to learn outside of the classroom, and they may be incorporating mixed messages into their understanding
depending on the formal and informal science sources from which they draw their knowledge. Moreover, learning can be gradual and assimilative, implying incremental changes in individuals’ conceptual understanding; or learning can be rapid, involving a substantial restructuring of knowledge (Mintzes & Wandersee, 1998; Mintzes, Wandersee, & Novak, 1997). Personal experiences comprise a powerful source of perceived evidence that can be incorporated into “lay theories” about how the world works. Where these lay theories relate to ecology, and evolution in particular, they can lead to misconceptions that can be very difficult to alter (Wandersee et al., 1994). So, if a nature program resonates on some level with individuals’ “lay theories” about evolution, it may have long-lasting effects on learning. For example, people identify with individuals, not populations, and the concepts of “improvement” and “adaptation” frequently are applied to individuals overcoming adversity – everyone loves the triumph of the underdog. Whether this application stems from a personal experience (such as a sibling that overcomes a serious disease) or an experience they perceive from watching television (such as the orphaned cheetahs that survive in the harsh and cruel savannah), it may end up as an unconscious embodiment of the process of evolution. Of course these events are relevant to biological evolution; who survives and who does not underlies a major component of fitness and the process of natural selection. The focus on changes within an individual, however, misrepresents the fundamental process of evolution – a turnover among individuals within populations.

Evolution is a complex concept, and the path of least resistance is often the wrong one. Picture someone relaxing in front of a large, high-definition television watching a gorgeous nature film with a carelessly articulated narrative. Narration that incorporates
teleology as a mechanism may not directly promote alternative “theories” to evolution, such as “intelligent design” (Dingwall and Aldridge 2006), but it can promote alternative conceptions nonetheless. Conceptual change is a complicated process, however; concepts about evolution may be so interwoven that a change in one requires a change in many others (Demastes, Good, & Peebles, 1996). New concepts cannot be easily learned if alternative models that explain a phenomenon already exist in the learner’s mind (Committee on Undergraduate Science Education, 1997). If undergraduate biology majors do not have an adequate understanding of evolution even after a year of college biology (Nehm & Reilly, 2007), how can we expect them to interpret beyond the misconception-laden narratives of nature programs? Lawson and Weser (1990) show that introductory non-major college biology students who were more skilled in reasoning, however, were less likely to hold nonscientific beliefs than were students less skilled in reasoning. Therefore, other metrics of understanding related to reasoning and epistemological beliefs may be required to address the interaction between formal and informal sources of science knowledge.

Personal epistemology, or beliefs about knowledge, may be closely tied to an individual’s learning outcomes about evolution. Numerous models are available that address how individuals’ beliefs about the certainty, source, justification, acquisition, and structure of knowledge affect learning (see Duell & Schommer-Atkins, 2001). Researchers generally agree that these beliefs play an important role in learning. For example, if people believe knowledge is certain and passed down by authority figures, they are less likely to question authority in the classroom (Schommer-Atkins, 2004) or in free-choice learning environments. This can be particularly worrisome with regards to
“ill-structured” problems (problems that cannot be solved with a high degree of certainty; King & Kitchener, 1994) and controversial or socioscientific issues (issues that require consideration of societal interest, effect, and consequence; Sadler 2004). Many ecological issues can be framed within these contexts. Epistemological beliefs, therefore, may be important in the interpretation of evidence regarding controversial topics, such as the relationship between human immunodeficiency virus and the AIDS syndrome (Kardash & Scholes, 1996), animals used in research (Zeidler, Walker, Ackett, & Simmons, 2002), and evolution (Sinatra, Southerland, McConaughy, & Demastes, 2003).

Similarly, epistemology is a component of the Nature of Science (NOS) framework (Sandoval, 2005). Many educators advocate teaching and learning the nature of the scientific endeavor to help students overcome misconceptions about evolution and other socioscientific issues (e.g., Khishfe & Lederman, 2006; Lombrizo, Thanukos, & Weisberg, 2008; Nelson, 2000; Pigliucci, 2007; Scharmann & Harris, 1992; Working Group on Teaching Evolution, 1998). NOS also is complex, however, involving abstract concepts such as uncertainty and the tentative nature of conclusions. Certainly, teaching NOS has met with mixed results (e.g., Abd-El-Khalick & Lederman, 2000; Akerson, Morrison, & McDuffie, 2006; Khishfe & Lederman, 2006; Nehm & Schonfeld, 2007; Sandoval & Morrison, 2003; Scharmann & Harris, 1992), and the research addressing how NOS affects evolution understanding is limited (Crawford, Zembal-Saul, Munford, & Friedrichsen, 2005; Lederman, 2006). Nevertheless, a sophisticated understanding of NOS may be a valuable indicator of the acceptance of evolutionary theory.

What, then, is the influence of nature programming on knowledge development related to ecology and evolution? Ultimately, two kinds of information are needed: (1)
whether viewers have and use the knowledge the nature program expects, and (2) what knowledge viewers actually have and use to understand the nature program (Livingstone, 1998). Providing viewers with knowledge they can use about evolution when watching nature programs depends on conceptual understanding of science and evolution. Wildlife and nature films that present evolutionary science poorly may be particularly insidious if audiences perceive the genre as educational. The prior experiences audiences have with specific genres are critical in their textual readings and interpretation of new experiences – for example, audiences expect certain types of character and plot development in soap operas because of past experiences with soap operas, and they interpret these elements in light of those past experiences (Livingstone, 1998). Moreover, emotional connections affect recall and memory (Fujioka, 2005). Past experiences with educational programming may leave audiences unaware that narratives in wildlife and nature programs are shaped from dramatic perspectives rather than real-life perspectives (Bousé, 2000; Mitman, 1999). For example, in wildlife programs orphans are often main characters in narratives, but life history evolution predicts that in species with high parental care (as in most charismatic megafauna), orphans will rarely survive to adulthood. Wildlife and nature programs are traditionally considered documentaries, a title that confers meaning to audiences, yet they routinely incorporate drama, adding emotional effect, so much so that Bousé (2000) suggested “docu-drama” as a more accurate label.

In my research, I examined the educational impact of wildlife and nature programs that address ecology and evolution (Figure 1.1). The overarching question for my work was “How does television affect learning about evolution and the natural
world?” Learning implies incorporating the “correct” information into knowledge schema. The public understanding of science is fraught with misconceptions, especially regarding difficult, and in the U.S. controversial, topics such as evolution. Ultimately, individuals draw on a web of knowledge sources that may or may not reflect current science understanding. Therefore, stemming from this broad overview question, I explored whether or not poor representation of science resulted in development or enhancement of misconceptions from a constructivist context. Specifically, I asked:

- Does the poor representation of scientific concepts in television lead to misconceptions about evolution?
- Does personal epistemology and/or prior knowledge affect the influence of wildlife and nature programs on evolution understanding?
- Do audiences perceive wildlife and nature programs as educational, and if so, does that perception influence their interpretation?
- If audiences do turn to wildlife and nature programs for educational content in the free-choice marketplace, are they getting good quality educational content?
- If understanding the nature of the scientific endeavor is important to acceptance of evolutionary theory, how early can we begin to teach these important concepts?
Figure 1.1. The research model. C2-C7 represent the chapters that address these theoretical constructs.
Overview of Dissertation

Chapter 2. Literature Review: Evolution in education and discourse

Purpose: To examine the context of the research by examining the relevant literature

This research is highly interdisciplinary, bringing together communication, conceptual change, cognition, educational psychology, evolution education, personal epistemology, public understanding of science, and television production. Throughout, the challenges of the nature of the scientific endeavor affect the decisions we make regarding the nature of knowledge, our acceptance of uncertainty, and the extent we accept the reality science paints. Chapter 2 reviews the literature related to evolution in education and discourse in this light, exploring how the controversy arose, the development of the theory of evolution, and finally how the controversy is situated in the most influential public court of opinion – the marketplace of ideas.

Chapter 3: Fatal Flower frailties: Using nature films to help address misconceptions about evolutionary theory

Purpose: To explore the conceptions students have about evolution and to determine the impact a curriculum based on the film Fatal Flower has on those conceptions.

➢ Does the poor representation of scientific concepts in television lead to misconceptions about evolution?
Understanding evolution is important to citizenship, but ever since the topic was returned to the science classroom in the late 1930s, educators have struggled with how to teach this complex theory. Students bring prior knowledge to the science classroom, prior knowledge that clearly affects learning (Clough and Wood-Robinson, 1987; Posner, Strike, Hewson, & Gertzog, 1982). Their concepts about processes, such as evolution, are often quite different from scientific explanations. These naïve conceptions arise from a number of sources, including (1) those that begin with vernacular issues related to the interpretation of “adaptation” and “fitness;” (2) those derived from personal experiences, like overcoming disease, or raising pets; (3) those that come from informal sources (television, internet, families, religions), such as wives tales about the nine lives of cats; and (4) those that arise because formal education does not adequately address the prior conceptions that students hold, resulting in newly constructed or modified alternative conceptions (Alters & Nelson, 2002; Committee on Undergraduate Science Education, 1997). It is especially important that formal education engage prior conceptions because the frameworks established in school affect whether knowledge construction outside of the science classroom reflects scientific thinking. Wildlife and nature programs are appealing and popular experiences, but they often represent evolutionary science poorly (Aldridge & Dingwall, 2003; Dingwall & Aldridge, 2006). If nature programs are used as a source of learning outside of formal classrooms (or if they are used unconditionally within the science classroom), then individuals are more likely to construct knowledge that does not reflect scientific thinking. However, these programs may be valuable tools in the science classroom, allowing teachers to use the narratives as examples of inadequate explanations of the evolutionary process.
Within a climate of controversy surrounding evolution education, the imperative for research in student understanding is that much greater. The only consistent result from a quarter century of research, however, is that broad misconceptions persist despite coursework (e.g., Chinsamy & Plagányi, 2007; Jensen & Finley, 1996; Nehm & Reilly, 2007). Meaningful learning may necessitate the reconstruction of a significant segment of the learner’s conceptual and propositional framework to include general and broadly inclusive concepts (Posner et al., 1982; Mintzes et al., 1997; Nussbaum, 1989). More recently, efforts have focused on the intricacy of student thinking and explicit approaches to overcoming misconceptions. Understanding evolution requires knowledge of a diversity of concepts that ranges from descriptive (e.g., populations and species) to highly abstract (e.g., genes and probabilities) (Lawson, Alkhoury, Benford, Clark, & Falconer, 2000). Therefore, research that addresses the conceptual ecologies students hold may provide valuable insight to how evolutionary knowledge is constructed and reconstructed.

This chapter explores the results of a curriculum designed using the nature program, *Fatal Flower*, as a surrogate for students’ conceptions, providing valuable insight to how students think about evolution in the context of their personal relationship with their television experience. The curriculum uses the nature program to draw out student misconceptions as a means to cultivate conceptual change. Specifically, the research addresses the prediction that patterns of students’ misconceptions will include more scientific conceptions after experiencing the curriculum than before. More importantly, the design of the curricula provides a unique opportunity to examine the
diversity of conceptions students hold at a single point in time as they transfer their knowledge among similar circumstances.

Chapter 4: Seeing is believing: The impacts of nature film narratives on student understanding of evolution

Purpose: To determine whether viewers incorporate the information presented in television shows into their conceptual understanding of evolution

- How important are misconceptions perpetuated in broadcast television to knowledge construction?
- Does prior knowledge, understanding of the nature of science, and/or personal epistemology affect the influence of wildlife and nature programs on evolution understanding?

Aldridge & Dingwall (2003) and Dingwall & Aldridge (2006) argue that wildlife film narratives may not necessarily espouse alternative theories to evolution, but they embrace an unexpectedly large number of teleological elements. Because the narrative does nothing to convey the scientific account, viewers simply hear the narration without disrupting whatever prior framing they have brought to the viewing, eventually leading to an opening for creationism or “intelligent design” accounts of evolution. Indeed, the video may serve as a powerful “virtual witnessing” event (Kirby, 2003), resulting in an epistemological impact difficult to overcome with controversial topics such as evolution. Although nature programs vary considerably in their structure, the ‘blue chip’ sub-genre focuses on the organism in an environment of visual splendor, using a dramatic story line
with a “grand” voice over, and marked by the absences of politics, people or historical reference points (Aldridge & Dingwall, 2003; Bousé, 2000). Sadly, the magnificent photography in these programs is marred by the most egregious abuse of evolutionary science. I use an experimental manipulation of one nature program to explore how this sub-genre of nature and science programs influences knowledge and knowledge retention, the prevalence of misconceptions, and the application of knowledge gained from broadcast.

*Fatal Flower* uses beautiful imagery in a traditional ‘blue-chip’ natural history film that explores how different species of orchids have adaptations that enable them to be pollinated by specific pollinators (insects and birds). These pollinators in turn have adaptations that allow them to extract the nectar from specific orchids that they are dependent on for food. Thus, from an educational perspective, the film appears to be an excellent example of co-evolution and natural selection. Unfortunately, the film is full of misconceptions (both intentional and inadvertent) and is a poor example of science in nature films (Dissertation Appendix 1).

Preliminary examination of the results from the curriculum suggested that the narration of *Fatal Flower* may indeed affect students’ understanding of evolution, but essential data were lacking. I developed an experimental design that included manipulation of the films narrative and imagery coupled with pre- and post-assessments to determine the effects that poor presentation of evolution may have on students’ conceptions. I predicted that a new version of the narrative that reflected an accurate presentation of evolutionary theory would enhance evolution understanding whereas the misconception-laden original would not. In addition, I predicted that if the video
functioned as a virtual witnessing event, then the imagery would greatly affect people’s attention (both in terms of viewing and in terms of learning). Reducing the films visual imagery to still images and/or less attractive imagery than the original version would partition the effects of visual and narrative effects on understanding. As a result, the experimental design included four versions of the program (original, manipulated narration/original imagery, original narration/manipulated imagery, manipulated narration/manipulated imagery).

Chapter 4 presents the results from pre- and post-assessments of students watching different versions of Fatal Flower. The chapter addresses whether narrative and imagery affected student conceptual understanding of evolution and explored the potential indirect effects these types of visual “experiences” had on schema construction. The chapter addresses a number of predictions:

1. Well-produced nature films provide a “virtual witnessing” experience for viewers.
   1a. Viewers incorporate the narrative framing into their understanding of evolution (e.g., teleology, environment as the driving factor for change).
   1b. Viewers incorporate specific examples of imagery into their schema for understanding evolution.

2. Poorly produced films (still imagery) will not serve as virtual witnessing events.

3. Imagery and narrative interact in learning: viewers watching the revised narratives with the original imagery will be less likely to incorporate
4. Prior knowledge affects how the narrative framing is incorporated into conceptions;
   4a. Viewers with greater prior evolution knowledge will be less likely to incorporate misconceptions than those with little prior knowledge.
   4b. Viewers with an understanding of the Nature of Science (NOS) will be less likely to incorporate misconceptions than those with little prior knowledge.

5. Viewers’ personal epistemology affects how the narrative framing is incorporated into conceptions; viewers that believe that knowledge is certain, is handed down from authority, or that knowledge is simple, not complex, will be more likely to incorporate misconceptions than viewers that understand NOS.
   5a. Incorporation depends on whether viewers believe they are viewing educational programs (addresses the importance of credibility in personal epistemology).
   5b. Incorporation depends on whether viewers believe they are viewing programs designed to be educational (addresses the importance of authority in personal epistemology).

6. Viewers’ attitudes toward science and evolution affect how the narrative framing is incorporated into conceptions.
6a. Viewers that accept scientific inquiry as a way of thought will be more likely to incorporate misconceptions than viewers that do not.

6b. Viewers that believe the age of the earth is less than 6000 years will be more likely to incorporate misconceptions than viewers that do not.

Chapter 5: What is “educational” in a free-choice science world? Determining what audiences believe about the educational value of nature programs

Purpose: To explore the goals and expectations audiences have coming into a free-choice learning opportunity.

➢ Do audiences perceive wildlife and nature programs as educational, and if so, does that perception influence their interpretation?

Nature film narratives are often fraught with misconceptions about evolution (Aldridge & Dingwall, 2003; Dingwall & Aldridge, 2006), but they are afforded a level of credibility as documentaries about the natural world (Bousé, 2000). Unfortunately, individuals who are motivated to learn from these free-choice opportunities also are most likely to incorporate the broad knowledge messages that are communicated (Falk, Heimlich, & Bronnenkant, 2008; Maurer & Reinemann, 2006). Research usually approaches free-choice learning experiences from the educator’s perspective; the underlying assumption is that these sources of science learning are good, quality sources reflecting correct and current understanding. From the audience’s perspective, defining a free-choice experience as “educational” is problematic because individuals must either already possess the knowledge to assess the quality of the experience or rely on an
assessment applied by some other source. In the “marketplace of ideas,” audiences are not necessarily always able to judge the true value of competing ideas, and to distinguish science from non-science. Audiences must look to descriptors like “educational” as they consider free-choice learning experiences. So, individuals motivated to learn about nature may assume that misconception-laden nature programs are providing an adequate explanation of important ecological processes, such as evolution.

Personal epistemology also may have an important role in the impact wildlife and nature programs have on the viewing public’s understanding of evolution. Indeed, beliefs about knowledge play an essential role in learning. If viewers believe knowledge is certain, then they may accept the information presented in wildlife films without question. Similarly, if they believe knowledge is passed down from authority figures, they may be even less likely to question the authority of free-choice learning environments.

I surveyed potential wildlife film audiences to determine their understanding of the educational context of wildlife films (e.g., are they meant to be educational? Are they credible sources of information?) Missoula, Montana, is host to the International Wildlife Film Festival each spring. Because the festival expends considerable effort to engage the community, the likelihood that individuals have at least thought about wildlife and nature films should be higher than a random sample of all adults in the U.S. My approach was to assess public literacy regarding nature programs, with the assumption that the sampled population would represent a slightly higher estimate of scientific literacy with respect to nature programs than the public at large.
Whether an individual defines something as educational or not depends on the context. The survey I developed operationalized educational through a series of questions designed to get at a specific context. For example, if a participant believed a nature show was educational, then they might be more likely to believe it was accurate, that the content was reviewed/approved by scientists, it told a story that really happened, it presented the most current scientific understanding, people should learn from watching it, it did not give wildlife human characteristics, and the content was reviewed/approved by other filmmakers. In addition, if a wildlife/nature film was designed to be educational, then viewers would be likely to believe that the primary goal of the program was to teach about wildlife and nature, the program was written to explain and clarify what we know about wildlife and nature, and the producers had advanced knowledge about wildlife and natural sciences.

This chapter presents the results of a large-scale audience survey to determine how the interpretations the audience makes of programs fits or challenges their prior experiences and the role their knowledge may play in interpretation of the narratives in wildlife and nature programs (Livingstone, 1998). Specifically, I predicted:

1. nature film audiences believe they are viewing educational programs (addresses the importance of credibility in personal epistemology), and
2. nature film audiences believe they are viewing programs designed to be educational (addresses the importance of authority in personal epistemology).
Chapter 6: Sources and sentiment: How nature programs may be leading science literacy astray

Purpose: To assess the science presented in nature and science programs.

- If audiences do turn to wildlife and nature programs for educational content, what is the quality of the educational content?

Despite enlisting science consultants during production, many wildlife and nature programs incorporate misconceptions about the science, especially about evolution (Dingwall & Aldridge, 2006; Dissertation Appendix 1). Misconceptions are one type of knowledge students bring into the classroom, and this prior knowledge clearly affects the outcomes of their learning experiences (Posner et al., 1982). In fact, the misconceptions evident in nature programs are highly similar to students’ ideas about evolution, materializing as teleological and need-based misconceptions about this important theory (Bright et al., 2003). Misconceptions can be especially egregious when they affect the public’s understanding of difficult and controversial topics, such as evolution. The theory of evolution is central to teaching biology, and public misconceptions have considerable impact on the inclusion of evolutionary theory in educational curricula. Certainly, public misconceptions about science may have broader affects if they impact decision making about topics with scientific foundations (e.g., forest thinning, genetically engineered crops) and public support for the scientific enterprise.

In a preliminary study, I designed the Science and Nature Program (SNaP) assessment tool to elicit the prevalence of misconceptions in wildlife and nature programming (Dissertation Appendix 1). I developed quantifiable criteria to evaluate
whether or not nature films represent science and the scientific process accurately and whether or not they use relevant metaphors to explain and interpret key ecological concepts. My goal was to create a rubric that could be used to analyze the scientific content of a broad selection of wildlife and nature programs.

Because SNaP permits quick and consistent assessment of the content available to viewers, it can be used to evaluate a large number of nature programs in short order. This chapter explores the science content, especially related to evolution, of programs appearing on the most popular nature programming channels during a “sweeps” month. If viewers are choosing to watch nature programs, they may do so because of their perceived educational value. “Educational” content that promotes misconceptions, especially about evolution, may significantly reduce the public’s understanding of evolution. Therefore, science educators need to be aware of this potential influence on prior knowledge both for the classroom and for civic discussions that involve evolution.

Chapter 7: Clio the Scientist: Using narratives to broaden the impacts of inquiry

Purpose: To determine the extent to which young children can be taught a complex subject such as the Nature of Science

- If understanding the nature of the scientific endeavor is important to acceptance of evolutionary theory, how early can we begin to teach these important concepts?

Understanding the nature of the scientific endeavor is critical to understanding evolution and evaluating science in civil discourse. The nature of the scientific process is very complex, however; even science teachers have difficulty grasping concepts such as
the tentative nature of conclusions and theory ladenness (Akerson, Abd-El-Khalick, & Lederman, 2000; Akerson et al., 2006; Lederman, 2006; Schwartz, Lederman, & Crawford, 2004). Because of these perceived difficulties, the paradigm for teaching the nature of science focuses on teaching very young students relatively simple views of science that do not require abstract thinking (National Research Council, 2007). Recent evidence indicates that children may be quite capable of sophisticated thinking, however, but most curricula do not reflect what is now known about younger children’s cognitive capabilities (National Research Council, 2007). In fact, early instruction in science can have lasting impacts (Novak & Musonda, 1991). Chapter 5 reports on a scientific inquiry about insect vision I developed for elementary school teachers and parents to help 1st and 2nd grade students explore issues related to the nature of science. Inquiry is a learner-oriented approach to scientific investigations designed to engage students in active learning. This inquiry includes a take-home story designed around the inquiry’s theme; students read the story at home with their families and re-visit concepts they learned in school during the inquiry about what scientists know and can know about insect vision.

One component of the National Science Foundation (NSF) GK-12 graduate funding through the Ecologists, Educators, and Schools program required that participants complete an original education research project for publication. This chapter not only fulfills that requirement, it provides valuable insight to how young children learn about the nature of the scientific endeavor.
Scientific Significance

This research will significantly advance our understanding of learning in the free choice/ informal science education sector. Few definitive studies have addressed how and when learning scientific concepts from television occurs, and attitude studies about perceptions of the environment after viewing nature programs do not examine the resulting scientific understanding of the environment or environmental processes (e.g., evolution) necessary for environmental, ecological, or scientific literacy. Indeed, Kozma (1994) suggested that it is time to move beyond concern with “proving” that media “cause” learning and begin to ask what the actual and potential relationships between media and learning are. My research will specifically examine what people learn about evolution from wildlife and nature programs. Moreover, insight into the interaction of personal epistemology, knowledge of the nature of science, evolution understanding, and informal sources of learning will facilitate theoretical development and allow us to build more accurate models of how people construct knowledge in the free-choice science information sector. Lastly, a more thorough understanding of how the public constructs knowledge about evolution will allow us to address this topic more thoughtfully in civic discourse.
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CHAPTER 2.
LITERATURE REVIEW:
EVOLUTION IN EDUCATION AND DISCOURSE

Never before in history has understanding evolutionary science been so important to the survival of the human species. Whether that understanding is directly related to our survival with issues such as antibiotic resistance, what have now come to be known as “super viruses”, and the struggle to understand and contain their influence – or less direct effects related to climate change and the impacts on biodiversity – a basic understanding of evolution is critical to civic and social decisions (Antolin & Herbers, 2001). These are broad topics where evolution plays a key foundational role. For example, resistance requires understanding how modifications within a population of bacteria come about and how time-honored drugs act as strong selective agents (Genereux & Bergstrom, 2005). Similarly, the outcomes of climate change may be extensive in terms of population variability and the ability to respond to new environmental conditions. Recently, with the threat of a swine flu pandemic, civically engaged people may turn to informal and free-choice science education sources to learn the facts, issues, and policies associated with the subject. Rarely will these sources address evolution, even though understanding the basic theory of evolution is a key element in solving and preventing outbreaks. Understanding the basic tenets of evolutionary theory has to be developed during formal education.
“There is probably no other single subject within the discipline of biology that has engendered as much misunderstanding and mistrust as has the subject of evolution.”

– Ehrle, 1960 (p. 276)

Antolin & Herbers (2001) report a case of a fundamentalist surgeon who unsuccessfully replaced a newborn’s heart with the heart of a baboon, without regard to evolutionary history, because it was the right size and shape. Clearly, the implications of policies that do not promote a strong and rigorous understanding of evolution in our educational system can be great. “Balanced treatment” legislation sets up a false dichotomy that implies only two viewpoints exist, despite mediating positions that have dominated evangelical academies for decades (Marsden, 1991). Similarly, the strengths and weakness legislation that passed in Louisiana “to allow and assist teachers, principals, and other school administrators to create and foster an environment within public elementary and secondary schools that promotes critical thinking skills, logical analysis, and open and objective discussion of scientific theories being studied including evolution, the origins of life, global warming, and human cloning” is a Trojan horse designed to allow alternatives to methodological naturalism to enter the science classroom. Critical thinking is already a requirement of scientific knowledge, and it brings an understanding and acceptance of a level of uncertainty about the kind of knowledge science generates. As science and technology progress, the proportion of science-related discourses in our society is likely to increase (American Association for the Advancement of Science, 1990), ironically at the same time legislation is eroding the very principles that have permitted the success we all enjoy.
Here, I examine both the ontological and epistemological commitments related to science and evolutionary knowledge in our society. I begin by examining the legal threats to evolution and science education, especially the shift in creationist tactics to redefine the nature and scope of scientific knowledge. This strategic shift necessitates an understanding of science as an endeavor and why the knowledge derived from this materialistic approach is so respected. As such, I explore the philosophical nature of science and the historical development of evolutionary theory in terms of ontological and epistemic assumptions. The theory of evolution is a complex subject, however, and evolution educators have been examining how people learn about this important topic for a quarter century. Obviously, understanding what educators know about how people understand evolution, the nature of science, and knowledge in general is important to putting this controversy in context.

Ultimately, it is a question of how the public understands science, however. Evolution is a socio-scientific issue (Sadler, Chambers, & Zeidler, 2004), and thus exists in an environment where knowledge can be idiosyncratic, and where free speech is the pre-requisite to “truth.” The “marketplace of ideas” is a competitive assortment of free-choice science education opportunities juxtaposed regularly with anti-evolution messages. The opportunities for individuals motivated to learn about the controversy are not always “educational” in terms of current science understanding, however, and potential audiences must have sufficient knowledge to assess the sources themselves or rely on other assessments of quality. As such, I conclude with an examination of one type of free-choice science learning opportunity afforded a high level of credibility as an educational resource, but whose contribution to science learning is highly questionable.
History of Fundamentalist Opposition

Formal public education in the U.S. arose out of a demand for access to education that was free and without regard to social class (Good, 1956). By the turn of the 20th century, Dewey (1916) had formulated many of his ideas about democratic education, arguing that in advanced societies learning by direct sharing was increasingly difficult as “much of what adults do is so remote in space and in meaning that playful imitation is less and less adequate.” Learning in a formal environment became disembodied from its social context – it became an act in and of itself (Bruner, 1966). Formal learning promoted ways of learning and thinking that were quite different from those nurtured in practical daily activities. Learning the sciences involved moving outside of a natural context – for example, numbers became things separate from their function as tools for determining length and no longer connected to that which was being measured (Scribner & Cole, 1973). Indeed, the interface of democratic education and non-contextual learning has been at the heart of the debate about evolution education ever since Darwin’s important treatise *On the Origin of Species (by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life)*. Dewey – ironically born the year Darwin published this famous treatise – was influenced by Darwin’s approach to science and how that approach could apply to education. He saw the battle to teach evolution as a matter of citizenship, overcoming opinion and emotion and taking a principled stand (Dewey, 1923).

Public education should help students overcome the fallacy of emotional argument and teach reason for making political and economic decisions (Dewey, 1924). Overcoming opinion and emotion is extremely difficult in science education. Unlike
science, controversies in science education come from sources outside of the field and grow from non-scientific considerations (Hildebrand, Bilica, & Capps, 2008). The clash of creationism and evolution is, in effect, a struggle for the control of public education and cultural hegemony (Taylor & Condit, 1988). It is a clash based on a fundamental criterion – the rise in methodological naturalism as an evidential requirement (Pennock, 2003).

The Scopes “Monkey Trial” was the most infamous event highlighting fundamentalist opposition to evolution, and it represented the first of many clashes between those embracing a literal reading of the bible and the burgeoning evidence for organic evolution. In 1925, Tennessee passed the Butler Act prohibiting teaching evolution in all schools, even Universities. House Bill No. 185 (Public Acts of the State of Tennessee, Chapter 27) focused specifically on Man’s place in the creation as taught in the bible. John Thomas Scopes volunteered to challenge the law using the textbook *A Civic Biology: Presented in Problems*, by George William Hunter, which included sections titled “Man’s place in Nature” and “Evolution of Man” (Hunter, 1914). Generally taking progressive stances in politics, William Jennings Bryan did not reject all of evolutionary biology, only human evolution (Larson, 1997). Conflated by the tenets of Social Darwinism, however, Bryan believed “Darwinism” caused German militarism in World War I and threatened traditional religion and morality (Marsden, 1991). Bryan typically joined movements in their final politicized stage (Larson, 2003), and the Scopes Trial was no exception. He assisted the prosecutor A. Thomas Stewart, an Attorney General of Tennessee (R. Moore, 1998). Although Scopes was found guilty (on the
insistence of Clarence Darrow), Darrow succeeded in casting doubt on strict ontological interpretations of the bible (R. Moore, 1998).

Evolutionists may have won in the court of public opinion, but not in the trenches of biology education. Evolution all but disappeared from high school textbooks until the late 1930s when two texts, though not popular texts, included extensive treaties on the theory (Grabiner & Miller, 1974). Unlike physics and chemistry, biology was considered a “soft” science, but in 1920, the Committee of Ten of the National Education Association recommended that biology be taught prior to chemistry and physics in high school curricula (McComas, 2007). Organizations that advocated science teaching as a profession soon followed. The National Association of Biology Teachers (NABT) was formed in 1938, in part, because of the inadequate place of biology in the curriculum in many schools and to facilitate the dissemination of biological knowledge (Riddle, 1938). In the next year, the Union of American Biological Societies, along with NABT, distributed a survey to biology teachers from across the US to determine the subjects related to biology that were taught. Results indicated that less than 50% of teachers taught evolution as the “principle underlying plant, animal and human origin” (Riddle, 1942). Pressure from school officials often was cited as a reason for not including evolution in the curriculum (Riddle, 1942). School administrators in Illinois, however, were more than happy to pressure students to attend “voluntary” classes in religion (Protestant, Catholic, and Jewish faiths), however. The common practice of mixing religion and education in public schools was about to be challenged with the First Amendment to the Constitution of the United States.
An earlier case about the expenditure of tax-raised funds related to Catholic instruction (Everson v. Board of Education 330 U.S. 1), had the court wrestling with the Establishment Clause in a 5-4 decision, but McCollum v. Board of Education, 333 U.S. 203 (1948) forced the U.S. Supreme Court’s resolution. In McCollum, the 8-1 decision was clear:

“This is beyond all question a utilization of the tax-established and tax-supported public school system to aid religious groups to spread their faith. And it falls squarely under the ban of the First Amendment (made applicable to the States by the Fourteenth) as we interpreted it in. There we said:

‘Neither a state nor the Federal Government can set up a church. Neither can pass laws which aid one religion, aid all religions, or prefer one religion over another. Neither can force or influence a person to go to or to remain away from church against his will, or force him to profess a belief or disbelief in any religion. No person can be punished for entertaining or professing religious beliefs or disbeliefs, for church attendance or nonattendance. No tax in any amount, large or small, can be levied to support any religious activities or institutions, whatever they may be called or whatever form they may adopt to teach or practice religion. Neither a state nor the Federal Government can, openly or secretly, participate in the affairs of any religious organizations or groups, and vice versa. In the words of Jefferson, the clause against establishment of religion by law was intended to erect ‘a wall of separation between church and State’’ (McCollum v. Board of Education, 333 U.S. 203, 1948).
The use of public funds to support religion, as opposed to science, was an important condition. As long as public monies were not involved, students were free to study religion (off of school grounds, and with their parents’ written permission; Zorach v. Clauson, 343 U.S. 306, 1952). Shortly thereafter, the launch of Sputnik I prodded fears of falling behind the Soviet Union technologically, and the U.S. government began providing federal money for new science textbooks – the Biological Sciences Curriculum Study (Grabiner & Miller, 1974). Evolution returned to the precollege curriculum. The fear of not being competitive in global science competition had cascading effects. The Butler Act, Tennessee’s antievolution law, was finally repealed in 1967 (Public Acts of the State of Tennessee, Chapter No. 237, House Bill No. 48, 1967). The first “pro-evolution” case was soon to follow.

Epperson v. Arkansas, 393 U.S. 97 (1968) distinguished between teaching religion and teaching evolution. Arkansas had adopted an “anti-evolution” statute by voter referendum in 1928 that made it unlawful for a teacher in any state-supported school or university to teach or to use a textbook that teaches “that mankind ascended or descended from a lower order of animals” (Epperson v. Arkansas, 393 U.S. 97). The U.S. Supreme Court recognized the State’s power to specify the public school curriculum but “the State’s undoubted right to prescribe the curriculum for its public schools does not carry with it the right to prohibit, on pain of criminal penalty, the teaching of a scientific theory or doctrine where that prohibition is based upon reasons that violate the First Amendment” (Epperson v. Arkansas, 393 U.S. 97, 1968).
A New Era: Religion as “Science”

Clearly creationists recognized the important distinction in the law; public monies could not be used to support religion. A “scientific approach” to the tenets of the bible, however, represented a new direction that exploited the philosophical underpinnings of science itself. Disillusioned by the BSCS to promote the theory of evolution in schools, Walter Lammerts began the Creation Research Society in 1963 to realign science based on theistic creation concepts and to publish creationist textbooks (Numbers, 2006). Lammerts promoted a strict interpretation of the six days of Genesis, and with great difficulty, finally found a textbook that served his ideology. The preface by Henry M. Morris, current president of the Creation Research Society, included the first attempt to put the “doctrine of evolution” on the same ground as the “doctrine of special creation” (Numbers, 2006). Despite its claims, however, the authors of Biology: A Search for Order in Complexity (by John N. Moore and Harold Slusher) chose “to discredit evolution rather than make any case for creation” (Thwaites, 1980). Taking a similar tack, Duane Gish, another charter member, wrote a letter to The American Biology Teacher, published by NABT, in 1970 to introduce the Creation Research Society as a group of “informed people” that do not accept that evolution is “a fact for which no further proof is needed.” Shortly thereafter, Morris split from the Creation Research Society to found the Institute for Creation Research and cater to the elementary grades (Numbers, 2006). In 1974, Morris published Scientific Creationism (Creation-Life Publishers, San Diego) that included his literal interpretation of Genesis (including a young Earth, global flood, and special creation of plants and animals) re-packaged as a scientific model (Numbers, 2006; Scott & Matzke, 2007).
American Biology Teacher clearly did not endorse creationist views, but the repackaging of creation science ultimately warranted some debate. Since its inception, the journal had published articles about the teaching of evolution, the conceptual difficulties, and the challenges (e.g., Beers, 1938; Ehrle, 1960; Packard, 1950). The renewed interest in creation science and the dispute it provoked regarding adoption of textbooks in California prompted editors of the American Biology Teacher to publish a variety of letters and articles related to creation science in the classroom. The journal published a lengthy review of Biology: A Search for Order in Complexity (Aulie, 1972a; Aulie, 1972b) that attempted to expose the fundamentalist beliefs that interfere with scientific interpretation of evidence without discounting the relevance of religion. Theodosius Dobzhansky had just given his famous paper “Nothing in biology makes sense except in the light of evolution” at the 1972 convention, when the journal published “Evolution, creation, and the scientific method” by John Moore. The editors included the disclaimer that “Although the views presented in this article are not acceptable to the majority of life scientists, the editorial staff feels that our membership should be aware of the creationist position as described by John N. Moore” (J. N. Moore, 1973). According to Moore, “scientific activity involves the search for facts that can be observed or demonstrated, and for laws that have been demonstrated also, by means of trustworthy methods of discovery” (p. 23). He goes on to claim that repeatability, or reproducibility, is at the core of the method, and that evolutionary theory is not repeatable (presumably because no two species are identical). Within this context, Moore clearly distinguished two models, the general evolution model and the creation model, and put them on even ground as conceptual ontological and epistemological frameworks to explain origins.
The last major article in the issue was the official statement of NABT, who joined the “National Academy of Sciences, the American Association for the Advancement of Science, and other learned societies in urging the State Board of Education to reject inclusion of an account of special creation in State-approved science textbooks” (National Association of Biology Teachers, 1973).

The “two models” rhetoric came to a head in 1982 in McLean v. Arkansas Board of Education (529 F. Supp. 1255, 1258-1264). Arkansas had enacted a law mandating “equal time” – the Balanced Treatment for Creation-Science and Evolution-Science Act (Act 590). Plaintiffs included a number of churches, clergy, parents, and teachers that brought suit as a check of the Establishment Clause. The judge ruled that creation scientists “...cannot properly describe the methodology used as scientific, if they start with a conclusion and refuse to change it regardless of the evidence developed during the course of the investigation.”

Five years later, a similar case, Edwards v. Aguillard (482 U.S. 578, 1987), was brought before the U.S. Supreme Court. Louisiana had enacted a similar “balanced treatment” act, although this time in the guise of “academic freedom.” Although the court ruled 7-2 that supernatural creation was a religious view and that the Louisiana legislature had violated the Establishment Clause by promoting it in public schools, the dissenting Justice Antonin Scalia, joined by Chief Justice William Rehnquist, indicated that academic freedom was a legitimate secular purpose. Creationists had a loophole (Pennock, 2003).

The rise of “intelligent design” was heralded with the publication of Of Pandas and People by Percival Davis and Dean H. Kenyon in 1989. The book was a thinly
disguised repackaging of creationist ideas, clearly documented by Barbara Forrest, immediately after *Edwards v. Aguillard*. (In fact, Forrest discovered an editing error in one version of the manuscript where the “c” and “ists” from the word “creationists” were missed as “design proponents” was being substituted, leaving the passage to state “evolutionists think the former is correct, cdesign proponentsists accept the latter view;” Scott & Matzke, 2007.) Nevertheless, in their promotion of the book the Foundation for Thought and Ethics, a group less tied to the literal interpretation of the bible, claimed to be developing a high school text book that presented plausible, scientific alternatives to conventional evolutionary theories: “[T]he book will not be subject to the major criticism of creation, that the supernatural lies outside of science, because its central statement is that scientific evidence points to an intelligent cause, but that science is silent as to whether that intelligence is within or beyond the material universe. So the book is not appealing to the supernatural” (Scott, 1990).

The scientific objections to *Of Pandas and People* were numerous and lengthy. In her review, Eugenie Scott, an anthropologist, was particularly disturbed by the treatment of human evolution (Scott, 1990). In addition, the book misrepresented variation and its role in natural selection, as well as mutation as a source of variation (Scott, 1990). Similarly, Frank Sonleitner wrote “What’s wrong with Pandas?”, and according to the National Center for Science Education, the ongoing critique is now longer than the actual book (http://ncseweb.org/creationism/analysis/sonleitners-whats-wrong-with-pandas, last accessed 4/09).

Around the same time, the Discovery Institute was founded as a political think tank and the official home of the “intelligent design” movement. From the Discovery
Institute, the Center for Renewal of Science and Culture (renamed Center for Science and Culture in 2002) developed the “wedge document” to pursue an aggressive public relations program that would create an opening for the supernatural in the public’s understanding of science and in the minds of policymakers (Forrest, 2007; Forrest & Gross, 2004). Their success was apparent when President George W. Bush announced support for teaching “intelligent design” and Rick Santorum was able to add equal-time wording to the “No Child Left Behind” education bill (Pennock, 2003). (The language was struck from the enrolled bill, however.)

The Discovery Institute was not prepared to test “intelligent design” in a court of law, however. In October 2004, the Dover School Board in Pennsylvania passed a resolution that:

“Students will be made aware of gaps/problems in Darwin’s theory and of other theories of evolution including, but not limited to, intelligent design.

Note: Origins of Life is not taught”

(Kitzmiller v. Dover Area School District, Case 4:04-cv-02688-JEJ, Document 342, 2005). One month later, the board announced that teachers would be required to read a disclaimer about the theory of evolution stating that the theory is not fact and significant gaps exist. Furthermore, teachers were to state that “intelligent design” was a valid alternative theory and recommend reading Of Pandas and People for any student interested. Apparently, the Discovery Institute urged the board to repeal the measure, fearing legal defeat (Forrest, 2007).

And a sound legal defeat it was. In December 2005, a federal district court struck down the school district’s attempts, declaring the effort to be an unconstitutional
establishment of religion (Kitzmiller v. Dover Area School District, 2005). According to Judge Jones, “intelligent design” not only violated the Establishment Clause, it was not science. Although the judge did not use the test established in McLean v. Arkansas, he invoked specific epistemological demarcation criteria. Science did not include supernatural causes, and proponents of “intelligent design” could not change the definition of science. Moreover, irreducible complexity was in fact testable and refutable. Acceptance by the community of scientists also was an important consideration in which “intelligent design” had failed. Nevertheless, a new strategy emerged – one that has come full circle – to use an argument of rhetoric to win in the public court of opinion.

The new tactic involved redoubling efforts at discrediting the evidentiary support for evolution and its acceptance by the scientific community. These new efforts represented an argument for ontology based on epistemological detraction. Their objective was not to provide new scientific explanations but to make empirical arguments to establish the limits of empirical science (Clark, Foster, & York, 2007). By suggesting that the theory of evolution was not well supported with evidence, detractors argued that science education needed to be teaching critical thinking skills. The implication was that by being taught to think critically, creationism would become an option in scientific discourse. This tactic had been reproached in both Kitzmiller and McLean:

“The court in McLean noted the ‘fallacious pedagogy of the two model approach’ and that [i]n efforts to establish ‘evidence’ in support of creation science, the defendants relied upon the same false premise as the two model approach ... all evidence which criticized evolutionary theory was proof in support of creation
science” (*McLean v. Arkansas*, 529 F. Supp. at 1267, 1269). We do not find this false dichotomy any more availing to justify ID today than it was to justify creation science two decades ago.”

Clearly, the approach resonated with the public, however. Louisiana passed new “strengths and weaknesses” legislation just 25 years after the “balanced treatment” act had been rejected by the U.S. Supreme Court in *Edwards v. Aguillard* (482 U.S. 578, 1987).

“The State Board of Elementary and Secondary Education, upon request of a city, parish, or other local public school board, shall allow and assist teachers, principals, and other school administrators to create and foster an environment within public elementary and secondary schools that promotes critical thinking skills, logical analysis, and open and objective discussion of scientific theories being studied including, but not limited to, evolution, the origins of life, global warming, and human cloning” (Louisiana Senate Bill 733, Section 1. R.S. 17:285.1B, 2008).

After a much heated debate, Texas soon followed with science standards that conjure “strengths and weaknesses” wording. The Texas standards were more direct in their criticism of evolutionary theory, employing the discredited creationist idea that that “sudden appearance” and “stasis” in the fossil record somehow disprove evolution (National Center for Science Education press release, March 30th, 2009). Now students were to “analyze and evaluate the sufficiency of scientific explanations concerning any data of sudden appearance, stasis and the sequential nature of groups in the fossil records” (Amendments Proposed for Science TEKS, Section 112.34(c) strike 7B, March
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27, 2009). Missouri, New Mexico, Florida, and Iowa have all introduced similar legislation without success.

What Is this Thing Called Science?

Science is ill-defined; knowing what it is not may be easier to define than what it is. McLean v. Arkansas was the first challenge to evolution that resulted in a precedent-setting “test” to determine whether an enterprise should be considered science. This test came with considerable input from Michael Ruse, a philosopher of science, and Ruse argued persuasively (the judge ruled that creation science was not science). He maintained the most striking aspect of science was that it was an empirical enterprise about the real world of sensation – including unobservables – and a search for order (i.e., unbroken, natural regularities). He added that laws affect explanation and prediction, and associated with explanation and prediction was the idea of testability – confirmation and falsification. One major difference between science and non-science was that scientific explanations were tentative; scientists, as a community, give up on theories that fail to answer to new or reconsidered evidence (although he freely admitted that not all scientists give up their ideas). Religious individuals tended to be dogmatic, retaining their ideas despite the evidence (Ruse, 1982a). But, Laudan argued that Ruse was perpetuating a view of science that simply was not true (Laudan, 1982). He contended that very little demarcates science from the so-called pseudo-science of creation science (or any other). Moreover, many philosophers of science have concluded that no universal, ahistorical, account is available that is capable of providing standards by which to judge science (Chalmers, 1999; Clark et al., 2007). Nevertheless, a philosophical
grounding of the nature of the scientific endeavor is vital to evolutionary biologists and anyone interested in the creation-evolution controversy.

Alan Chalmers (1976, 1982, and 1999) asked a fundamental question about the scientific enterprise, not to challenge science, but to understand sincerely why the knowledge derived from science is so highly esteemed. Although he subscribed to the concept that there is no general account of science that applies to all sciences at all stages in their development, he tried to capture the distinguishing features of science in the face of the philosophical challenges (Chalmers, 1999). Indeed, philosophers have been debating the fundamental nature of science, including its epistemological, ontological, and axiological, commitments for decades. The result has been a complex, and sometimes contentious, discussion that can be pooled into two overlapping issues (although by no means the only issues) related to public understanding. Epistemological issues appeal to evidence and the nature of evidence used in science, and ontological issues deal with the kinds of things there are in the world and what we can know about them.

**Epistemology**

Traditional views of science have centered on the production of facts, observation and experiment, and logical induction, but scientific knowledge cannot rest on such weak appeals. Science cannot be derived from facts, as so many people assume, because facts are not directly given to careful unprejudiced observations via the senses. Facts do not exist prior to or independent of theory; facts have to be practically constructed and are subject to revision and dismissal. They do not provide a firm reliable foundation for
scientific knowledge. Because of this fallibility, scientific knowledge can neither be conclusively proved nor disproved by appealing to observable facts (Chalmers, 1999). Experimental results also are fallible. As with facts, results from experiments are not derived via the senses in a straightforward manner, and judgments about the adequacy of those results are dependent on theory. More importantly, appealing to experimental results cannot settle a dispute between proponents of opposing theories because of this circular dependency (in order to judge the adequacy of experimental results, scientists appeal to theory, and those same experimental results are used as evidence for the theory). Nevertheless, in a philosophical sense, if the experimental outcomes actually do reflect how the world works rather than just theoretical views about the world, then testing the adequacy of theories against experimental results has meaning (Chalmers, 1999). A recent philosophical realm has been exploring whether the reality of experimental effects can be established without recourse to large-scale theory, however.

Given these failings, science philosophers began to consider what Sir Karl Popper called the problem of demarcation (Popper, 1963). The problem of demarcation rested in the idea that certain characteristics should be able to differentiate science from non-science. As Popper (1963) saw it, evidence could be twisted out of counter-evidence with ad-hoc interpretations to confirm theories, such as Freudian psychoanalysis and Alderian psychology, so that nothing distinguished one as better able to explain human behavior than the other. As a result, he tried to draw a line “between statements, or systems of statements, of the empirical sciences, and all other statements – whether they are of a religious or of a metaphysical character, or simply pseudo-scientific” (p. 38). Popper claimed the criterion of falsifiability was the solution – statements or statement
systems must be capable of conflicting with possible, or conceivable observations; that is, in order to be scientific, a theory must take risks by predicting testable outcomes (Popper, 1963).

Interestingly, Popper claimed that parts of the principle of natural selection, for example, were pseudo-science – that they failed to satisfy his falsifiability criterion (Curd & Cover, 1998). In fact, Popper first claimed that “the survival of the fittest” was tautological (an idea picked up upon by the creation scientist, Henry Morris, that all of evolutionary theory is neither predictable nor testable). Indeed, Popper changed his mind, but as he did, he himself illustrated how difficult his ideas could be to interpret. Popper had never condemned all of Darwin’s theory, even when he judged an important part could be falsified (Curd & Cover, 1998). Thus, one problem was that observation might not lead to straightforward conclusive falsification of theories because of the possibility that some part of the complex test situation was responsible for an erroneous prediction (the Duhem-Quine thesis; Chalmers, 1999). Moreover, history has shown that science does not “progress” based on this line of thinking; many important theories were not rejected after falsification (e.g., Newton’s gravitational theory and the Copernican Revolution; Curd & Cover, 1998, Chalmers, 1999). Testable consequences also were a very weak requirement – although they perhaps are a necessary condition for science (Curd & Cover, 1998). As a result, the weakness of the unqualified demarcation criteria was that many pseudo-sciences and non-sciences could make falsifiable claims, such as any literal interpretation of the bible would. Creation science made empirical assertions fully capable of falsification (Laudan, 1982).
Ontology

Scientific knowledge claims depend on the kinds of things there are in the world and what scientists can know about those things. One aspect of the truth in scientific knowledge deals with the extent to which a scientist prescribes to realism. Realists assume that scientific knowledge informs about the nature of the world beyond what appears on the surface, even though it may not be directly observable. Furthermore, not only does science give us knowledge of these unobservables, it has succeeded in doing so (Chalmers, 1999). The line between supernatural and unobservable is razor thin, especially when examining the history of science, however. Mayr (1997) argues that the demarcation between science and theology is easy because scientists do not invoke the supernatural to explain how the natural world works. In this light, supernatural seems only to imply human-like deities, not imaginary concepts like “ether,” “factor,” or “gemmule.” In point of fact, anti-realists counter that many of the entities postulated by past theories are no longer believed to exist (e.g., ether, Newton’s corpuscles, phlogiston, and Darwin’s gemmules; Chalmers, 1999). Similarly, Laudan (1981) provides examples of theories that were successful and their central explanatory terms did not refer, e.g. crystalline spheres of ancient astronomy, electromagnetic ether, and Mendel’s “genes” (Mendel was referring to entities that did not actually exist – “factors,” and assigned causal roles that have been divided up among other entities; Curd & Cover, 1998). Even though these past theories were instrumental to the generation of current knowledge, many have since been rejected as false. Therefore, the theoretical aspect of science is not securely established (Chalmers, 1999). Many anti-realists argue that theories are merely instruments necessary for correlating and predicting the results of observation and
experiment; they are not appropriately interpreted as being true or false (Chalmers, 1999). One motivation for this anti-realism stance seems to be restricting science to claims that can be justified by scientific means (Chalmers, 1999).

Certainly, as a principle goal, scientists aim to accept true claims about the natural world and reject false ones (Curd & Cover, 1998). Scientific value, however, relies on more than just statements of truth. Curd and Cover (1998) provide the example of a scientist counting the number of hairs on a dog; without the context of a theory of a drug’s affect on the dog’s hair loss, simply knowing the hair count has no scientific value. Scientists are interested in more than discovering mere truths about the world; they are interested in discovering interesting truths. Consequently, the judgments about what constitute interesting truths are based on criteria such as generality, predictive and explanatory power, and simplicity (Curd & Cover, 1998). These constitutive values often compete, compromising the objectivity of science and undermining its rationality for theory choice (Longino, 1990). So, even though truth may be the primary cognitive value, it is not independent of other cognitive values when deciding which theories are true. Moreover, contextual values affect the way scientists do the science that drives these cognitive values. Contextual values (norms, preferences, beliefs, and interests) vary with time and across cultures. How scientists evaluate and judge evidence depends on contextual values, and objectivity is a matter of degree that depends less on methodological rules and more on the way the scientific community is organized (Longino, 1990). Of particular importance is the way contextual values shape the formation of hypotheses in the context of scientific discovery (Okruhlik, 1994). The production of scientific knowledge is always within a social context and related to other
practices with other aims, such as personal and professional intentions of scientists, the
economic intentions of funding agencies, and the ideological intentions of religious
groups (Chalmers, 1999). In fact, Thomas Kuhn examined the history of science to claim
that contextual values shape scientific judgments about theories so much so that scientific
revolutions lack rationality and objective progress (Kuhn, 1970).

But progress is a hallmark by which many define the scientific enterprise. Indeed,
the Ultimate Argument (van Frassen, 1980) states that the success of science cannot be
explained unless these scientific theories have the virtues of verisimilitude (approximate
truth) and reference. According to van Fraasen, science can be explained without appeal
to approaching truth using Darwinism, however; the success of scientific theories is a
result of the survival of the fittest and not necessarily because of their verisimilitude. In
rebuttal, Brown (1985) outlines three features of successful scientific theories: their
empirical adequacy (they explain and unify), their increasing adequacy (temporal
increase in these abilities), and their novel predictions (predictions that turn out to be true
more often than guessing). Van Fraasen’s Darwinian analogy cannot account for novel
predictions (Brown, 1985).

Understanding the limits of scientific knowledge is vital to understanding the
controversy surrounding religion and science. Obviously, much uncertainty exists about
the scientific enterprise, what exactly science is, what are its goals, the knowledge it
produces, and what kind of certainty it can attach to its claims. Chalmers (1999) suggests
that comparing the kinds of knowledge claims that are sought, the kinds of methods
available for establishing those knowledge claims, and the success that has been achieved
should distinguish a science, such as biology, from a non-science, such as creation science.

The Science of Evolution

Given that no universal, ahistorical, definition of science is available (Chalmers, 1999; Clark et al., 2007), one has to ask about the history of evolutionary science; when did evolution become science? Like so much of Western tradition, evolutionary thought was rooted in Greek philosophy. Plato (ca. 427-347 BCE) argued that the gods created the world (an idea appropriated in the Christian interpretation of the bible; Futuyma, 1998) and attend to it (Clark et al., 2007). In that world, everything had a transcendent ideal form imperfectly imitated by its earthly counterpart (i.e., essentialism; Futuyma, 2005). Plato’s view of purposiveness resided in the gods (Ariew, 2007). Aristotle (384-322 BCE) was a biologist, however; he believed in an inner principle of teleological change – the cause responsible for reaching a preconceived ultimate goal came from within the organism (Ariew, 2007; Lombrozo & Carey, 2006; Mayr, 1961).

The materialist foundations of modern evolutionary science appeared with Epicurus (341-270 BCE). He insisted that empirical investigation was the means to the best explanation, recognizing uncertainty and the limitations of observation (Clark et al., 2007). The gods were not excluded from Epicurus’ worldview, they just were not related to the material world (knowledge of the gods came through dreams; Clark et al., 2007). It was Epicurus’ contribution to modern day science, in general, that is eschewed most by anti-evolutionists (Clark et al., 2007).
Early in the 19th century, however, evolutionary thought began to blossom. Naturalists approached the world looking for proof of an obviously intelligent designer (in that day they just admitted it was God), but the discovery of more and more fossils indicated an earth that had undergone radical changes in the diversity and kinds of organisms that existed (Larson, 2004). Georges Cuvier employed the idea of “progressive catastrophism” to explain the sequence in the geologic record as suites of animals were wiped out allowing new and fertile ground for God’s next plan (Larson, 2004). Other naturalists struggled with explanations for the history of life that did not require omnipotent intervention. In 1802, Jean Baptiste Pierre Antoine de Monet, Chevalier de Lamarck, published the first comprehensive theory of organic evolution (Larson, 2004). He proposed the idea of transformationism – from spontaneous generation of the lowest forms, life progressed to the highest by the inheritance of acquired traits (Kampourakis & Zogza, 2007; Larson, 2004). In context, Lamarck’s contribution was one of many ideas being offered at the time (Corsi, 2005), but it piqued the interests of both believers and detractors. No longer were kinds static; Lamarck offered a comprehensive theory to explain the history of animals, including man (Mayr, 1982). Whether scientists, naturalists, and the educated elite cared for the work or not, Lamarck clearly infected Victorian society with ideas about a theory of evolution (Corsi, 2005). Catastrophists, like Cuvier, countered that creation had been progressive, but life forms did not progress (Futuyma, 1998; Larson, 2004). Charles Lyell despised the Lamarckian thought of human transformation, but he disagreed with progressive stances like Cuvier’s (Larson, 2004). He argued for environmental change that was cyclical and consistent throughout the geologic record (Larson, 2004). The absence of fossils to
support this idea just meant they had yet to be found (Larson, 2004). Although he believed in special creation, Lyell was unwilling to attribute the natural to the supernatural (Larson, 2004). He proposed that currently observable forces were responsible for shaping the earth’s features (Larson, 2004). This uniformitarian approach to viewing the world was grounded in methodological naturalism, and methodological naturalism would become the nucleus in enlightenment thinking.

The Enlightenment

As a signal of the new era of enlightenment thinking, during the 1830s the term “scientist” was coined to distinguish methodological naturalism from idealistic philosophies like romanticism (Futuyma, 1998; Larson, 2004). Methodological naturalism was an epistemological belief (a belief about what knowledge is and how we can obtain it) and a procedural protocol (Forrest, 2000; Pennock, 1996). It has often been conflated with philosophical naturalism, which operates in the realm of ontology (truth claims; Forrest, 2000; Pennock, 1996). Although some authors (e.g., Forrest, 2000) have argued that philosophical naturalism is the logical extension of methodological naturalism, others have urged that science need only be committed to methodological naturalism, remaining neutral to philosophical naturalism and metaphysical beliefs (Pennock, 2003). Charles Darwin also embraced methodological naturalism; in that light, natural selection was a logical extension of Malthusian economics and Llyell’s uniformitarianism (as well as utilitarianism, imperialism, and capitalism; Clark et al., 2007; Larson, 2004).
As the years past after Darwin’s legendary trip, relentless pursuit of evidentiary support for his theory caught him in a professional trap; he needed to present his thesis. Evolutionary ideas had been creeping into social acceptance, and a young naturalist, Alfred Wallace, soon approached Darwin with his own theory (Larson, 2004). Where Darwin’s theory of natural selection emphasized individual competition (from his imperialist perspective), Wallace approached evolution as a result of the selective power of ecological forces (Wallace had grown up poor; Hull, 2005; Larson, 2004). A year after both theories were presented to the Linnean Society in London, Darwin published *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life* (Larson, 2004).

Although immensely successful, the *Origin of Species* was not universally accepted and built into a unifying theory (Caton, 2007; Larson, 2004). With no understanding of modern genetics, and therefore no mechanism for generating, let alone maintaining variation, evolution became a hotly debated topic. Darwin had proposed the ill-fated idea of “gemmales” – tiny, unobservable entities – to carry hereditary information (Chalmers, 1999; Larson, 2004). In addition, a new calculation put the age of the earth at only one hundred million years, too short a time frame for the slow process of natural selection (Larson, 2004). Many scientists returned to idealist philosophies and the belief in a harmonious, transcendent order in nature guided by some mystical meaning or theological being (Futuyma, 1998). Theistic evolution, Lamarckism, orthogenesis, and mutation theory eclipsed natural selection as viable pursuits in evolutionary science (Futuyma, 1998; Larson, 2004). Even Darwin engaged Lamarckian ideas to speed the process by which change occurred (Larson, 2004). In the early 1900s,
selection theory had all but disappeared from the scientific landscape, but no sufficient replacement had been found (Larson, 2004).

The discovery of Gregor Mendel’s important work in 1900 ushered in a new era to evolutionary science. With genetics as a mechanism, Darwin’s ideas about natural selection and adaptation were further marginalized for a time, however, even considered non-scientific because of the lack of rigorous laboratory experiments (Futuyma, 1998). Genetics disproved Lamarckian concepts of inheritance, but mutations, at the exclusion of natural selection, were given the primary role (Futuyma, 1998).

In the 1930s and 1940s, Ronald A. Fisher, John B.S. Haldane, and Sewall Wright developed a mathematical theory that synthesized understanding of population genetics (Futuyma, 1998). Mutation was not an alternative to natural selection, but its raw material (Futuyma, 1998). Darwin was vindicated. Sergei Chetverikov and Theodosius Dobzhansky showed convincingly that populations were not uniform; genetic variation was prevalent, and mutations added to that variation (Futuyma, 1998).

Ernst Mayr in Systematics and the Origin of Species (1942) clarified the relationship between genetics and the evolution of species, and Julian Huxley (1942) used genetic principles to explain the major patterns of evolution that had been described, in the process redefining evolutionary “progress” as a contingent factor (as opposed to a mystical, guided factor).

In Tempo and Mode in Evolution (1944), George Gaylord Simpson resolved population genetics and paleontological data (Futuyma, 1998). Methodological naturalism had proven to be highly successful, and a massive body of knowledge was directly attributable to its adoption (Forrest, 2000).
The history of evolutionary science clearly indicated a path defined by context. Early evolutionists struggled with epistemological claims, but adopting the methodology of science permitted defensible pronouncements about what exists in the natural world (Forrest, 2000). Indeed, with the establishment of methodological naturalism as a philosophical commitment, science could be defined by the kinds of knowledge claims being sought, and the uncertainty that came with that commitment (Pennock, 2003). Although creation science has a history of knowledge claims, it offers no methods, and its success has had more to do with power than an epistemological grounding (Forrest, 2000). Negative argumentation does not, as many creationists try to claim, count as positive evidence (Pennock, 1996). Legal precedent has now defined evolutionary science as: (1) guided by natural law, (2) explanatory by reference to natural law, (3) testable against the empirical world, (4) reference to conclusions that are tentative, and (5) falsifiable (McLean v. Arkansas, 529 F. Supp. 1255, 1982; see also Ruse, 1982a). Although this definition is highly tenable to those concerned with the constitutional issue, not all philosophers of science agree (e.g., Laudan, 1983). Nevertheless, Ruse (1982b) argues, the U.S. Constitution does not bar teaching weak science in public schools, only religion.

Ultimately, however, concern lies with our current understanding of evolutionary theory. The Modern Synthesis organized evolutionary theory and brought together a diversity of disciplines. Indeed, Theodosius Dobzhansky contended that “nothing in biology makes sense except in the light of evolution” (Dobzhansky, 1973). Understanding this complex theory centers on several key concepts (D. L. Anderson, Fisher, & Norman, 2002; Nehm & Schonfeld, 2007):
1. Individuals within a population vary in their characteristics.

2. Genetic variation is heritable.

3. Mutation, recombination, and sexual reproduction are constant sources of variation within a population.

4. Individuals have the capacity to reproduce at a very high rate.

5. Natural resources are limiting (or become limiting).

6. Limited resources bring about a struggle for existence.

7. Survival in the course of this struggle is not random but related to the characteristics of the individual.

8. The population changes with respect to the proportion of individuals with certain characteristics through the differential survival and reproduction of these individuals.

As straightforward as these eight points may seem to educators and evolutionary biologists, however, each entails understanding a number of ideas that vary significantly in their conceptual abstractness. Individuals’ “alternative conceptions” may interfere with understanding these points, and misconceptions must be overcome before conceptualizations of this complex theory can be said to approach those of the scientific community.

**Evolution Misconception Research**

Constructivism is the idea that knowledge is actively constructed and constantly evolving over time (Driver, Asoko, Leach, Mortimer, & Scott, 1994). Human constructivism focuses on learning as a process of making meaning (Mintzes,
Wandersee, & Novak, 1997; Novak, 1993), and meaningful learning requires organized webs of interrelated propositions (Ausubel 1963). Individuals come to learning situations with pre-existing ideas about how the world works, however (Ausubel, 1968; Clough & Wood-Robinson, 1985a; Driver & Easley, 1978; M. A. Johnson & Lawson, 1998; Wallin, Hagman, & Olander, 2000; Wandersee, Mintzes, & Novak, 1994). This prior knowledge may or may not reflect current thinking – about scientific theories for example – and when it does not, has been termed misconceptions, alternative conceptions, non-scientific ideas, or limited or inappropriate propositional hierarchies, to name a few.

Misconceptions about evolutionary theory can be constructed from a variety of sources (Committee on Undergraduate Science Education, 1997; Mintzes et al., 1997). One common source relates to vernacular issues, where different connotations of important scientific phrases are misapplied in scientific settings. For example, in everyday language “adapt” may refer to the ability of individuals to alter their form or behavior through their own efforts, and “fitness” may refer to physical strength (Bishop & Anderson, 1990). “Theory” also is commonly thought of as a “guess” rather than a well-supported explanation that generates testable predictions (National Academy of Sciences, 1998). Everyday experiences are another source of misconceptions. The inheritance of family characteristics, such as grandpa’s baldness or cousin Martha’s cleft chin, may affect how individuals think about heritability, variation, and time. Other important sources of misconceptions can be parents, television programs, news, websites, fiction, and religious and myth-based stories. These informal sources can affect how individuals think about dinosaurs and the age of the earth, where lightning is likely to strike, or the possibility of obtaining warts from frogs. Of pressing concern are the
misconceptions that arise in formal environments. If new information is taught without confronting students’ preconceived notions and nonscientific beliefs, individuals may simply accommodate the new knowledge into old frameworks (Alters & Nelson, 2002; Committee on Undergraduate Science Education, 1997). For example, teaching genetics does not necessarily teach students that genes are the mechanism by which populations change over time (Clough & Wood-Robinson, 1985b). Without proper grounding, students may continue to believe that within an evolutionary context, mutations are only bad, yielding “hopeful monsters” that natural selection must “weed out” of the population.

Conceptual change is a mechanism for addressing misconceptions. Traditional conceptual change research emphasizes major conceptual restructuring that results from a logical dissatisfaction with and abandoning of prior conceptions (Posner, Strike, Hewson, & Gertzog, 1982; Nussbaum, 1989). As a result, meaningful learning can require the reconstruction of a significant segment of the learner’s conceptual and propositional framework to include more general and broadly inclusive concepts (Groves & Pugh, 2002; Nicholls, 1999; Songer & Mintzes, 1994). This kind of superordinate learning is rare, however, more characteristic of experts than students (Mintzes et al., 1997; Novak, 1993; 2002). Misconceptions may not be barriers to learning but important components of the learning process. Hamza and Wickman (2008) suggest that misconceptions can be integral in the learning process as they are encountered and questioned (see also Lawson, Alkhoury, Benford, Clark, & Falconer, 2000; Taber, 2001). In fact, students may hold theory-like conceptual frameworks – structures of relatively coherent domain-specific knowledge characterized by a distinct ontology and causality that give rise to prediction
and explanation (Vosniadou & Ioannides, 1998). As a result, conceptual change may be a much slower revision than Posner et al. envisioned, through the gradual incorporation of elements of currently accepted scientific explanations (Vosniadou & Ioannides, 1998). Restructuring these naïve theories requires addressing modes of learning and reasoning, and the development of meta-conceptual awareness, intentionality, and epistemological sophistication (Vosniadou, Vamvakoussi, & Skopeliti, 2008).

Alternatively, naïve theories may be highly fragmented, displaying limited coherence. To understand conceptual change, “knowledge in pieces” approaches generate questions about grain size of elements and their coherence and contextuality (diSessa, 2008). In this view, conceptual change is a complex, multi-faceted process that takes time, multiple contexts, approaches to meta-cognition that require understanding personal epistemology, and assessments that address all the pieces (diSessa, 2008). Because conceptual ecologies lack coherence, students may bring both alternative and scientifically acceptable conceptions into play in response to different problem contexts (Kampourakis & Zogza, 2008b). Some misconceptions may disappear on their own as individuals learn more about a specific topic, such as natural history (Evans, 2000, 2001).

Evolution is a complex theory, involving disciplines from geology to ecology and biology to behavior. These disciplines entail structural concepts that can be classified according to different levels of abstraction, any of which can be stumbling blocks for conceptual understanding. Lawson, Abraham, & Renner (1989) and Lawson et al. (2000) describe four types of concepts, including apprehended, descriptive, theoretical, and hypothetical. Apprehended concepts are concepts whose complete meaning can be derived from the internal or external environment, such as blue or hunger. Descriptive
concepts are mentally constructed from readily available exemplars, such as chair, running, populations, and species. Theoretical concepts are the most abstract because their defining attributes are not perceptible – their causal agents cannot be observed. Osmosis, genes (Lawson et al., 2000) and, most likely, probabilities, are all theoretical concepts. Hypothetical or intermediate concepts exist between descriptive and theoretical concepts because they could derive meaning if not restricted to a normal observational time frame. Natural selection, evolution, and convergent evolution, as well as limiting factors, and even the process of fossilization, are hypothetical concepts (Lawson et al., 2000). The level of abstraction of concepts may very well be linked to ease of understanding. Descriptive concepts may be understood more readily especially by individuals that have not developed reasoning skills; hypothetical and theoretical concepts that require more abstract thinking may be more difficult to comprehend (Lawson et al., 2000).

Ontological misclassification may operate at a similar grain size within conceptual ecologies (Chi, 2008). Family-resemblance categories are defined by correlations among features in sets of similar memorized exemplars and allow inferences about the observable products of history, whereas classical categories of concepts are defined by formal rules that allow inferences within idealized law-governed systems (Pinker & Prince, 1996). Entities and processes can be thought of as family-resemblance and classical categories, respectively, in mental models. Events are bounded and sequential entities whereas equilibrations are ongoing, unbounded, and simultaneous processes (Ferrari & Chi, 1998). If students misclassify the concept of evolution as an event rather than an equilibration, overcoming that ontological misclassification requires
creating the new process category or shifting concepts across categories. In other words, evolution would be a theoretical concept (cf. Lawson et al., 2000) misclassified as a descriptive concept.

Major efforts to overcome misconceptions have met with equivocal results (e.g., Chinsamy & Plagányi, 2007; Crawford, Zembal-Saul, Munford, & Friedrichsen, 2005; Ingram & Nelson, 2006; Kampourakis & Zogza, 2008a; Nehm & Reilly, 2007; Nehm & Schonfeld, 2007; Scharmann, Smith, James, & Jenson, 2005; Verhey, 2005/2006). Research has shown that even after significant coursework students retain serious misconceptions about the process of evolution (Brumby, 1984; Nehm & Reilly, 2007; Wandersee et al. 1994). In general, students believe that the environment causes individuals to change, all individuals change simultaneously, and traits gradually change rather than changing proportions of individuals with those traits (Bishop & Anderson, 1990).

Several researchers have suggested that students’ explanations of natural phenomena resemble theories offered by previous generations of scientists and natural philosophers (Mintzes et al., 1997; Novak, 1993, Shtulman, 2006; but see Kampourakis & Zogza, 2007). For example, Shtulman (2006) explored the possibility that modern naïve theories paralleled early “transformational” theories of evolution. He argued that because students embraced essentialist ideals (i.e., each biological kind has an underlying essence that makes it what it is; see also Evans, 2008), they were predisposed to think about evolution as a transformation of essences, just like early naturalists. Kampourakis & Zogza (2007) argue that this type of characterization may be historically incorrect; examination of Lamarck’s theory indicates student explanations are actually quite
different. Therefore, although teaching the history of science may be a valuable tool for overcoming some misconceptions (Wandersee, 1986), the similar patterns are more likely related to the language of shared experiences with the natural world (Driver & Bell, 1986) and developmental constraints (Evans, 2008; Sinatra, Brem, & Evans, 2008).

Intuitive cognitive biases are part of a developmental framework and may act as conceptual barriers to evolutionary thinking (Evans, 2008; Sinatra et al., 2008). Essentialism, teleology, and intentionality are found in all age and cultures and result from intuitive beliefs about the way the world works (Evans, 2008). Indeed, as individuals grow and learn, thinking shifts from a naïve psychological world to a naïve biological world (Evans, 2008). The shift to a richer, more coherent knowledge structure that includes abstract concepts related to evolutionary theory may be age-related, but not age-dependent (Evans, 2008). In fact, these developmental constraints may be an underlying factor in studies where students differentially apply concepts among varying problem contexts (see Kampourakis & Zogza, 2008b).

If developmental constraints are a factor in understanding evolution, innovative techniques and strategies for teaching this important theory are necessary. Clearly, educators need to consider new insight into the development of cognitive capabilities. Recent evidence indicates that children may be quite capable of sophisticated thinking, but most curricula do not reflect what is now known about younger children’s cognitive capabilities (National Research Council, 2007). In fact, early instruction in science can have lasting impacts on science concept learning (Novak & Musonda, 1991). Indeed, Nussbaum (1989) suggests that if conceptual change is an evolutionary process,
educators should start exposing students to scientific ideas, such as evolution, much earlier than is customary to allow for the development process.

**Overcoming Misconceptions Using the NOS Framework**

Because of the complexities of evolutionary theory, conceptual change approaches often incorporate the philosophical nature of science (NOS) as a conceptual framework (National Academy of Sciences, 1998; Alters & Nelson, 2002). The NOS framework emphasizes the process of science as inquiry by addressing the durable but tentative character of scientific knowledge; that scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments, and skepticism; methods in science vary; science explains natural phenomena only; laws and theories have different roles (hierarchy of terminology); diversity in science; the clear and open reporting of new scientific knowledge; accurate record keeping, peer review, and replicability; that observations are theory-laden; science is creative; the history of science; science is a part of culture; the role of technology in society; and the social implications of results (American Association for the Advancement of Science, 1990; National Academy of Sciences, 1998; Zeidler, Walker, Ackett, & Simmons, 2002), although these criteria are not necessarily consistent among educators or within the philosophical realm (Alters, 1997; Eflin, Glennan, & Reisch, 1999).

While this approach is appealing, the impact of incorporating NOS concepts on learning is not straightforward. Socioscientific issues are public issues where both social and scientific factors play central roles in the debate (Sadler, 2004). Ideally, these issues are well-suited to examine the impacts NOS understanding has on individuals’ decision
making. In addition, creationists have been quite successful in making teaching evolution a socioscientific issue. In his review of the research, Sadler (2004) concludes that NOS conceptualizations are indeed related to the decisions individuals make about socioscientific issues, perhaps not directly, but related in some way to reasoning and evaluation of evidence. The public may recognize the importance of scientific evidence, but they also may rely more often on informal evidence (i.e., common sense, circumstantial evidence, and personal experience) as a means to bridge scientific or technical assertions with their own personal, political, and practical understandings (Tytler, Duggan, & Gott, 2001). If individuals do not understand what constitutes scientific data (Sadler et al., 2004), however, a tendency to rely on informal evidence, as opposed to scientific evidence, may not be that surprising. One problem with socioscientific issues as a metric of the influence of NOS understanding is the implicit assumption that NOS should carry weight with all issues. For example, Bell & Lederman (2003) show that the decision making of university professors with and without well-grounded understandings of NOS is not necessarily related to NOS issues. A socioscientific issue such as fetal tissue implantation does not, and should not, necessarily elicit questions about science-related knowledge in decision-making (Bell & Lederman, 2003).

With regards to academic disciplines, however, NOS may be a very appropriate means to helping students learn. NOS understanding is clearly related to accepting evolution (R. L. Johnson & Peebles, 1987), as well as improvements in understanding (Crawford et al., 2005; Scharmann, 1990; Scharmann & Harris, 1991). In fact, measures of student acceptance of evolution also may be highly correlated with NOS
understanding, even after the effects of general interest in science and past science education are controlled (Lombrozo, Thanukos, & Weisberg, 2008). Courses designed to teach evolution by including NOS can be very effective at helping teachers overcome misconceptions and understand evolutionary principles (e.g., Nehm & Schonfeld, 2007; Scharmann & Harris, 1992). Improved understanding of the NOS may not affect beliefs about teaching alternatives to evolution, however (Nehm & Schonfeld, 2007).

Nevertheless, research indicates that both teachers and students hold a range of conceptions about NOS (Lederman, 1992; Sadler et al., 2004; Zeidler et al., 2002). Like conceptual ecologies of evolution, students may hold a variety of conceptions about NOS and apply them in different contexts (Sandoval & Morrison, 2003). Overcoming these misconceptions requires multiple contexts and approaches (diSessa, 2008). Teachers’ understanding of NOS likely affects students’ understanding, yet treatments designed to affect teacher understanding typically range from a few hours to a few days (Abd-El-Khalick & Lederman, 2000). Given these approaches to teaching NOS, outcomes that show little gains are perfectly understandable. In addition, NOS understanding is difficult to measure. A number of instruments are available, but emphases vary and questions exist about whether the instruments are actually addressing epistemological NOS, methodological NOS, or simply attitudes and beliefs (Lederman, 2007).

Indeed, the NOS approach also is confounded by two questions, those related to teaching the process of science as inquiry, and those related to teaching the epistemology of science. Moreover, inquiry can be a pedagogical approach, a way of organizing the classroom. How it is implemented can directly affect the epistemological ideas students develop (Sandoval, 2005). Scientific inquiry involves the process of doing science (see
Barrow, 2006), but NOS refers to the epistemological underpinnings of the activities of science and the characteristics of the resulting knowledge (Lederman, 2006, 2007). Delineating the process of science and the resulting body of knowledge is important, especially when considering the relationships between understanding NOS and evolution. Scientific inquiry alone does not necessarily enhance conceptions of NOS (Schwartz, Lederman, & Crawford, 2004). Several authors emphasize that explicit teaching strategies, rather than “doing” science, are necessary to change NOS views (Abd-El-Khalick & Lederman, 2000; Akerson, Abd-El-Khalick, & Lederman, 2000; Bell, Lederman, & Abd-El-Khalick, 2000; A. R. Irwin, 2000; Khishfe & Lederman, 2006; Sandoval & Reiser, 2004; Scharmann et al., 2005; Schwartz et al., 2004). Although epistemology is one part of the NOS framework, it more accurately reflects the goals of science education (Sandoval, 2005). Indeed, the purpose of science education should be to get students to question the nature of science, understand the kind of questions science can and cannot answer, and the kinds of evidence that can and cannot be used to support propositions – the primary goal should be effective citizens, not scientists (Smith & Scharmann, 1999).

Understanding Knowledge – Personal Epistemology

If NOS understanding is the goal, personal epistemology may be a valuable metric for examining how well people understand tenets such as the weight of evidence, the tentative nature of scientific conclusions, and the context and credibility of scientific claims. Personal epistemology is a branch of psychology that examines the beliefs and theories that individuals come to hold about knowledge and knowing (Hofer, 2004).
Numerous models are available that address the relationships among beliefs about the nature of knowledge and learning (Duell & Schommer-Atkins, 2001). These models examine a variety of overlapping dimensions that can be grouped into two broad categories related to epistemology (Hofer, 2004):

1. the nature of knowledge (what one believes knowledge is), including dimensions of certainty of knowledge and simplicity of knowledge; and
2. the nature or process of knowing (how one comes to know), including dimensions such as source of knowledge and justification for knowing (a dimension specific to the Reflective Judgment Model that describes how individuals evaluate knowledge; King & Kitchener, 1994).

An important distinction among models, however, is the approach to the developmental relationship among the dimensions included. Multi-dimensional models assume dimensions develop independently of one another (Duell & Schommer-Atkins, 2001). For example, in their multi-dimensional models, Schommer (1990) and Schraw et al. (2002) characterize personal epistemology along five axes: (1) the stability of knowledge, ranging from unchanging knowledge to tentative knowledge; (2) the source of knowledge, ranging from omniscient authority to reason and empirical evidence; (3) the structure of knowledge, ranging from isolated bits and pieces to integrated concepts; (4) the speed of learning, ranging from quick to not-at-all; and (5) the ability to learn, ranging from fixed at birth to improvable. As a result, education can predict beliefs about the structure and stability of knowledge, whereas age can predict beliefs about the ability to learn (Schommer, 1998).
In contrast, uni-dimensional models assume the various epistemological
dimensions develop concurrently (Duell & Schommer-Atkins, 2001). The Reflective
Judgment Model is a stage model that describes epistemological growth as people
become better able to evaluate knowledge claims and to explain and defend views on
controversial issues (King & Kitchener, 1994; King & Kitchener, 2004). King &
Kitchener outline seven stages grouped into three levels: pre-reflective, quasi-reflective,
and reflective thinking. The earliest stage is pre-reflective thinking, characterized by
judgments that knowledge is certain and single correct answers exist that usually come
from authority figures. Later, individuals develop quasi-reflective thinking,
understanding that knowledge is an abstraction and that it is constructed – not simply
accepted from others. Individuals recognize different types and rules of evidence and
that uncertainty is part of the process of knowing. Their judgments, however, indicate a
tenuous relationship between gathering evidence and drawing conclusions, resulting in
idiosyncratic views of knowledge claims. The transition to reflective thinking is marked
by a clear understanding of the role of evidence across contexts and that evaluated
opinions of reputable others can be known and compared to one’s own thinking.
Reflective thinkers consistently use evidence and reason. The model clearly stresses the
relationship between development and cognition; people’s ways of making meaning
changes predictably over time (King & Kitchener, 1994).

Regardless of the model used to assess personal epistemology, researchers
generally agree that these beliefs play an important role in learning. For example, if
people believe knowledge is certain and passed down by authority figures, they are less
likely to question authority in the classroom (Schommer-Aikins, 2004). This can be
particularly worrisome with regards to controversial or socioscientific issues (issues that require consideration of societal interest, effect, and consequent; Sadler, 2004) because, like many ecological issues, these are issues that cannot be solved with a high degree of certainty (i.e., “ill-structured” cf. King & Kitchener, 1994). For example, epistemological beliefs may be important in the interpretation of evidence regarding controversial topics, such as the relationship between human immunodeficiency virus and the syndrome (Kardash and Scholes 1996), animals used in research (Zeidler et al. 2002), global climate change (Sadler et al. 2004), and evolution (Sinatra, Southerland, McConaughy, & Demastes, 2003).

In the U.S., public acceptance of evolution is clearly an ill-structured problem. King & Kitchener (1994) report the results of international comparisons of stages achieved by individuals of different ages. One question based on evolution and used successfully in interviews with people in the U.S. could not be used in Germany, however, because Germans do not perceive evolution to be ill-structured. Miller et al. (2006) indicate a similar trend with their survey of public acceptance of evolution; the U.S. is ranked near last in the proportion of people accepting evolution and Germany ranked much higher. The public debate in the U.S. centers around the consequences of evolutionary processes, especially in relation to the special position of humans, confounded by a persuasion campaign to create uncertainty and dissonance toward the science. In fact, research conducted by Sinatra et al. (2003) relates students’ epistemological beliefs to human evolution only, and not to the general acceptance of animal evolution or even photosynthesis.
Sadly, these results may reflect the state of an education system that does not adequately address complex thinking, presentation of arguments, and critically analyzing claims. Indeed, results from extensive assessment of U.S. college students using the Reflective Judgment Model indicates that Freshman operate at a stage level ranging from 3 to 4, and Seniors operate at a stage level ranging from 3 to 5 (King & Kitchener, 1994). Although the consistent progression in scores across class levels provides encouraging evidence for the benefits of college education, few Seniors demonstrate an understanding of the role of evidence in making interpretations (stage 5) or critical evaluation of judgments (stages 6-7). Indeed, one could argue that the misconception “I don’t believe in evolution because I don’t believe that people came from apes” is indicative of a stage 3 thinker, one who still believes knowledge is absolutely certain or only temporarily uncertain. Clearly then, by the time adults finish college, they are unable to evaluate scientific uncertainty and the ill-structured problems at the center of the creation-evolution controversy. The fact that evolution is not an ill-structured issue in Germany (King & Kitchener, 1994) supports the need for explicit teaching about the nature of scientific knowledge and reasoning (see also Hofer, 2000).

Learning to think about evolution, the nature of science, and the nature of knowledge occurs within a broader context than just formal education, however. Preparing students to become citizens capable of participation in a democratic society is one of the founding principles of our education system. When average citizens cannot comprehend the bodies governing society, public affairs will no longer be under lay control and cease to be public (Prewitt, 1983). Within this broader public understanding
of science is a complex relationship between knowing science and knowing about science-related situations in a democratic society (Roberts, 2007).

**Public Understanding of Science**

The importance of science in our society has garnered interest from science educators, public opinion researchers, sociologists, and informal science educators (Laugksch, 2000). The resulting body of research generally falls into three broad realms: basic literacy, public understanding of science, and science and society (Bauer, Allum, & Miller, 2007). Early research addressed basic literacy issues – what do people know about science and the scientific process and why (Ziman, 1992). Whether it be strictly fact-based understanding, as in some recent papers about climate change (e.g., Spellman, Field, & Sinclair, 2003; Unger 2000; Wilson K. M. Wilson, 2000a, 2000b), or a focus on the misunderstanding of “how science works” (e.g., Durant, Evans, & Thomas, 1989; Miller, 1983), this research examined the knowledge gap between current expert’s and the public’s understanding.

Focusing on a knowledge deficit, however, raises questions about the breadth of knowledge expected from the public, let alone the certainty of scientific knowledge, and the nature of the scientific endeavor (Ziman, 1992). In fact, to distinguish science as a way of knowing requires serious consideration of goals, methods, and knowledge claims (Chalmers, 1999). Indeed, scientists are not particularly well equipped to discuss the nature and status of science because they can’t articulate what scientific progress is despite their own progress (Chalmers, 1999). Moreover, the production of scientific knowledge is always within a social context and related to other practices with other
aims, such as personal and professional intentions of scientists, the economic intentions of funding agencies, and the ideological intentions of religious groups (Chalmers, 1999).

As a result of these boundary issues, research began to examine the “public understanding of science”, focusing instead on attitudes and the relationship between attitudes and knowledge (Bauer et al., 2007). Attitudes are either a product of information processing with a positive relationship between knowledge and attitude (normative-rationalist view), or value-loaded relations with the world confounded by the complexities of values, emotions, cognition, and rationality (realist-empiricist view; Bauer et al., 2007). Attitudes and knowledge are difficult to segregate, however. Knowledge is clearly an important determinant of attitudes toward science, but the relationship is not a straightforward linear main effect. Other domains of knowledge “contextualize” attitudes adding to an already positive influence (Sturgis & Allum, 2004). In fact, science is viewed more favorably when individuals understand the intricacies of scientific knowledge development and the political landscape (Sturgis & Allum, 2004).

Indeed, recent models of the interface between science and society have broadened the focus from an absolute assessment of science literacy to more social and philosophical viewpoints, focusing instead on who is engaging with what (e.g., A. Irwin & Wynne, 1996c). These models challenge the notion of science as an isolated body of knowledge, recognizing its socially constructed nature (A. Irwin & Wynne, 1996b). Members of society clearly do not place the same emphases on different ways of knowing, and public understanding models should avoid any assumptions about defining all knowledge based on the epistemological commitments of science (A. Irwin & Wynne, 1996a). Rational choice and contextual models incorporate utilitarian and affective
approaches (Ziman, 1992; Sturgis & Allum, 2004; Wynne, 1992b). Rational choice models ask what people need to know in order to be good citizens, and when the public has to make practical decisions, what knowledge is relevant (Ziman, 1992). Prewitt (1983) considers this approach scientific “savvy.”

Science educators have identified socioscientific issues as issues at the interface of science and society, dilemmas where both social and scientific factors are crucial (Bingle & Gaskell, 1994; Sadler, 2004). Although scientific literacy for citizenship is often identified as an outcome, understanding and evaluating knowledge claims play a central role in the discussion (Bingle & Gaskell, 1994; Kolstø, 2001; Sadler et al., 2004). In fact, an important component of epistemological understanding with these dilemmas is understanding the differences between ready-made science and science-in-the-making (Latour 1987) and the gray area between them (Kolstø, 2001). At the extremes, ready-made science – that of textbooks – are areas in science where consensus has been broadly achieved (for example, that organisms share a common ancestry), and science-in-the-making are areas at the forefront of research where debatable claims are still subject to revision (for example, whether anthropogenic changes in the environment are affecting the natural selection of resistance in human pathogens; Eldredge, 2008; Martínez, 2008).

Contextual models argue that the public understanding of science must consider more diverse, independent, and context-sensitive sources of scientific information than just institutionalized science (Wynne, 1991). Social identity explains responses to science (Wynne, 1996). Knowledge can become idiosyncratic in these democratic contexts, however, with debates about what constitutes expertise and how local knowledge held by diverse publics can be equally valid. For example, Davison, Barns, &
Schibeci (1997) argue that some people with little specific knowledge of formal
biological concepts and processes often have a great deal of everyday knowledge.
Nevertheless, everyday knowledge of natural selection and evolution may be highly
essentialist, intentional, and teleological (Evans, 2008), thus representing a mis-
conceptual barrier to consensus on issues related to this important theory. Likewise,
although the public understands some level of uncertainty and risk (A. Irwin & Wynne,
1996a; Wynne, 1992a), NOS research clearly indicates that the public does not
understand uncertainty in the philosophical sense. Uncertainty in the sense of risk is an
epistemological factor, whereas the tentative nature of conclusions is ontological. Thus,
contextual models of public understanding of science and science literacy focus on
models of the public and models of science from fundamentally different directions
(Locke, 1999).

Ultimately, models of the interaction of science in society vary depending on (1)
the absolute nature of the literacy component and (2) the extent of social consideration
(Laugksch, 2000). In essence, public understanding models segregate along axes that are
cconcerned with the role of knowledge and the role of “truth” in a democratic society.
Indeed, in a two-dimensional space, the literacy component can be thought of in terms of
epistemological considerations and the social component can be thought of in terms of
ontological considerations. The research areas can then be mapped onto the axes to
describe the extent of each of these considerations in the agenda (Figure 2.1). For
example, science and society models emphasize ontological considerations more than
epistemological considerations. Epistemology is certainly important, but these models
tend to weigh trust and credibility heavily. Citizen science programs that emphasize
collective praxis are clearly more interested in coming to some social “truth” than questions about methodological naturalism. Certainly, within the science literacy program, emphasis is more often on the methodology of science and the kind of knowledge that methodology generates specific to the scientific enterprise. In addition, each of the three realms may include different literacy components, for example science literacy, the literacy of democracy, or institutional knowledge (cf. Wynne, 1991). Ideally, teaching for public understanding finds some intermediate in these positions, grounded in an understanding that different sources of information have different epistemological and ontological commitments that yield very different outcomes.

**Marketplace of Ideas**

Clearly, creationists have been extremely successful in bringing their anti-evolution campaign to the public arena. In fact, the irony of the First Amendment is that it both restricts creationist ideas from entering the science classroom and defends their rights to a forum. In the United States, that forum is broadly protected as the “marketplace of ideas.” The concept of a marketplace where ideas compete is attributed to Oliver Wendell Holmes in his dissent of *Abrams v. United States*, (250 U.S. 616, 1919). He argued that “when men have realized that time has upset many fighting faiths, they may come to believe even more than they believe the very foundations of their own conduct that the ultimate good desired is better reached by free trade in ideas-that the best test of truth is the power of the thought to get itself accepted in the competition of the market, and that truth is the only ground upon which their wishes safely can be carried
Figure 2.1. The relative importance of epistemological and ontological considerations in public understanding of science (PUS) research programs. Where these programs converge serves as an optimal goal for science educators concerned with developing effective citizens.

out.” Two theoretical perspectives combine to idealize the marketplace as a source of competitive, efficient, and unregulated ideas highly sensitive to consumer preferences that yields informed decision-making and a well-functioning democracy (Napoli, 1999). The economic perspective of this free-speech model focuses on maximizing consumer
welfare and competition, whereas the democratic theory perspective focuses on the marketplace as a source of maximum idea exchange in the context of effective self-government (Napoli, 1999). Although the marketplace concept may be too broadly applied in jurisprudence (Hopkins, 1996), the metaphor is useful in the context of consumers’ and citizens’ rights to receive information (Sweeney, 1984 in Napoli, 1999). More important criticisms of the marketplace of ideas metaphor focus on the issues of ontology associated with the “truth” to which Judge Holmes refers, cognitive dissonance (Ingber, 1984; Baker, 1989), and epistemology.

Within the marketplace, then, the truth claims of creationists can be weighed equally with the truth claims of evolutionary science. Simply because public knowledge, as a body of shared knowledge, by definition may not be democratic does not argue against the democratic standing of all ways of knowing (e.g., Smith & Scharmann, 1999). Stephen Jay Gould (Gould, 1997) enlists the ideas of non-overlapping magisteria, or ways of knowing, to distinguish what can be known with science and what can be known in other ways. For example, religion and science are two distinct ways of knowing with very different approaches to truth and evidence. In public discourses, even scientists may step away from methodological naturalism and frame their personal worldviews in terms of different ways of knowing (Smith & Scharmann, 1999). Nevertheless, few but the most highly educated experts can understand all of the intricacies of the various disciplines that contribute to the modern synthesis of evolution. To complicate matters, science proceeds by managing the uncertainty associated with the knowledge it generates. These uncertainties are manifest in misconceptions about human evolution and discomfort with regard to human’s place in the universe. Additional uncertainty develops
when people confuse the science of evolution with the consequences of evolution, and methodological naturalism with philosophical naturalism. Without basic understanding of fundamentals of evolution, however, people have to have “faith” in evolution in a manner that equates easily with “teaching the controversy” and alternative theories. It is within this misconception framework that persuaders create cognitive imbalance and dissonance in the marketplace to alter beliefs, attitudes, and intentions (Ilardo, 1981) about evolutionary theory.

Rhetoric of the “Controversy”

Cognitive dissonance is a model of human behavior based on consistency theory that describes how people behave when faced with new information that conflicts with current beliefs or notions (Festinger, 1957). Humans act predictably when exposed to dissonance-producing messages: they avoid the conflicting attitude or behavior, reduce the importance, or acquire new beliefs that change the balance (Festinger, 1957). In fact, substantial evidence indicates this model reasonably predicts the future outcomes of messages. Purveyors of messages often use discrepant or inconsistent information with the purpose of bringing about attitude change (Baker, 1989). Fleming and Goodall (2002) suggest the goal of such communications is to produce true believers not true skeptics and intellectual honesty.

Although evolutionary science is misused by anti-evolutionists, persuasion science is not. Those with strongly held fundamentalist views want to persuade the “uncertain” public to question the fundamentals of evolution, and even science as a whole. Ultimately, the goal is to return our society to its fundamentalist roots starting
with the removal of evolution education (and perhaps all of science education) from the
public schools. The Wedge Strategy is a carefully calculated strategy developed by the
Discovery Institute designed to “defeat scientific materialism and its destructive moral,
cultural and political legacies and to replace materialistic explanations with the theistic
understanding that nature and human beings are created by God” (Center for the Renewal
of Science & Culture, 1999; also see Forrest & Gross, 2004) through a deliberate attack
on the public opinion-making process in the marketplace of ideas.

The persuasive campaign targets the public’s attitudes toward evolution and
science. Inducements are both logical and non-logical (Ilardo, 1981). Logical
inducements include chains of reasoning (usually based on the misuse of evolutionary
science) refuting the evidence supporting evolution, and emotional proofs, such as the
need for morals and values in society. Anti-evolutionists want to maintain the public
misconception that people came from apes because it fits with their persuasive rhetoric;
because scientists agree that people did not come from apes, evolution must not be true.
They impart information that implies skepticism and fair treatment, elevating the
contestability of the discrepant information. Fear appeals, such as the misguided Social
Darwinist argument (see Figure 2.2 below), heighten dissonance through non-logical
inducement. The false dichotomies persuaders establish require choice on the part of the
public; choosing evolution means denying God (see also Marsden, 1991). Indeed, the
campaign purposively ignores any middle ground. For example, the American Scientific
Affiliation, founded prior to the Creation Research Society (Numbers, 2006), is a
Christian fellowship of “men and women of science and disciplines that can relate to
science who share a common fidelity to the Word of God and a commitment to integrity
in the practice of science” (http://www.asa3.org). Anti-evolutionists consider any notion of theistic evolution an apostate affiliation (Numbers, 2006). Their position is clear: the choice may be free, but the punishment will be great.

These tactics magnify dissonance and leave the public subject to the persuasive messages championed by opponents of evolution, such as “teach the alternatives,” “balanced treatment,” and “critical analyses” legislation. Those with strongly held fundamentalist views want to persuade the “uncertain” public to question the fundamentals of evolution and science as a whole (Clark et al., 2007; Scott & Matzke, 2007). Moreover, opponents of evolutionary biology cast doubt on the credibility of scientists and the knowledge generated by such diverse disciplines as chemistry, geology, biology, and social science (Clark et al., 2007). Although casting doubt on high-credibility sources reduces persuasive effects, people tend to disassociate sources and their opinions over time, especially with low-credibility sources (see Severin & Tankard, 2001). One final part of the persuasion strategy includes the tactic of arguing for “equal time” in the guise of “it’s only fair”. More than any other, this strategy appeals to people’s sense of reciprocation (Cialdini, 1993). It also plays well with journalists trying to meet some semblance of “balance”, and the appeal to “fairness” creates additional uncertainty by casting doubt on the credibility of anyone who won’t “play by the rules” (Taylor & Condit, 1988). As a result, dissonance purveyors with a message perceived as strong by the uncertain public may be treated with the same respect as a scientist in time.

Ultimately, the anti-evolution persuasion campaign is designed to alter behavior. Messages are intended to change public attitudes about teaching evolution, especially those that influence behavior in terms of casting appropriate votes. The relationship
between attitude change and behavioral intentions is complex, however; behavior is not a simple function of attitude. In fact, Cialdini (1993) suggests that attitude is not even a factor when social proof is operating. Social proof is a means for determining the correct behavior based on other people’s behaviors; in the face of uncertainty, look to and accept the actions of others as correct. Cialdini (1993) even suggests that social proof underlies the strengthening of cultist beliefs after the inevitable failure of their prophecies: the greater the number of people who find any idea correct, the more the idea will be correct. If this tenet of social proof holds, the persuasive messages designed to generate uncertainty about science, scientists, and evolution teaching could lead to a majority acceptance of anti-evolutionism simply through the ever-increasing numbers of people looking to others to determine the correct course of action. Indeed, the more people intending to vote to include evolution “alternatives” in the science classroom, the more likely the uncertain public will find a strong role model and model their behavior towards that role model. Therefore, the small step of accepting the teaching of evolution “alternatives” may be the first leading to serious consequences for the science classroom.

Past behavior is a strong predictor of future intentions to behave. Whether the relationship is caused by behavioral consistency (Cialdini 1993) or increased cognitive accessibility of behaviors (i.e., priming; Trafimow & Borrie, 1999), the implications for the future of evolution education may rest on that first step.

The success of the anti-evolutionist campaign is apparent in surveys addressing public acceptance of evolution. A recent survey of Louisiana residents indicates that 40% do not believe evolution is well-supported by evidence or generally accepted within the scientific community (Baton Rouge Advocate, April 14, 2009). Similarly, Miller,
Scott, & Okamoto (2006) show that the proportion of adults accepting the idea of evolution has declined over the past 20 years (from 45 to 40%), but the proportion of rejecting evolution also decreased from 48% to 39% (see also Pew Research Center for the People & the Press, 2009). Perhaps the persuasive campaign is creating a dissonance “backlash” in fundamentalists. Indeed, acceptance of evolution may be directly related to the proportion of anti-evolution and pro-evolution messages to which people are exposed (Brem, Ranney, & Schindel, 2003). Nevertheless, the fact that the proportion of U.S. adults accepting evolution is one of the lowest in the world does not bode well for the future of evolution education and research without radical intervention by educators. If uncertainty is the metric of imbalance in cognitive dissonance, the campaign waged by the anti-evolutionists is clearly affecting the public arena.

**Media Effects in the Marketplace**

The media may play a powerful role in the delivery of messages in the marketplace. Both the language and the visual images used add a sense of certainty to evidence; the auditor/observer is experiencing the evidence “first hand” (Kirby, 2003). In fact, the effects of these experiences may outlast the sources. Metaphors are one of the more powerful language tools available; their ability to evoke concrete images can help make complex issues understandable to the public and foster debate (Väliverronen & Hellsten, 2002). Especially in television news environments, metaphors can add the context needed by the audience in a fairly quick and precise manner (Rowan, 1992). In addition, metaphors can be used to promote certain political interests or reinforcing scientific and professional authority. For example, Väliverronen and Hellsten (2002)
found that metaphors helped scientists define the biodiversity issue by likening it to a “library of life”. These metaphors, if used as part of transformative explanations, can help audiences recognize, test, and overcome lay theories (i.e., alternative conceptions; Rowan, 1992). Stephen Jay Gould (1977) specifically enlisted the “bush metaphor” to help the public discourse of evolution move beyond the search for “missing links”.

Visual representations also have a powerful communicative value because they allow the viewer to “witness” the phenomena. Images evoke certainty, and can serve as highly persuasive inducements. They can be very effective in persuasive campaigns (Figure 2.2). In addition, visual elements, such as photographs and television images, can help conceptualize abstract problems (Väliverronen & Hellsten, 2002). Indeed, images enhanced viewer recall in television news through the “explanation” and “emotional bond” they add (Graber, 1990; see also Zhou, 2005). In the History Channel’s From Ape to Man, a documentary about human evolution, the producers used graphic representation to effectively represent the generations involved in speciation. The camera whizzed by thousands of individuals representing one branch of the evolutionary tree/bush. Another visual aid had a scientist drawing out the branching tree along a long stretch of beach. The camera stayed fixed as he moves farther and farther away from the common ancestor. Both images leave the viewer with a concept of time that more closely matches the scientific understanding. Even fictional images, such as those in movies, affect acceptance of scientific concepts. Padian (1987) found that these images didn’t necessarily correspond with reality, but they were plausible. In addition, popular images can be powerful determinants of perceptions in science – by scientists – more so than scientific evidence (Padian, 1987). According to Padian, “a picture is not only worth a
Figure 2.2. Social Darwinism and the effects of imagery. The text uses irony to mock the supposed consequences of accepting evolutionary theory and setting up a false dichotomy (http://www.answersingenesis.org).

thousand words; however inaccurate, it may be worth a wealth of well-documented evidence to the contrary” (p. 76).

Audio and video can have unintended consequences with equally persistent effects. Metaphors can create uncertainty if they are overused or vague, or establish false dichotomies if they are apocalyptic, such as “the battle over nature” (Väliverronen & Hellsten, 2002). Despite the “permanency” of images, they too can be misinterpreted. Indeed, history has been manipulated by photographers both intentionally and unintentionally. Pictures tell stories, and those stories are interpreted and re-interpreted by viewers; without input from the author, they take on the story of the viewer whether it was the author’s intent or not (Sandweiss, 2002). Indeed the depiction of different hominid species was likely designed to show similarity (Figure 2.3). Its recent use has been on creationist websites to discredit the notion that man descended from apes.

Because television includes both strong visual and audio messages, it is the subject of much criticism and review. Television has a long history of viewing audiences
Figure 2.3. Unintended consequences: images that may have been developed to represent the character evolution of *Homo sapiens* may instead encourage the “people came from apes” misconception.

as passive receptacles of the medium’s account of the world (T. Wilson, 1993). In fact, Gerbner, Gross, Morgan, & Signorielli (1986) suggest that as passive viewers, the more people watch television, the more they think the real world is like the world portrayed on television. First, persuasive processes may encourage or discourage people to believe that television messages are an accurate reflection of the world, and second, the availability heuristic posits that people infer the prevalence of a construct from the ease with which an example is retrieved (i.e., its accessibility from memory; Shrum, 1999). Television viewers are not necessarily passive vessels, however; activity is evident in people’s utility, intention, selectivity, and involvement with the media (Blumler, 1979). Still, cultivation may result as audiences actively compare the probability of events through cognitive rationalizing (Potter, 1991; Potter, Pashupati, Pekurny, Hoffman, & Davis, 2002). In fact, the elaboration likelihood model explains how people can fluctuate in the extent to which they rationalize judgments through both passive and active mechanisms (Schroeder, 2005). The likelihood of elaboration, “issue-relevant” thinking, or critical evaluation of the messages being received depends on whether the messages are processed through (1) a central route that entails extensive elaboration, or (2) a peripheral route, where little elaboration occurs and viewers rely on heuristics (Petty &
Cacioppo, 1986). Indeed, several social scientists suggest that the negative images of science on television serve as heuristics that ultimately lead either to reservations about the discipline (Gerbner, 1987; Nisbet et al., 2002) or the promise of science (Nisbet et al., 2002).

Other models of media effects examine audiences as active communicators, motivated, selective, and involved in their communication choices (Rubin & Perse, 1987). The models explore how people use media to gratify their needs, understanding the motives for media behavior, and identifying the consequences that follow from these needs, motives, and behaviors (Rubin, 2004). Media effects, such as perception of scientists and science, may be heavily influenced by individual characteristics such as social and psychological circumstances (Rubin & Rubin, 1982), science knowledge (Nisbet et al., 2002), and motivation (Perse, 1990; Rubin, 1983; Rubin & Perse, 1987). Indeed, cognitive motivation may facilitate information gain (Blumler, 1979). Learning, therefore, is a clear, positive, outcome of uses and gratifications research.

Narrative likely plays an important role in the effect of television content as well. Indeed, narratives can affect the public’s understanding of science both positively (e.g., Lowe et al., 2006) and negatively (e.g., Barnett et al., 2006). Narratives also are powerful persuasive tools and can interact with ideology in discussions of controversial public policies (Slater, Rouner, & Long, 2006), like teaching evolution. After all, narratives positively affect memory (Graesser, Haut-Smith, Cohen, & Pyles, 1980; Shapiro & Fox, 2002) and can increase the plausibility and persuasiveness of information presented (Voss, Wiley, & Sandak, 1999). Because the narrative is the predominant form taught for teaching and reading, the “narrative experience” of our lives may make it
easier to comprehend and recall content than expository texts much less related to life experiences (Norris, Guilbert, Smith, Hakimelahi, & Phillips, 2005). We relate to narratives. Indeed, “transportation into a narrative world” may be a key mechanism of narrative impact (Green & Brock, 2000).

Audiences are actively making sense of narratives (Livingstone, 1998). As they interact with different media, they process three types of realism: fictionality, external realism (matching with external reality), and narrative realism (coherence within a story) (Busselle & Bilandzic, 2008). External realism, however, is not necessarily the most essential. Audiences make judgments about the consistency of narratives constructed from a narrative experience (i.e., story world, character models, and situation models) in relation to their own experiences (Busselle, Ryabovolova, & Wilson, 2004). The result is that instead of being concerned with verisimilitude (i.e., the “truth”), audience members are concerned with coherence and logic within a particular fictional context (Busselle & Bilandzic, 2008; Busselle et al., 2004). Enjoyment is not dependent on how well a television program, for example, reflects real-world truth (Green, Brock, & Kaufman, 2004). In fact, readers, and television viewers, that are “highly transported” maintain beliefs that are consistent with the stories, regardless of their realism (Green, 2004). Perceived realism is highly correlated with the perceived “typicality” of the narrative event, however; audiences use some commonsense plausibility criterion (Busselle & Bilandzic, 2008) and generate a relative realism (Shapiro & Fox, 2002). Unfortunately, prior knowledge and experience affect transportation (Green, 2004) in a counter-intuitive manner, at least with regards to science. More experience yields a greater likelihood of transportation (Green, 2004) rather than any kind of skepticism. Engagement with a
story may leave viewers with the sense that that story was authentic (Busselle & Bilandzic, 2008), whether it accurately reflects the current understanding of science and evolution or not.

Media effects models provide valuable insight to the influence of educational television. One model of learning from television incorporates the theoretical construct of “mental capacity” with three components: processing of the narrative, processing of educational content, and distance (how integral the educational content is to the narrative; Fisch, 2000). Indeed, comprehension of educational content is greater when the distance between narrative and educational content is small than when it is large (Fisch et al. 1995 in Fisch 2000). Although prior knowledge, in this model, reduces the demands of processing (Fisch, 2000), television producers have no metric of audiences’ general understanding. Production ultimately yields to the least common denominator.

A number of studies support the notion that television is an environment for learning. The Public Broadcasting Service (1987) examined the appeal, learning, and emotional impact of television programs watched by a random sample of 2000 adults using logging diaries similar to the Nielson ratings system. Science and nature programs scored high on the appeal and learning scales. The “CSI effect” has resulted in a significant increase in the numbers of students pursuing degrees in forensic sciences at universities (Houck, 2005). Television programming that combined entertainment with education also was used to direct social change (e.g., Comstock & Scharrer, 1999; Singhal & Rogers, 1991). More specifically, research has shown that children do learn scientific content information from television series designed to teach science and mathematics (Chen, 1983; Johnston & Luker, 1983). In addition, adults learned about
health and nutrition from watching a single program (Chew, Palmer, & Kim, 1995), and Frey & Wolsky (2006) developed a television format that reinforced key lessons about engineering and engaged audiences. Fortner (1985) found that watching nature programs increased knowledge that was retained at a level equal to the same information presented in lecture format, but attitude changes were apparent only in the television treated group. Furthermore, exposure to science through films and other media outside of classroom settings has had positive impacts on science learning by individuals in school (Bitgood, Serrell, & Thompson, 1994; Chen, 1994; Dhingra, 2003; Wright et al., 2001). Other research has shown that viewing educational television results in significant gains in children’s general academic knowledge and skills (D. R. Anderson, 1998; Fisch, 2005; Salomon, 1979; Southwell, 2005). Television learning was shown to extend into symbol systems, teaching unique cognitive skills not taught in school (Salomon, 1979). Children who watched educational programs tended to have better grades in high school than those that watched strictly entertainment programs (Wright et al., 2001). And despite innuendo, little evidence has been found to indicate that watching television has negative effects on learning (including reading) except in extreme cases (Wartella, 1987). In this light, television can be classified as a free-choice science education opportunity.

**Free-choice Science Learning**

Most commonly referred to as informal learning, free-choice science education advocates that the process of learning is the same outside of the classroom as it is in the classroom (Falk, 2001). As a lifelong learning process, however, free-choice learning is typically characterized as being self-directed, voluntary, and motivated mainly by
intrinsic interests, curiosity, exploration, and social interaction (Dierking, Falk, Rennie, Anderson, & Ellenbogen, 2003; Falk & Dierking, 2000). Motivational factors (Falk, 2006), rather than testing drives learning in the free-choice world. The marketplace of ideas is full of competing ideas all vying for some competitive grasp of the public’s idea of “truth.” In the marketplace, the learning process may be the same as formal learning environments, but marketplace influences, not standards-based influences, visibly dominate. As a result, not all of the competing ideas are of equal “educational” value.

Individuals looking for educational opportunities in the marketplace of ideas are faced with truly educational opportunities, as well as many opportunities unintentionally, or even purposefully, masking themselves as opportunities to learn about science and evolution. For example, *All About Science* (http://www.allaboutscience.org/) is a website hosted by AllAboutGod.com. Although ostensibly describing Darwin’s Theory of Evolution, the site quickly turns to “intelligent design” rhetoric outlining the “crisis” in evolutionary understanding that irreducible complexity poses. The site comes complete with a literature cited section, (including only Darwin, and Michael Behe and Michael Denton [intelligent design proponents]).

The issue of educational content is not limited to the vast amount of material on the internet, however; resources considered traditional sources for science education may or may not promote standards-based (e.g., National Science Education Standards) content in the marketplace. The Glendive Dinosaur and Fossil Museum is situated at the highway exit for Makoshika State Park, a park devoted to the preservation of the Montana Badlands and the Hell Creek Formation. The Hell Creek Formation dates back 65 million years and is the site of several important paleontological discoveries. The
museum is operated by the Foundation Advancing Creation Truth and is not a sanctioned member of the Montana Dinosaur Trail, a product of the Montana Tourism Advisory Council (the Makoshika Dinosaur Museum in Glendive is). It offers similar fare, however, including fossil digs used to promote the literal truth of the bible and an interpretation of the fossil record from a creationist perspective (http://www.ultimatemontana.com/businessdirectory/buspages/sec01/glendivedinomus.html). Unlike the transparent mission of the Creation Museum in Petersburg, Kentucky, sponsored by Answers in Genesis (Slack, 2008), the mission of the Glendive Dinosaur and Fossil Museum is hidden from unsuspecting consumers.

Less clear are free-choice opportunities often considered “educational” by convention. Wildlife and nature programs have the potential to engage and teach large audiences about the natural world in free-choice learning environments, but they also may be implicit in the public’s misunderstanding of evolution. Both Mitman (1999) and Bousé (2000) have clearly endorsed embracing a highly skeptical view of reality presented in wildlife films, warning that this genre is driven by the need for compelling story lines rather than scientific accuracy. More recently, Dingwall and Aldridge (2006) suggest that nature film narratives implicitly endorse creationist accounts of life on earth, especially in the “blue-chip” sub-genre, with their high production values and strong visual appeal. Obviously, these programs tend to be designed and developed with the producer’s best interests in mind, not necessarily the learner’s (Chen 1994). Wildlife and nature films that present evolutionary science poorly may be particularly harmful if audiences perceive the genre as educational because genre experiences are critical in textual readings and interpretation (Livingston 1998). In fact, the narrative story of many
wildlife films imply evolution is driven by some purpose, and watching may actually increase the differences in understanding of evolution between the general public and biological scientists (Dingwall & Aldridge, 2006). Narration that incorporates teleology as a mechanism may not directly promote alternative “theories” to evolution, such as “intelligent design” (Dingwall and Aldridge 2006), but it promotes alternative conceptions nonetheless.

In essence, learning from wildlife and nature films is a cultivation effect. Cultivation theory posits that television portrayals systematically distort reality, and long-term viewing of these distortions is likely to have an effect on audiences (Gerbner et al., 1986). Poor presentation of natural processes, like evolution, in these visually stunning “virtual witnessing” events (Kirby, 2003) may affect evolution understanding through both active and passive routes. Because the educational content is integral to the narrative (i.e., explanations of evolution that include design and advancement that individuals can relate to), the parallel mental processes responsible for comprehending narrative and educational content complement each other (Fisch, 2000). Moreover, individuals motivated to learn are most likely to elaborate and incorporate the broad knowledge messages communicated through free-choice venues (Blumler, 1979; Falk, Heimlich, & Bronnenkant, 2008; Maurer & Reinemann, 2006); motivated learners (i.e., those most likely to engage in science and society debates) may learn incorrect conceptions about this key ecological processes. In addition, being transported into the narrative world of nature programs may have considerable consequences related to viewers’ emotional connections with characters (Green, Brock, & Kaufman, 2004). Recalling the triumphant return of an orphaned lion cub to become head of the pride
surpassing all odds does not represent an evolutionary process, but a teleological process. These kinds of teleological misconceptions easily can lead to “intelligent design” considerations (see also Dingwall & Aldridge, 2006), especially if the “witnessed” events serve as heuristics when making civic decisions about teaching evolution and creationism in the science classroom (Busselle & Bilandzic, 2008; Shapiro & Fox, 2002; Shrum, 1999).

Because the learning process is the same as formal environments, science educators in the free-choice marketplace should expect schema construction that is based on prior knowledge and conceptual frameworks that may be coherent or in pieces. Intuitive theories that act as developmental biases (Evans, 2008) combined with highly abstract concepts (Lawson et al., 2000) make teaching for conceptual change in formal environments difficult, let alone once individuals have left the classroom. A single experience can change an individual’s understanding if it appeals to need or interest, engages prior knowledge, and the conceptual relationship is evident (Stocklmayer & Gilbert, 2002). In fact, images may be more memorable than a science course (Aikenhead, 1988) or a lab experiment (Barnett et al., 2006). Moreover, interest in the topic is an important factor related to recall of, and learning from, narrative texts (Schiefele, 1998). Knowledge constructed from poor sources obtained in the marketplace of ideas can lead to misconceptions that can be very difficult to alter (Wandersee et al., 1994), especially in free-choice learning environments. The key is distinguishing fictional science from non-fiction (Nowotny, 2005). Despite their largely fictional content, nature programs are considered by many to be highly educational opportunities.
Clearly, this disconnect can have profound effects on the public understanding of evolution, especially given the current climate of rhetoric.

Conclusions

The science concepts held by individuals are the result of a combination of the formal explanations learned in school, their personal experiences and observations, the culture, and language (Wandersee et al., 1994). Understanding the theory of evolution is complex, however, and misconceptions may be influenced by other ways of knowing than just science understanding. Teaching about the epistemological commitments of the NOS framework may help individuals grasp the kind of knowledge science generates and ultimately influence how people think about the epistemological and ontological underpinnings of the knowledge they use when engaging in civil discourses.

In the marketplace of ideas, formal and free-choice science learning interact to affect public understanding of evolution. Scientists and creationists present different versions of the world in rhetorical terms of competing logoi (the reasoning of an argument); they use similar argumentative modes and techniques (Locke, 1999). The messages may be different, but they are all designed to persuade. Persuasive messages about evolution can interact with individuals and their personal epistemology through the free-choice learning environment. Audience experiences with media may affect how they approach different sources as well as their motivation to learn about science. They may use descriptors such as “educational” to make their choices, unaware that the source they believe is credible does not actually reflect current understanding of evolution at all. Personal epistemology, or the beliefs an individual holds about knowledge and its
production, may provide the theoretical grounding to predict media influences, and more broadly, the learning outcomes about science in the marketplace of ideas. Specifically, personal epistemology may be closely tied to the kind of knowledge viewers use when understanding wildlife and nature programs. The result is a web of inter-related factors that affects how the public understands evolution as a science and how the public responds to decisions about evolution and creationism in civic decisions (Figure 2.4). In this free-for-all marketplace, acceptance and rejection of messages depend on individuals’ levels of understanding, their experiences, their culture, and the rhetorical organization that influences their responses to authoritative knowledge (Locke, 1999).

In general, the knowledge individuals have is practically inadequate, incoherent, inconsistent, and incredible (Ziman 1992). In other words, what evolution knowledge individuals do use from their formal education in regards to important civic issues, such as the N1H1 virus, antibiotics, and biodiversity, represents only one small element in a complex and varied response; little of what they do retain from school is actually supplemented by free-choice sources later on; contradictions are resolved using bits and pieces of formal science within a system of different ways of knowing; and the credibility of sources depends on their perceived interest in these situations (Ziman 1992). Clearly, the literature strongly indicates a need for more insight into the complex relationships among how people learn about evolutionary theory – what they learn, when they learn it, and from where that knowledge comes. Evolution educators must be aware of the web of knowledge contributing to citizen’s understanding and focus and enrich educational opportunities that will help overcome misconceptions about this important theory.
Figure 2.4. The formal and informal influences on public understanding of evolution. Some influences influence understanding directly, while others act indirectly.
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CHAPTER 3.

FATAL FLOWER FRAILTIES: USING NATURE FILMS TO HELP ADDRESS MISCONCEPTIONS ABOUT EVOLUTIONARY THEORY

Abstract:

Evolution is a central underlying concept to a significant number of discourses in civilized society, but the complexity of understanding basic tenets of this important theory is just now coming to light. A number of misconceptions have been described, including the process of developing new traits, the role of variation, and the transformation of species. Research into strategies to overcome these misconceptions has been equivocal, however. As part of a curriculum that used a nature program as a surrogate to help students explicitly recognize their cognitive illusions, we developed specific teaching tools that elicited the diversity of concepts held by individuals. One tool required students respond to four incorrect prepared alternative statements about the co-evolution of orchids and their pollinators. Students’ responses indicated they simultaneously held a number of misconceptions, proximate conceptions, and evolutionary conceptions. Indeed, students’ “conceptual ecologies” were highly diverse, diversity that scaled with the abstract nature of the concepts associated with evolutionary theory. Students with more evolutionary conceptions included fewer misconceptions in their responses than students with few or no evolutionary conceptions. The composition of conceptual ecologies suggested that students may shift to a conceptual ecology dominated by proximate conceptions prior to incorporating evolutionary conceptions, then return to an ecology that incorporates both misconceptions and proximate
conceptions as they begin to grasp evolutionary concepts. As a result, the broad misconceptions that confound pedagogical strategies may reflect the way students’ struggle as they incorporate new concepts into their pre-existing schema. Teaching strategies that explicitly address misconceptions may be one effective approach to bring forth conceptual change.

Keywords: evolution misconceptions, nature programs, conceptual change

Over the past two decades, science educators have been struggling with how to improve evolution education. Misconceptions (also known as alternative conceptions, non-scientific ideas, or limited or inappropriate propositional hierarchies [LIPH’s cf. Novak, 2002]), persist despite research and innovative teaching practices. Indeed, specific interventions designed to help teachers and students overcome misconceptions about the theory of evolution have shown encouraging, but equivocal results (e.g., Chinsamy & Plagányi, 2007; Crawford, Zembal-Saul, Munford, & Friedrichsen, 2005; Ingram & Nelson, 2006; Kampourakis & Zogza, 2008a; Nehm & Reilly, 2007; Nehm & Schonfeld, 2007; Scharmann, Smith, James, & Jenson, 2005; Verhey, 2005/2006).

Part of the problem may stem from how we treat misconceptions. Misconceptions may be a part of a coherent framework analogous, perhaps, to a scientific theory (Vosniadou, Vamvakoussi, & Skopeliti, 2008), or they may be fragments that exist among other fragments of knowledge that are combined based on the context of the situation (J. P. Smith, III, DiSessa, & Roschelle, 1993; diSessa, 2008). Traditional conceptual change research emphasizes major conceptual restructuring that results from a
logical dissatisfaction with and abandoning of prior conceptions (Posner, Strike, Hewson, & Gertzog, 1982; Nussbaum, 1989). New concepts are linked to concepts already present in the learner’s cognitive structure through progressive differentiation and integrative reconciliation as learners delineate similarities and differences among existing concepts, ultimately resulting in a more cohesive and integrated framework (Ausubel, 1963, 1968, 2000; Ausubel, Novak, & Hanesian, 1978). In this view, misconceptions can be a barrier that must be overcome to attain scientific understanding (Groves & Pugh, 2002; Hamza & Wickman, 2008; Nicholls, 1999; J. P. Smith, III et al., 1993; Songer & Mintzes, 1994). Unfortunately, this kind of superordinate learning is rare, more characteristic of experts than students (Mintzes, Wandersee, & Novak, 1997; Novak, 1993; Novak, 2002).

The conceptual ecologies of students may be much less theory-like, however, gradually evolving to include more scientific understanding as new pieces of knowledge are added and assimilated in different contexts (J. P. Smith, III et al., 1993). For example, integrated within a learner’s conceptual ecology (intellectual ecology; cf. Toulmin, 1972) are epistemological commitments, anomalies, metaphors, analogies, metaphysical beliefs, alternative conceptions, knowledge from outside of the field (Demastes, Good, & Peebles, 1995), and heuristics (Schroeder, 2005). Indeed, in a very Darwinian approach, Toulmin (1972) argues that variation and selection exist at all these levels of concept use. So if the conceptual ecologies learners are building are not coherent, theory-like frameworks, then examining the structural elements and the context of their use (grain size) may provide valuable insight to construction and reconstruction of knowledge (diSessa, 2008).
Whether conceptual change is thought of as a revision of a conceptual system as elements of the currently accepted scientific explanations are gradually included (Nussbaum, 1989; Taber, 2001; Vosniadou & Ioannides, 1998), or as pieces of knowledge invoked contextually (diSessa, 2008), misconceptions may be commonly included in conceptual ecologies (Clough & Driver, 1986; Demastes, Good, & Peebles, 1996; Hamza & Wickman, 2008; Kampourakis & Zogza, 2008b; Lawson, Alkhoury, Benford, Clark, & Falconer, 2000; Metz, 1991; D. H. Palmer, 1999).

Depending on the context of the problem, students may use misconceptions or scientifically acceptable conceptions when queried (diSessa, 2008; Kampourakis & Zogza, 2008b; Tytler, 1998; Welzel & Roth, 1998). In fact, Hamza and Wickman (2008) suggest that misconceptions can be integral in the learning process as they are encountered and questioned (see also Lawson et al., 2000; Taber, 2001). Clearly, individuals vary in their employment of different aspects of their conceptual ecologies, as well as the logical and affective considerations for doing so (Demastes et al., 1995; Tytler, 1998). Some elements of misconceptions may disappear on their own, as individuals learn more natural history, for example (Evans, 2000, 2001). Therefore, what we expect at the end of instruction may either be (1) complete adoption of a new and, hopefully, more evolutionary perspective if misconceptions are cohesive frameworks; or (2) a mixed assemblage of scientifically sound concepts and misconceptions that exist in different frequencies than prior to instruction if the misconceptions are transitional, contextual frameworks.
Identifying Misconceptions in Evolution

Exploring elements of coherence and grain size requires a methodological approach that is sensitive to both sub-conceptual structure and integration (diSessa, 2008). Evolutionary theory is complex and includes a variety of disciplines, each of which may interact in a complex way with prior knowledge to produce the conceptions individuals hold. In their influential work, Bishop and Anderson (1990) describe three ways that student conceptions about evolution differ from scientific conceptions: (1) students fail to distinguish between appearance of traits and survival over time (the environment causes traits to change over time); (2) students do not consider the role of variation (evolution is seen as a process that changes the entire species simultaneously); and (3) students do not see evolution as the changing proportions of individuals with traits (they see gradual changes in the traits themselves). Considering misconceptions in this broad classification may mask any understanding of smaller, more discrete, less abstract concepts that students may hold and use to build their understanding. Indeed, misconception research often has focused on discrete issues, such as adaptation (D. Palmer, 1996; Renner, Brumby, & Shepherd, 1981) and genetics (Clough & Wood-Robinson, 1985; Demastes in Good et al., 1992; Halldén, 1988), that may influence overall interpretations of student understanding. Integrating scales of interpretation that include broad and discrete, topic-oriented conceptions may permit a snapshot of conceptual change from a transformational perspective, however.

Darwinian evolution has been characterized by a number of authors (e.g., Anderson, Fisher, & Norman, 2002; Nehm & Schonfeld, 2008) as incorporating several different levels of abstraction. For example, evolution can be broadly summarized as
follows: random variation exists within species, certain traits are heritable, individuals differ in survival rates, individuals differ in reproductive rates, and changes accumulate over many generations (from Ferrari & Chi, 1998). The structural concepts that form the building blocks of these principles can serve as major stumbling blocks for conceptual understanding and, indeed, within each of these principles are concepts that can be classified according to different levels of abstraction. Lawson, Abraham, & Renner (1989) describe a general classification of concepts into apprehended, descriptive, and theoretical. Apprehended concepts are those whose complete meaning can be derived from the internal or external environment, such as blue or hunger. Descriptive concepts can be mentally constructed when readily available exemplars exist, such as a chair or running. Theoretical concepts are those whose defining attributes are not perceptible – their causal agents cannot be observed directly (osmosis and time, for example). Within this framework, concepts related to evolution understanding such as population and species can be considered descriptive; genes (Lawson et al., 2000), time (Dodick & Orion, 2003), and probabilities (Slovic, 1987; Nicholls, 1999) can be considered theoretical concepts. Lawson et al. (2000) suggest that evolution, natural selection, and convergent evolution, as well as limiting factors, and even the process of fossilization, should be considered hypothetical concepts – intermediate between descriptive and theoretical – because these concepts could derive meaning if not restricted to a normal observational time frame. Whether theoretical or hypothetical, however, evolution clearly represents an abstract conceptual understanding that is beyond a descriptive framework.
Similarly, Ferrari & Chi (1998) suggest that evolution can be considered one of two types of process categories: events and equilibrations. Events are bounded and sequential (like a baseball game; Ferrari & Chi, 1998), and may be analogous to descriptive concepts with readily available exemplars (cf. Lawson et al., 2000). Equilibrations are ongoing, unbounded, and simultaneous (Ferrari & Chi, 1998), and as such, are more abstract hypothetical or theoretical concepts (cf. Lawson et al., 2000). Indeed, students often consider evolution as an event rather than an equilibration (Ferrari & Chi, 1998), employing a descriptive conceptual understanding as opposed to a more abstract process.

Vernacular issues common to many misconceptions and interpretations, such as how individuals define “adapt,” “theory,” and “fitness” (Bishop & Anderson, 1990; Bizzo, 1994), also can be considered in terms of their level of abstraction. Outside of their scientific application, “adaptations” frequently are considered responses to changing environmental conditions, i.e., individuals alter their form, function, or behavior by their own efforts. This conception is descriptive; for example as a verb “adapting,” like running, is a mental construction derived from experience. In the scientific form, the concept is hypothetical and abstract; as a noun, an adaptation is a concept only indirectly testable. Similarly, “fitness” in reference to an individual’s health, strength, or intelligence (Bishop & Anderson, 1990) is descriptive, but the scientific application is abstract and theoretical.

Causal explanations also can be classified along different levels of abstraction. Biological philosophers maintain that two types of causal explanation in evolution exist. Ernst Mayr distinguishes proximate- from ultimate-cause explanations based on the
differentiation of immediately versus historically derived functions (Mayr, 1961). Ariew (2003) argues that Mayr’s proximate causes are more precisely individual-level causal explanations and are very different from statistical evolutionary explanations. In fact, ultimate causes are concretely evolutionary, requiring sophisticated knowledge of probabilities (Ariew, 2003). The distinction is important in that it translates directly into classification of conceptual explanations of evolution offered by students. Concepts that address individual-level phenomena are not necessarily misconceptions. These proximate, individual-based concepts may be less abstract than evolutionary population-based concepts, however.

Clearly, understanding evolution as a broad theory and offering evolutionary explanations involves conceptually deep levels of abstraction. Individuals may have an easier time understanding concepts that are descriptive, especially if they have not developed reasoning skills; hypothetical and theoretical concepts that require more abstract thinking may be more difficult to comprehend (Lawson et al., 2000). In addition, most people have considerable difficulty understanding uncertainty and probabilistic properties (Slovic, 1987; Nicholls, 1999). In fact, cognitive illusions develop from difficulties in quantifying and dealing with probabilities, uncertainty, and risk (Nicholls, 1999). Like optical illusions, misperceptions at such an abstract scale can lead to errors in judgment, for example, about climate predictions (Nicholls, 1999) and ozone depletion (Groves & Pugh, 2002). It follows that cognitive illusions may interfere with developing evolutionary causal explanations. Deeply abstract concepts may interact with less abstract, descriptive concepts within an individual’s conceptual ecology, resulting in the complex patterns of conceptual change that have been observed (e.g., Demastes et al.,
If a student is struggling with misconceptions about mutations (for example, mutations can only be beneficial), the net effect may be an overall misconception of directed evolution rather than differential survival and reproduction. (Of course, mutations in and of themselves may be considered abstract, theoretical concepts if they are defined as cascading effects of sequence alteration.) Kampourakis & Zogza (2008b) consider three types of causal explanations that differ based on a philosophical approach to answering “how” and “why” questions: (a) evolutionary explanations include the historical development of species, (b) proximate explanations relate the current characteristics of individuals to evolution, and (c) final cause explanations suggest predestined outcomes. Because the focus is broad – how students explain evolution – this system does not allow examination of the specific conceptual structure (the “grain size”) within students’ explanations, however. Using a continuum that characterizes concepts from descriptive to abstract within a similar system may function in classifying many of the issues surrounding evolution misconceptions. Indeed, this descriptive-abstract continuum may be a valuable framework for describing student conceptions and exploring conceptual grain size (Figure 3.1).

**Teaching for Conceptual Change**

Several teaching approaches have been developed that help students overcome some of their misconceptions about evolution, including historically rich presentations and paired problem-solving instructional strategies (Jensen & Finley, 1996), emphasizing the Nature of Science (Johnson & Peebles, 1987; Scharmann, 1990; Scharmann & Harris, 1991, 1992; Farber, 2003; Khishfe & Lederman, 2006; Sandoval & Morrison, 2003),
Figure 3.1. The descriptive-abstract continuum for describing conceptions about evolution. Misconceptions can be related to any kind of concept, whereas concepts related to evolution can be proximate (incorporating relatively descriptive concepts) or evolutionary (incorporating relatively more abstract concepts).

Incorporating technology and inquiry-based tasks (Crawford et al., 2005), using the learning cycle and developing reasoning skills (Lawson et al., 1989), active learning courses (Nehm & Reilly, 2007), and teaching sequences (Kampourakis & Zogza, 2008a). Broad misconceptions are tenacious, however, and often persist even after coursework (Nehm & Reilly, 2007; Wandersee, Mintzes, & Novak, 1994). Traditional conceptual change research has suggested that changing conceptual ecologies requires that learners recognize where their concept/propositional frameworks are limited, inappropriate, or poorly organized into hierarchies (Novak, 2002), and as discussed above, this logical approach is not the only pathway to learning a concept (Demastes et al., 1996). Conceptual change strategies require educators consider the knowledge students bring to the classroom and design instruction that helps students begin down some pathway of
cognitive restructuring (National Research Council, 2007; Nelson, 2007). Directly engaging prior conceptions can be very effective (Verhey, 2005). If, as Sinatra et al. (2008) suggest, students are reluctant to alter their misconceptions because those misconceptions fit their understanding of the world, then activities that help students see those misconceptions as errors may be one approach to initiating conceptual change. Clearly, calling attention to students’ personal understanding is inappropriate, but finding an appropriate surrogate that employs equivalent errors may function to highlight errors indirectly. We developed a curriculum plan using a nature program as a surrogate for individuals to identify with commonly held misconceptions to help students deal with their own misconceptions and recognize the errors.

**Nature Programs and Misconceptions**

Nature programs provide an incredible opportunity to share the wonders and awe of the natural world with students. In fact, nature films may be an important source of free-choice learning outside of school. For example, a single viewing of a nature program featuring Jacques Cousteau can affect knowledge gains and attitudes about marine mammals at least as well as comparable material presented in a science classroom (Fortner, 1985). Unfortunately, few definitive studies address how and when learning evolutionary concepts from television occurs, and attitude studies about perceptions of the environment after viewing nature programs do not examine the resulting scientific understanding necessary for environmental, ecological, or scientific literacy. In fact, recent analyses of nature program content reveal a serious problem explaining evolutionary processes. Narratives are often filled with “design” rhetoric, emphasizing
the perfect fit of an organism to its environment (Aldridge & Dingwall, 2003; Dingwall & Aldridge, 2006), as well as need-based and purposive misconceptions (Dissertation Appendix 1). Indeed, Dingwall & Aldrich (2006) contend that the manner in which scientific issues are portrayed in wildlife and nature programs may actually enhance, rather than diminish, the differences in understanding between biologists and the rest of society. Moreover, video images designed to enhance these narratives may serve as a powerful “virtual witnessing” events for viewers (Kirby, 2003; see also Graber, 1990), resulting in an epistemological impact difficult to overcome, especially with socially controversial topics such as evolution.

*Fatal Flower* (Natural World, BBC), is a visually stunning nature program about the co-evolution of orchids and their pollinators replete with misconceptions about evolution. For example, the narrator explains:

“The crucifix orchid also *tries to be something that it is not*; it *copies* other plants nearby which have clusters of yellow and red flowers. The color guides the butterflies to the nectar, which is produced in the yellow parts of the flower heads. *The crucifix orchid seems to know this*, and its flower heads have the same color pattern, too. Some of the flowers are dark red, while the freshest are orange and yellow. But there, the similarity ends, as this orchid is a cheat. It may look like the others, but its flowers are empty. There is no nectar reward at all, so the butterflies are fooled into pollinating it for free. Orchids really are the *femme fatale* of the natural world. *They’ve made cheating an art form, using it get exactly what they need* from the creatures that fall for their many and varied charms” (emphases added).
Although this passage may appear as simple story telling, it builds on the narration for the entire program, potentially leaving the viewer with the understanding that evolution is an individual-based phenomena (versus population-based) that occurs because an organism needs to change, and that changes an individual makes (like changing the color of one’s hair) will be passed to offspring. The imagery in the program is spectacular and may offer the kind of natural history experiences to viewers that resonate with prior knowledge and add to misconceptions.

*Fatal Flower* served as an ideal proxy for students in an introductory biology course to recognize their own conceptions about evolution as they critically scrutinized the narration for incorrect conceptions, and by reflection as they were prompted to compare their own conceptions with the misconceptions they identified as errors in the program. Although the goal of the curriculum was to help students overcome misconceptions about evolution, the format of one of the tools developed also provided a unique approach to framing evolution understanding. As a result, this research represents a shift from a traditional pedagogical approach to a “knowledge in pieces” approach (cf. diSessa, 2008; Figure 3.2).

By assessing student responses to four very similar prepared statements that included alternative conceptions, I was able to examine whether students conceptions were logically related (Greene, 1990). In particular, the exercise permitted examining the multiple levels of misconceptions students may hold at one time as they transferred their reasoning to new situations. Therefore, I was able to examine the following questions:

(1) Can a curriculum of explicit conceptual teaching help students overcome misconceptions about evolution?
(2) Do students hold a diversity of misconceptions about the theory of evolution that includes both scientifically sound concepts and misconceptions and apply them in different contexts?

(3) If student’s concepts are logically related, then are misconceptions related to evolutionary explanations in a predictable fashion?

Figure 3.2. The shift in the approach to conceptual change using the Fatal Flower curricula. The flow diagram on the left signifies how students’ prior knowledge is confronted, proved unsatisfactory, and altered to reflect evolution understanding. The flow diagram on the right represents an approach that predicts misconceptions are part of a conceptual ecology but they shift in number and importance as a result of instruction.
Methods

The curriculum was developed to help students overcome misconceptions about evolution using a poorly crafted nature program about the co-evolution of orchids and their pollinators as a surrogate for their thinking. *Fatal Flower* was a striking example of excellent footage of orchids and their pollinators with a script that was fraught with misconceptions about the evolutionary process. Indeed, its science content scored a mere 18% using the Science and Nature Program Assessment Tool (Dissertation Appendix 1). This approach allowed students to criticize the narrative without targeting students’ personal beliefs directly. In each of two introductory biology courses, students watched the program and were directed through a series of exercises that included group and individual work, lectures, and reading.

The curriculum was implemented in two different semesters of introductory biology at The University of Montana. Implementation differed in the application of these exercises in the curriculum to examine how the role of time spent on the material and individual versus group work affected student understanding (Figure 3.3). The goal was to compel students to confront their personal misconceptions about evolution through the surrogate narrator of *Fatal Flower*. Student conceptions were identified in the first step of the Full Curriculum. After viewing the program, students were asked to describe how Darwin would have explained the evolution of this relationship using examples from the program. The second step required students to recognize misconceptions they held personally. Using “someone else’s” explanations (i.e., explanations that mirrored their own naïve conceptions) allowed the students to be critical without forcing them to publicly acknowledge their own naïve personal beliefs.
Figure 3.3. Instructional models used to help students confront their misconceptions about evolution.
After recognition and deconstruction of students’ misconceptions, lectures and discussion groups were used to help students incorporate accurate information into their conceptions of evolution. This step was reinforced by having students either re-examine their original explanation of the co-evolution problem (Full Curriculum) or using group dynamics to critique the written explanations they had been critiquing as individuals (Abridged Curriculum). A question on the final exam (weeks after the curriculum) served as a longitudinal measure of the effect of the curriculum on students’ understanding.

A major component of the curriculum involved having students respond to four prepared statements that answered the initial question and were purposely crafted to include specific misconceptions about the evolutionary process. One alternative included need-based purpose to evolution, a second included environmental cause for evolution, a third addressed complexity arguments common to intelligent design rhetoric, and a fourth included Lamarckian misconceptions (Table 3.1). Students were asked whether an evolutionary biologist would agree or disagree with the alternative, and why they believed as they did. These crafted alternatives provided a unique opportunity to examine the diversity of conceptions held simultaneously by individual students. Because the misconceptions written into the alternative statements served to prompt student thinking, I predicted that comparing student responses across all four alternatives should elicit responses that reflected the total diversity of concepts held by individuals.

For example, students with a good command of the theory of evolution would be expected to respond with consistently scientifically accepted conceptualizations of evolutionary theory. Responses of those with a poor command of the theory should reflect the misconceptions elicited in the four alternatives, and most importantly, the
Table 3.1

Alternative explanations provided to students to draw out their understanding of evolutionary theory. Students were asked whether an evolutionary biologist would agree or disagree with each alternative and why.

**Alternative 1 – Need based:**

Orchids would be better adapted if they had a means to ensure that their pollen would be carried to other plants of the same species, so they gradually developed complex structures that would trap or attract insects and attach the pollen to the insect as it came into contact with the flower. The orchids in each generation had better and more effective means of attracting or trapping the insects than their parents did. In turn, insects needed to extract the nectar from the flowers so they became adept at getting the nectar from specific flowers.

**Alternative 2 – Environment caused:**

Because the environment of tropical birds favored species that could sip nectar from deep within the flowers of abundant orchids, mutant individuals arose that had long beaks. Natural selection favored these individuals (hummingbird-like ancestors) and eventually there were many birds that had these adaptations. Repeating this process led ultimately to modern day hummingbirds. Orchids that were successfully pollinated by these birds were also favored by the environment.

**Alternative 3 – Intelligent design:**

The existence of structures as complex as orchids and their relationship to animal pollinators cannot be explained by traditional evolutionary theory because structures and relationships like these are too complex to arise by chance.

**Alternative 4 – Lamarckian:**

Birds in search of nectar needed to reach the nectar deep within the petals of flowering orchids. Their beaks grew longer as they needed to reach deeper and deeper pockets to obtain the nectar. The next generation of birds had even longer beaks. This eventually led to modern day hummingbirds. The “lips” or petals of orchids that acted as landing pads or contact places for pollinators became elongated and shaped differently from so much contact by pollinators. The next generation had larger and more complex lip petals. Eventually they evolved into the intricate and complex orchid structures we see today.
diversity of scientifically sound concepts and misconceptions held simultaneously by an individual.

The analyses were designed to investigate understanding, and student responses were examined using a combination of qualitative analysis techniques. Content analysis identified and classified the use of concepts related to language, such as “adapt”, but it did not function to investigate the breadth of student conceptions well. As a result, responses were classified using microanalysis techniques to address the understanding inherent in student responses (Corbin & Strauss, 2008). Initially, I developed a pool of concepts from all responses to the four alternatives looking for words and phrases that identified the concepts students addressed. I identified and classified broader concepts based on in-depth analysis of the conceptual understanding students employed when including the concepts (Corbin & Strauss, 2008). This broader coding scheme was rooted in the results of previous analyses of student conceptions, such as Bishop and Anderson (1990). I categorized concepts to reflect misconceptions that were prompted, misconceptions particular to student explanations, level of abstraction of those misconceptions, and correct conceptions. Sub-categories within each category could then be further refined based on the level of abstraction of the concepts employed.

Following Kampourakis & Zogza (2008b), I organized the concepts into proximate and evolutionary conceptions, however I based the distinction specifically on students’ less abstract, individual-level, causal reference and more abstract, statistical-level, evolutionary reference (Ariew, 2003; also see Figure 3.1). Each category was counted only once per response even though a student may have employed the concept several times in that response. I explored the effects of the curriculum and the impact of
the narrative surrogate using responses from the Full Curriculum. Only the Abridged Curriculum included individual student responses to the four alternatives, so that curriculum served as the primary source of data for analyses. However, group responses were included as points of comparison where appropriate.

The goal of both curricula was to help students recognize and overcome misconceptions about evolution using the nature program as a surrogate that could be criticized with less personal ramifications. Exploring specific student conceptions was not part of the curriculum development, and the two curricula took different approaches to group and individual work. As a result, different phases of the two curricula were used to examine different effects. The effect of the curriculum itself was examined using the Full Curriculum model; 41 students completed both an initial assessment (response to the Scenario) and a final assessment (final exam question). The Abridged Curriculum did not ask for individual responses to the original Scenario, only group responses, but their responses to the final assessment provided valuable insight to the generality of conclusions (Figure 3.3). The Abridged Curriculum was used to examine student conceptions for cohesion, however, because only the Abridged Curriculum included individual responses to the four alternatives used to examine the contextual application of concepts (n = 42 per alternative). Clearly, the group responses in the Full Curriculum did not accurately reflect individual students’ conceptual diversity, but the 13 group responses provided interesting points of comparison.
Results

Concept Analyses

The most difficult aspect of this analysis was that not all students used all concepts; there was no “right” answer that included all concepts. The coding scheme that developed included categories that represented both scientific conceptions and misconceptions that could be grouped into various levels of abstraction. Time, for example, was considered abstract when considering the millions of years necessary for some evolutionary changes to occur. “Generations” was a much less abstract conception of time, as most students know grandparents and even great grandparents (see also Renner et al., 1981). Students’ conceptions of the effects of time frame of “generations” ranged from the development of traits to the development of species. Two examples of student responses illustrated the nature of their thinking related to time frame:

*Student #1d:* “The whole idea of natural selection is that certain favorable traits that are necessary for survival get passed on and change over generations, not just over one generation. Some changes may occur during a short period of time, but most of the major ones that involve natural selection occur over many generations;”

*Group #29b:* “It went through years and years of changes and many generations before it became the hummingbird that we know today.”

Moreover, these responses showed variation in the thinking from abstract to descriptive; Student #1d separated the trait from the whole being, whereas Group #29b apparently considered evolution affecting the entire being.
Other categories that included different levels of abstract thinking were organized around heredity, favor, and variation. Heredity was evident in concepts in student responses related to the passing of traits from parent to offspring. Genes were often identified as the currency of heredity, especially in response to Alternative #4 (Table 3.1), but not necessarily in relation to the genetic underpinnings of traits. As a result, genetic concepts may or may not have been discussed in relation to heredity and were included in a separate category. For example, one student wrote:

*Student #33d*: “they pass on their genetics,” in response to Alternative #4 (Lamarckian misconception), indicating a conception of heredity and the mechanism of genetics (as opposed to phenotypic changes) representing two different concepts. Genes, as a concept, were quite abstract. Lawson et al. (2000) described the concept of genes as “theoretical,” that is a concept that functions as an explanation for an event that needs a cause but for which there are no observable exemplars. Knowing that genes are the root of heredity may have been less abstract than the differential concept of understanding the consequences of meiosis and the relationship to traits, however. Subcategories of concepts classified under heredity included the wholesale passing of traits to the next generation, wholesale passing of traits to an individual’s offspring, or the differential production and variable genetic contributions to offspring.

“Favor” was an *in vivo* concept suggesting the influence of the trait – how individuals fared in the world because they possessed the attribute. Subcategories focused on influence as an outcome; possession of a “favorable” trait either enhanced the ability to survive and/or reproduce, or it was perceived in the abstract as a statistical
effect of natural selection. Some individuals were simply “better” because of the trait (“the orchids that had the best adaptive traits would survive...” [Student #54p]), implying that evolution was progressing or moving along some trajectory toward perfect adaptation. Categorization of these concepts was often, but not necessarily, based on the use of the word “favored,” especially in responses to Alternatives #1 and #2. For example:

Student #48a: “An evolutionary biologist would argue that orchids with more complex pollinating systems were favored more, and therefore passed on these traits to their offspring, and so on.”

Student #23a: “The environment favors the genetic mutation and those individuals with the mutations are better able to survive and produce offspring.”

Student #24b: “The orchids that were most successful at attracting pollinators were able to pass on their traits to future generations.”

Stochasticity was specifically addressed in Alternative #3, but the idea of variation among individuals and random processes was worth considering in all responses because of the important role it plays in evolutionary theory (Clough & Wood-Robinson, 1985). As a result, variation became a category with two subcategories addressing different levels of abstraction: the variation among individuals within a population (1) within a specific time frame and (2) across generations (“Transformation” as discussed above). Understanding the variation associated within the population that led to differential survival and reproduction was an abstract concept.
Student #8c: “With a greater number of offspring, an organism would be able to have a better chance to evolve because there is a possibility of more genetic mutations, which are a random occurrence after all.”

The evolutionary concept of variation was more common in responses to the original scenario of the Full Curriculum (see below) than in response to the four alternatives in the Abridged Curriculum, however.

Misconceptions were classified based on purpose. Subcategories included those concepts that (1) fulfilled some life requirement specific to that individual, (2) those that were strategic, gaining relative access to those resources or life requirements, (3) “symbiotic” becoming a better fit to each other, and (4) catastrophic – adapt or die.

Natural selection and the role of the environment were initially distinct categories with two levels of abstraction, proximate and evolutionary. Responses indicated that students often believed natural selection was an actor, a cause of the outcome, rather than a process, so the causal concept was re-classified as a misconception.

Student #61p: “The more extreme the orchid mutations became, the more extremely the pollenators [sic] were selected.”

Other well-defined conceptualizations of natural selection in student responses were covered by other proximate and evolutionary categories. Likewise, if students indicated that the environment caused the animal to change as opposed to being the context for the process, then that conception was considered non-scientific – a misconception.

Two conceptual classifications were more related to how students thought in general than to evolution understanding in particular. The “reason” for both sides of the co-evolutionary relationship was often an important factor students used to assess the
quality of the four alternatives. If the alternative did not explain enough of why the relationship formed, including both sides of the co-evolution event (e.g., both the orchid and the insect), the explanation was deemed inappropriate. A subcategory addressed whether the alternative adequately explained why the organism “evolved.” Clearly, many individuals believed that adequate answers foremost had to address all sides of the relationship; the conceptual underpinning of the explanation was secondary.

“Completeness” was especially important for Alternatives #1 and #2.

The definition of evolution also was a frequent concept given in student responses, especially in response to the prepared alternatives. The absoluteness of this definition was consistent:

*Student #36p:* “The orchids have change through time.”

*Student #21a:* “I think an evolutionary biologist would agree to this answer because it states the fact of change through time.”

*Student #40a:* “Evolutionary biologists believe in evolution, which is defined as change through time.”

“Change through Time” is a common characterization of evolution in educational contexts, but as a metaphor, it may not fit well with complex conceptual ecologies where simultaneous misconceptions and proximate conceptions may affect overall conceptual understanding. For example, the metaphor does not exclude need-based misconceptions or even some elements of design. Some students indicated a dominant position for this concept in their understanding, however, especially when defending the stochasticity of the evolutionary process.
Student #35c: “I disagree with this answer. I do believe that the existence of the complex structures of the orchid species can be explained by the definition of evolution, which is change over time. Though it would be a lengthy and complex explanation that you would have to derive, it is still explainable.”

Most of the categories that developed were not mutually exclusive, nor were they additive; they could not be summed across categories or subcategories. For example, “generations,” “universal,” and “transformation” all referred to wholesale adoption of traits in the next timeframe. “Generations” was a time-centered concept and implied wholesale adoption of a trait in the next generation, whereas “universal” was a statement about heredity, not time, that involved wholesale adoption (the trait was passed on to everyone), and “transformation” referred to a general, slow transformation of a species across generations. Although these concepts appear similar, separating them into distinct categories accounted for the context of their use. “Generations” could be compared to longer (“Eons”) or shorter timeframes (“Personal” the time it takes for an individual to change). “Universal” could be compared to concepts that accounted for differences in reproductive effort. “Transformation” could be compared to population variation. “Genetics” and “Heredity” represent another example of non-additive response categories.

A variety of studies have examined the use of the word “adapt” and noted significant differences in how students and scientists apply the term (Brumby, 1984; Halldén, 1988; Renner et al., 1981). “Adapt” was flagged wherever it was used in responses and categorized as either an active use of the word (i.e., the verb “to adapt”), a
description of a characteristic (i.e., a “trait”), or a broader, more abstract concept implying the outcome of natural selection (i.e., an adaptation”).

The Effect of the Curriculum

Initial Conceptions. The Full Curriculum included an initial assessment of students’ conceptual ecologies; students were asked to explain the co-evolution of orchids and their pollinators seen in Fatal Flower the way they believed Darwin would explain it. Need-based misconceptions were common in students’ responses to the co-evolution scenario. In fact, nearly half (48%) included a concept related to “Life Requirements,” that is the individual needed food (nectar) to be pollinated to survive:

Student #56p: “Birds need the nectar in the flowers to survive, so birds with characteristics that make it easier to reach nectar are favored (i.e., long beaks) by natural selection.”

Similarly, the co-evolution was often addressed as a “symbiotic” relationship where each species was ensuring the survival of the other; 23% of students included this concept in their response. For example:

Student #33p: “Without one another, the bees and the orchids would be unable to reproduce and survive.”

As with all concepts, the inclusion of these two categories was not mutually exclusive. Many students argued that the “Life Requirements” enabled the “Symbiosis.” About a fifth (18%) of students included concepts that referenced Lamarckian development as the individual changed within its lifespan. In addition, the conception that individuals that
did not adapt would die off was common in student responses to the scenario. This concept also was linked quite often to concepts of need, as in this example:

Student #8p: “The flower will die if it is not pollinated the insect or bird will die if it is not fed. An example is how the humming bird adapted to the specific flower but the fly got out of pollinating the same flower by eating through the ovum. In this case the flower adapted to the bird but not the insect. So therefore the flower may go extinct if it cannot evolve to meet the needs of both the humming bird and the fly or find a means of repelling the fly.”

Natural selection was frequently (28% of responses) considered the actor in the relationship between organism and environment, actively weeding out or favoring certain individuals. Likewise, the environment caused individuals to change; 23% of responses included concepts related to environment-caused misconceptions. Although evolutionary concepts were far less common than misconceptions, the concept that individuals differ from each other within a population appeared in one fourth of these initial responses. Proximate concepts, such as better ability as a result of the trait and wholesale passing of traits to offspring also were relatively common (>20%).

Student #57p: “This genetic trait is selected for and more individuals that have it are present in the population.”

One third of individuals’ responses to the original scenario in the Full Curriculum included the use of “adapt” as a verb; only two individuals referred to “traits” as “adaptations.” Of these, every single student response that used “adapt” to imply an individual changes in response to the environment also was classified as including a need-based or environment-caused misconception, not surprising considering the
frequency of misconceptions in student responses. Over a third of the responses were classified as incorporating Lamarckian elements. Evolutionary concepts were not completely absent in responses from students using the verb form of “adapt;” three responses (6%) included concepts of time that extended beyond “Generations.”

The Effect of the Surrogate. Based on the examples students included, the narration in Fatal Flower appeared to have been an adequate surrogate for student conceptions. Not all students included examples, nor did they include the same examples. Three examples were popular, however; the bucket orchid and its euglossine bee pollinator, Hexitia and its hummingbird pollinator, and the bee-mimicking orchids were included in 10 or more responses (approximately 25%; other examples were included in only one or two responses). This frequency permitted cursory exploratory comparisons of the kinds of conceptual ecologies associated with each example.

In the program, Fatal Flower, the narration regarding the bucket orchid includes several references to need-based evolution. The orchid excretes a scented oil that attracts male bees. According to the narration, “the males need this strange oil to make a perfume to attract their own females.” In addition, the segment emphasizes the flower’s devious trap and its need to be pollinated.

The narration surrounding Hexitia and its hummingbird pollinator emphasizes the perfect design of the flower:

“This little orchid is called Hexitia, and each of its flowers is designed to be operated by the tip of a hummingbird’s beak. A dark splotch shows the bird where the nectar tube is.”
The narrator goes on to say that the lip serves as a place for the hummingbird to rest its bill while it feeds.

The narration used to describe the bee-mimicking orchids does not include explicit need-based references. The male bee is simply fooled by the flower’s imitation of virgin female bees with whom to mate.

Use of the bucket orchid example was associated with need-based misconceptions more so than the other two examples; 85% of students using this example employed need-based misconceptions (versus 42% of students including the hummingbird as an example and 50% of students including the bee mimic). In addition, students often referred to how “fit” a bee had to be to get through that trap, enlisting a somewhat Lamarckian element in their response.

*Student # 14p:* “At the same time the bee was evolving to where it could still get what it came for as well as surviving the trap and retain its desire for nectar again.”

Not surprisingly, the misconception that individuals “adapt or die” also was more common in responses where students included the bucket orchid example (62% versus 10% with the bee mimic and 42% with the hummingbird). A frequent use of the “adapt or die” concept associated with the hummingbird example reflected students beliefs that hummingbirds needed the food supplied by the nectar. On the other hand, students incorporating the bucket orchid example included concepts of “symbiosis” less frequently (23%) than students including the bee-mimic example (33%) or the hummingbird example (50%), this approach likely reflected an incongruity between the harmony of “symbiosis” and the difficulties through which male euglossine bees must go once they
have become trapped in the bucket of slimy goop (bees end up squeezing through a
tunnel formed from the throat of the flower where the pollen sacs come in contact with
the bees thorax). Although few in number, more proximate and evolutionary concepts
were associated with students response that included the bee mimic example:

   Student #2p: “In those instances, the flower that had evolved the most to look like
   the insect they needed would have the best luck being pollinated and would
   therefore survive the longest.”

Although this response included a need-based concept, it also incorporated some
understanding of the variation among individuals and the relative frequency of
pollination and survival associated with having the trait. Apparently, the “need” to have
sex did not fit with “Adapt or Die” and “Symbiosis” concepts. Clearly, the use of
examples in students’ responses was likely more correlative with their prior conceptions
than causative, and the narration cannot be completely blamed for the outcome.
However, the fact that these examples did resonate with students indicates that narration
from these types of programs in combination with exquisite visual imagery may affect
their conceptual ecologies resulting in a poor understanding of evolution.

   Outcomes of the Curriculum. A question designed to assess the overall impact of
the curricula was included on the final exam for both the Full Curriculum and the
Abridged Curriculum (Figure 3.3). The question was shorter, included less explanation,
and students had less time to respond. Nevertheless, 65% and 71% of students in the Full
and Abridged curricula, respectively, recognized the central misconception in the
question’s statement. In fact, some students read more than one misconception in the
statement, usually a combination of recognizing need-based and goal-based misconceptions.

In addition, most students in the Full Curriculum (82%) included relatively fewer misconceptions in their response to the question on the final exam than in their original response to the Scenario. (The Abridged Curriculum did not include individual responses to the Scenario.) Similarly, 78% of students included more evolutionary concepts in their response to the final question than they included in their original response to the Scenario. Proximate concepts also decreased relative to the Scenario responses; only 36% of students included a greater proportion of proximate concepts in their final response than in their original response to the Scenario.

The use of the term “adapt” was relatively absent from responses to the final in both curricular approaches: 16% in the Full Curriculum versus 5% in the Abridged Curriculum. Both curricular approaches seem to have been effective at assisting students in beginning the transition from misconception-laden ecologies to ecologies that include more scientifically acceptable concepts. The Abridged Curriculum seemed to be equally effective; 87% of students disagreed with the statement provided in the final exam question and 71% noted the inclusion of a misconception. Students may not have developed a full command of the complexity of evolutionary theory, but they knew how to recognize incorrect arguments.

**Drawing out the Pieces of Conceptual Ecologies**

The most basic way to determine contextual use of concepts and the application of reasoning patterns was to compare students’ outright agreement or disagreement with
the four misconception-laden alternatives. I predicted that students with an understanding of evolution should have at least recognized the misconception in the alternative statement. The details of both the need-based and environment-caused explanations in Alternative #1 and Alternative #2 (Table 3.1) were often overlooked by both individuals (Figure 3.4) and groups (Figure 3.5) however, and the majority of students agreed with both alternatives in both curricula. Lamarckian references in Alternative #4 were detected a bit more often than other misconceptions, and more often in the Abridged Curriculum than in the Full Curriculum. A strong majority of students completing the curriculum (regardless of version) disagreed with the intelligent design explanation in Alternative #3.

This analysis illustrated that students did indeed hold misconceptions about evolution but suggested that their conceptual understanding was not uni-dimensional. Quite often students included an assortment of proximate and evolutionary concepts as they re-interpreted an alternative with which they stated an evolutionary biologist would agree. Similarly, students often identified the misconception and then repeated, rather than refuted, the concepts. This exercise allowed analysis of the diversity of concepts held simultaneously by individuals, however. In their responses, students included different arrays of concepts as they transferred their knowledge from one situation to the next. Responses were grouped first by alternative, and then by individual.
Figure 3.4  Proportion of students in the Abridged Curriculum indicating that they agreed with the need-based, environment-caused, intelligent-design, or Lamarckian alternative.

Figure 3.5.  Proportion of groups in the Full Curriculum indicating that they agreed with the need-based, environment-caused, intelligent-design, or Lamarckian alternative.
Alternative #1 – Need-based Explanation: As would be expected from the previous analysis, only 17% of individuals in the Abridged Curriculum included some recognition of the need-based misconception; over half of individuals actively included or reiterated a need-based misconception in their response. In the Full Curriculum, however, 54% of groups recognized the inclusion, and 54% of groups included some need-based explanation in their response. Again, these categorizations are not mutually exclusive; individual students or groups could have included recognition of the need-based misconception but then included a need-based explanation at some other point in their response:

Student #34a: “Although the statements are correct about the flower and the insects adapting to each organisms specific needs, I think that the statement is not totally true about how the adaptations came about. I don’t think that the organisms could purposely adapt themselves to the environment...”

The need-based conceptions tended to focus on the life requirements (need for food or to reproduce; “Life Requirement”) of individuals or their need to ensure their survival or reproduction (“Strategy”). “Life requirement” needs were more common than “Strategy” needs in the Abridged Curriculum whereas strategies to ensure survival and reproduction were more common in the Full Curriculum (Table 3.2). These two types of needs were often represented as a single concept of “symbiosis” – the relationship between the orchid and the pollinator arose because each needed the other and to ensure survival. “Symbiosis” appeared slightly more often in groups in the Full Curriculum than in the Abridged Curriculum. Apparently, the idea of the co-evolution of two species elicits some need-based relationship between them.
Table 3.2.

The proportion of concepts enlisted by individuals and groups experiencing the Abridged and Full curricula, respectively.

<table>
<thead>
<tr>
<th>Concept</th>
<th>Alternative #1</th>
<th>Alternative #2</th>
<th>Alternative #3</th>
<th>Alternative #4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Abridged(^a)</td>
<td>Full(^b)</td>
<td>Abridged</td>
<td>Full</td>
</tr>
<tr>
<td><strong>Misconceptions</strong></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Life Requirement</td>
<td>24%</td>
<td>8%</td>
<td>17%</td>
<td>0%</td>
</tr>
<tr>
<td>Strategy</td>
<td>15%</td>
<td>31%</td>
<td>12%</td>
<td>23%</td>
</tr>
<tr>
<td>Selfish</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>8%</td>
</tr>
<tr>
<td>Symbiosis</td>
<td>12%</td>
<td>15%</td>
<td>12%</td>
<td>23%</td>
</tr>
<tr>
<td>Adapt or Die</td>
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<td>8%</td>
</tr>
<tr>
<td>Actor</td>
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<td>15%</td>
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<tr>
<td>Cause</td>
<td>27%</td>
<td>23%</td>
<td>5%</td>
<td>38%</td>
</tr>
<tr>
<td>Lamarckian</td>
<td>10%</td>
<td>8%</td>
<td>2%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Proximate Conceptions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Better</td>
<td>17%</td>
<td>15%</td>
<td>10%</td>
<td>8%</td>
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<tr>
<td>Opportunity</td>
<td>17%</td>
<td>15%</td>
<td>17%</td>
<td>15%</td>
</tr>
</tbody>
</table>

\(^a\) Abridged
\(^b\) Full
<table>
<thead>
<tr>
<th>Concept</th>
<th>Alternative #1</th>
<th></th>
<th>Alternative #2</th>
<th></th>
<th>Alternative #3</th>
<th></th>
<th>Alternative #4</th>
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<tr>
<td></td>
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<td>Full(^b)</td>
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<td>Full</td>
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<td>Full</td>
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<td>Universal</td>
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<td>8%</td>
<td>5%</td>
<td>23%</td>
<td>12%</td>
<td>0%</td>
<td>12%</td>
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<tr>
<td>Offspring</td>
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<td>8%</td>
<td>7%</td>
<td>8%</td>
<td>0%</td>
<td>0%</td>
<td>2%</td>
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<tr>
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<td>29%</td>
<td>15%</td>
<td>10%</td>
<td>23%</td>
<td>7%</td>
<td>15%</td>
<td>27%</td>
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<tr>
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<td>7%</td>
<td>8%</td>
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<td>10%</td>
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<tr>
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<td>15%</td>
<td>7%</td>
<td>15%</td>
<td>17%</td>
<td>0%</td>
<td>2%</td>
</tr>
<tr>
<td>Variation</td>
<td>12%</td>
<td>0%</td>
<td>10%</td>
<td>8%</td>
<td>7%</td>
<td>8%</td>
<td>10%</td>
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<td>8%</td>
<td>15%</td>
<td>8%</td>
<td>10%</td>
<td>8%</td>
<td>5%</td>
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<tr>
<td>Differential</td>
<td>7%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>2%</td>
<td>8%</td>
<td>0%</td>
</tr>
<tr>
<td>Eons</td>
<td>10%</td>
<td>0%</td>
<td>2%</td>
<td>0%</td>
<td>7%</td>
<td>8%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Other Concepts</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adapt</td>
<td>59%</td>
<td>77%</td>
<td>24%</td>
<td>38%</td>
<td>22%</td>
<td>23%</td>
<td>32%</td>
</tr>
<tr>
<td>Completeness</td>
<td>22%</td>
<td>31%</td>
<td>27%</td>
<td>15%</td>
<td>0%</td>
<td>0%</td>
<td>10%</td>
</tr>
</tbody>
</table>

\(^a\) n = 41.

\(^b\) n = 13.
Alternative #1 also included subtle wording that could have affected student responses, wording such as “the orchids in each generation” and “better and more effective means.” These two statements consisted of three non-evolutionary concepts: generation as a timeframe, the transformation of species, and evolution progressing to something better. So, the responses should have reflected these non-evolutionary concepts if students were incorporating these words from the alternative. Almost a quarter of students’ responses included time in terms of generations, and “Generations” as a concept was identified more often than any other concept for this alternative (Table 3.2). “Transformation” was not as commonly included in responses though, but the similar hereditary concept of wholesale passing of traits to offspring (“Offspring”) was slightly more common. Likewise, the idea that organisms get “better” over time was included frequently in responses to Alternative #1.

Other unprompted misconceptions common in responses to Alternative #1 focused on the process of evolution. Natural selection often took an active role in weeding out or favoring certain individuals; 15% of responses in both curricula included natural selection as an “Actor” in the process (Table 3.2). Similarly, the environment “Caused” individuals to change in 27% of responses in the Abridged Curriculum and 23% of responses in the Full Curriculum. For example:

Group #9a: “Yes, the biologists would probably agree with this answer because the orchids and the insects coevolved and so if one changes the other will probably change to adapt to the new environmental circumstances.”

“Completeness” was an important classification element for Alternative #1. Two examples illustrate how important this apparent rule of thumb for explanations was to
students. Some students were satisfied that the alternative adequately discussed both
sides of the co-evolutionary relationship, whereas others were not:

Student #10a: “I think an evolutionary biologist would agree to this statement
because it shows both causes for the evolution to take place...”

Student #2a: “This explanation would be agreeable in general to an evolutionary
biologist’s way of thinking, but it does not necessarily answer the question 1 –
gives some explanation on the orchids side of the coevolution, but not much
elaboration on the side of the insects.”

Alternative #1 specifically used the word “adapted” but the context was
intentionally vague: “Orchids would be better adapted...” could have referred to
individuals or populations (in spite of the implication that evolution progresses toward
something better). Clearly, the use of the word elicited similar responses from students
(Table 3.2). In the Abridged Curriculum, all of the individuals’ responses that used
“adapt” as a verb (that is to indicate an organism responded to the environment) were
recorded as need-based or caused by the environment, and none recognized the need-
based misconception included in the alternative. In addition, 20% included a Lamarckian
element. Nearly 40%, however, interpreted the concept as a trait or an adaptation in their
responses; two thirds of these students recognized the misconception in the alternative,
but half used another misconception in their re-interpretation. The verb “adapt” appeared
in 46% of the group responses in the Full Curriculum, but only half of those responses
were classified as including need-based misconceptions. The other 50% recognized the
misconception in the alternative. Nearly a third of the groups interpreted the concept as
an “adaptation” or a “trait.” “Generations” as the concept of time, and even Lamarckian,
elements also were common classifications associated with the use of “adapt” as a verb. One individual included the evolutionary concept of genetic variation, however.

**Alternative #2 – Environment-caused Explanation:** Alternative #2 included the misconception that the environment caused the organism to change, indicating that the environment “favored” certain traits of species. The alternative also included the phrase “natural selection favored” – a subtle difference in terms of classifying short student responses and separating conceptual understanding from misunderstanding. In addition, the use of the word “mutant” likely had consequences in terms of students’ responses.

Not surprisingly, only 7% of responses included some recognition of the environment-caused misconception in this alternative. Nevertheless, “Cause” was not nearly as common in individual responses as in response to Alternative #1 (Table 3.2). Groups apparently responded differently to the alternative; over a third of groups included the idea that the environment caused the individuals to change. Natural selection as the actor, rather than the process, however, appeared in about one quarter of both individual and group responses. The word “favored,” on the other hand, appeared often in student responses, but the concept was applied with some proximate level of understanding of the evolutionary process. Students reframed the concept to refer to the enhanced opportunity the trait provided in terms of survival and/or reproduction in the environment. This “Opportunity” was the most common concept included in the individual responses in the Abridged Curriculum (Table 3.2). In addition, nearly as many individuals recognized that the ability to survive or reproduce relative to other individuals was an important factor. In the Full Curriculum, 15% of group responses included the
enhanced ability to survive or reproduce as a result of the trait, but few groups recognized any kind of differential success.

As expected, the word “mutant” affected how students incorporated concepts about mutations. Nearly one third of individuals (n = 13), and over one third of groups (n = 5) included the concept in their responses. As a result, the concept was split in the analyses to explore how students viewed mutations: as only harmful or beneficial, as potentially harmful or beneficial, or with no reference to harm or benefits. Despite the potential negative connotation of the word “mutant,” only one individual and one group indicated that mutations were harmful, however. Rather, students incorporating the concept of mutation gave no indication of benefit or harm (54% of individuals in the Abridged Curriculum) or indicated some sense of random occurrence of both potentially beneficial and harmful mutations (60% of groups in the Full Curriculum). For example:

Student #28b: “I agree with this statement, because it shows evolution as a process resulting from genetic mutations and natural selection.”

Group #42b: “Mutations are random, and don’t necessarily benefit the species.”

Clearly, this alternative, with all of its good points, elicited more proximate and evolutionary concepts from students and groups than the more misconception-laden Alternative #1 (Table 3.2). However, many individuals and groups were concerned about the adequacy of the alternative at explaining the evolution of the orchids. Indeed, many indicated want of a more complete explanation (“Completeness”; Table 3.2):

Student #13b: “This answer does not really explain how the orchids evolved in tune with the hummingbirds. This answer basically shows that the hummingbirds evolved while the orchids stayed the same.”
Alternative #2 used the word “adaptation” (a noun form) rather than the verb form as in Alternative #1. In their reinterpretations of the alternatives, however, only 15% (n = 6 students) used the word “adapt” as a verb, and only one of those included an environment-caused misconception. Instead, half of these students were classified as using natural selection as an actor that weeded out the less fortunate organisms. Interestingly, two of the four students that incorporated “adaptation” into their responses also enlisted natural selection as an actor.

Alternative #3 – Intelligent Design: Alternative #3 was targeted directly at student understanding of the limits of science. The alternative used the intelligent design movement’s argument of irreducible complexity. As a result, the alternative should have elicited comments about stochasticity or chance. Indeed, a relatively large proportion of individuals in the Abridged Curriculum included the concept that mutations represented chance occurrences (Table 3.2). Although this concept was the most common concept identified in the individual responses, it was non-existent in the group responses of the Full Curriculum. The diversity of concepts groups included in response to this alternative was low, however; only eight different concepts were included in responses. Nevertheless, of the concepts identified, groups included the time in which this relationship could develop, whether that was the more proximate concept of generations or the more evolutionary concept of eons. Groups also included concepts associated with differential survival and reproductive success more than responses to any other alternative.

The “complexity of the relationship” was addressed directly; both individuals and groups argued that the relationship was not too complex to arise by chance (Table 3.2).
Despite these encouraging results, approximately one quarter of responses included a need-based misconception in their re-interpretation of the development of the relationship. For example:

(Student #8c: “While the relationship between orchids and animals is complex, it started out simplistically and kept evolving in order to achieve a greater reproductive success.”)

Alternative #4 – Lamarckian: The Lamarckian element in Alternative #4 was quite obvious. The focus of the alternative was on the individual bird’s ability to grow a longer beak to reach deep into the flower. As noted above, however, just over half of individuals and groups disagreed with the alternative. The students’ misunderstanding about the evolutionary process was evident as they re-interpreted the alternative in their responses. In the Abridged Curriculum, 37% of individuals recognized the Lamarckian element, but three of these individuals still included the concept of individual changes being heritable in their responses. In the Full Curriculum, 54% of groups recognized the Lamarckian conception of evolution. Moreover, the alternative elicited references to genes as the mechanism for heritability, as would be expected given this alternative (Table 3.2):

(Student #12d: “It is true that the landing pads of the orchid could have changed shape through so much use but the change would be environmental not genetic and so would not be passed on to its offspring.”)
Group #46d: “As for the petals of orchids getting stretched out and elongated, this could happen, but if it did this stretching is not a genetic trait and so the longer petals would not be passed on to the next generation.”

Indeed, group work may have been influential with responses to this alternative. Besides identifying the Lamarckian element, groups in the Full Curriculum more often included concepts related to the influence of the trait on reproduction, heredity, and time (although usually in terms of generations) than individuals in the Abridged Curriculum. Interestingly, though, groups included references to need-based misconceptions more often than individuals (Table 3.2). The idea that the two species needed each other and were becoming more adapted to each other to ensure each of their survival (“Symbiosis”) also was appealing to students, especially to the groups in the Full Curriculum:

Group #42d: “This is a form of natural selection where these two organisms co-evolved to better each other and ensure their own survival at the same time.”

Although this alternative did not include concepts about adaptation, over one fourth of individuals in the Abridged Curriculum incorporated the verb form of “adapt” into their re-interpretations. Of those, half included a need-based misconception, and another third included an environment-caused misconception. One student’s use provided especially valuable insight to how the vernacular use could be interpreted:

Student #18d: “The growing of beaks to reach the nector [sic] is adapting, but that doesn’t mean they will pass this trait on.”

Adapting, by definition, is changing, but phenotypic change is not synonymous with genotypic change. Only one group in the Full Curriculum used “adapt” as a verb, and they incorporated a need-based misconception in their response.
Diversity of Concepts Held by Individuals

Examining the diversity of responses across all alternatives for each individual and group indicated that students indeed held a variety of scientific, proximate, and incorrect conceptions simultaneously. Two examples illustrate this diversity, one with few evolutionary concepts and one with many evolutionary concepts. In response to the four alternatives, Student #28 includes one evolutionary concept along with two instances of misconceptions and four proximate concepts. Student #28 disagrees with the need-based statement in Alternative #1 but includes need-based statements in response to Alternatives #2 and #3. Clearly, the student understands genes as the mechanism of inheritance and the stochastic nature of mutations (an evolutionary concept). Nevertheless, Student #28 misses the Lamarckian element in Alternative #4, the alternative that specifically elicited responses that included genetics more than any other alternative.

Alternative 1 – Need-based Explanation (agrees): “An evolutionary biologist would not agree with this statement for one huge reason. The statement makes it sound like these advantages were developed because of the benefits they create, yet, in reality, these advantages came from a random mutation....”

Alternative 2 – Environment-caused Explanation (agrees): “...These long beaks probably did develop over time in order to help the birds drink nectar....”

Alternative 3 – Intelligent Design Explanation (disagrees): “...Organisms adapt and change in order to benefit from these relationships. Evolution definitely explains how orchids developed into their current form in order to better assist itself in pollination....”

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Alternative #4 – Lamarckian Explanation (disagrees): “…Genetic mutation leads to changes over generations, and this statement exemplifies this....”

Clearly, this student’s developing conceptual ecology is inconsistent, at one point arguing against need-based mechanisms, and at another, arguing for them.

Similarly, Student #30 includes multiple evolutionary concepts in the responses to the four alternatives, such as variation among members of a population, differential survival, and time as a concept that extends beyond generations. In addition, a few proximate concepts are apparent, including enhanced survival and reproduction of individuals as a result of the trait, and natural selection as a process. The appearance of a need-based conception with a design element in response to Alternative #3 is surprising, however:

Alternative 1 – Need-based Explanation (agrees): “…Adaptations occur as mutations and through some genetic recombination. The offspring might possibly have a productive mutation that would enable them to reproduce more effectively allowing them to spread more of their genes until they dominate the landscape. These genetic mutations, however, occur over long periods of time and it would be hard to see a huge change from parent to daughter organisms.”

Alternative 2 – Environment-caused Explanation (agrees): “An evolutionary biologist would agree with this answer because it explains how the mutation might have come about, how long it might have taken, and a reason for its dominance in the environment being favored by natural selection....”

Alternative 3 – Intelligent Design Explanation (disagrees): “…It seemed as if the orchids and the animals were complexly suited for each organism’s specific
needs. The pollination methods, for example, are almost perfectly adapted for both the flower and the insect. This could be explained only through adaptation and natural selection and not by pure chance.”

*Alternative #4 – Lamarckian Explanation* (disagrees): “An evolutionary biologist would disagree with this statement because it is not probable that physical changes caused by the environment could be passed down to the next generation simply because they are not part of the genetic code of that organism....”

The relative blend of misconceptions and proximate and evolutionary conceptions within individual and group conceptual ecologies is apparent in plots of evolutionary versus proximate conceptions and misconceptions (Figures 3.4 and 3.5). As responses transition to conceptual understanding of evolution more in line with scientific thinking, the presence of misconceptions included in responses appears to decrease. Indeed, both need-based and process-based misconceptions are incorporated into student responses less often as the use of evolutionary concepts increases, at least in the Abridged Curriculum (Figure 3.6). The relationships are not as clear in the Full Curriculum (Figure 3.7), however, likely a result of the group dynamic. Obviously, the group responses in the Full Curriculum are influenced by a variety of individuals, some more dominant in the conversation than others, which likely masks effects. In both curricula, proximate conceptions seem to remain relatively stable and may reflect students’ incomplete grasp of concepts as they attempt to elaborate in their responses.

Similarly, when the proportion of evolutionary, proximate, and misconceptions per individual were examined, an interesting trend appeared. Individuals offering a greater proportion of evolutionary conceptions across the four alternatives included fewer
misconceptions (Figure 3.8). The proportion of proximate conceptions peaked, however, in the transition between misconceptions and evolutionary concepts. Again, responses from the Full Curriculum were masked by the difficulties examining group work creates, but this relationship is evident in the distributions of concepts across groups as well (Figure 3.9).

Discussion

Effects of the Curriculum

Students enrolling in an introductory biology course pursue one of two paths in their college careers: they continue on in the life sciences or they do not. If they continue on in the life sciences curricula, they enroll in additional courses that broaden their understanding of evolution, such as genetics and evolution courses. If they do not pursue a life sciences degree, an introductory biology course may be the only exposure to evolutionary science in their adult life. Therefore, it is imperative that science educators across levels (pre-college and college) help students develop a conceptual framework that allows them to assess future information in terms of correct application and interpretation of evolutionary theory. Our results suggest that a curriculum designed to explicitly address misconceptions may help students begin to deal with the complexities of evolutionary theory and construct more accurate conceptual understanding.

A vast majority of students that experienced this curricular approach were able to recognize major misconceptions about evolution at the end of the semester. Indeed, the curriculum may have altered the diversity of the conceptual ecologies held by individuals toward a more evolutionary perspective than they had early in the course. Jensen &
Figure 3.6. The presence of both misconceptions and alternative conceptions displayed by individuals in the Abridged Curriculum as they responded to the four diverse misconception-laden alternatives.

Figure 3.7. The presence of both misconceptions and alternative conceptions displayed by groups in the Full Curriculum as they responded to the four diverse misconception-laden alternatives.
Figure 3.8. Proportion of misconceptions, proximate conceptions, and evolutionary conceptions held by individuals in the Abridged Curriculum. Each bar represents the total concepts held across all four alternatives for a single individual.

Figure 3.9. Proportion of misconceptions, proximate conceptions, and evolutionary conceptions held by groups in the Full Curriculum. Each bar represents the total concepts held across all four alternatives for a single group.
Finley (1996) also found that students justified responses by indicating that a statement would be considered incorrect by biologists. In our analysis, however, students had to single out their problem with the alternative in addition to agreeing or disagreeing that an evolutionary biologist would find the statement acceptable.

Nevertheless, recognizing and understanding misconceptions are entirely different issues. Understanding evolution requires a thorough grasp of some very complex and abstract topics, topics that may comprise an entire discipline. Most introductory biology courses only treat evolution as one unit among a number of other topics (Farber, 2003), although more and more faculty are embracing evolution as a unifying theme in their instructional design (e.g., Flammer, 2006; Nickels, Nelson, & Beard, 1996; Wilson, 2005). Moreover, there may be some logical progression of the influence of misconceptions, proximate conceptions, and evolutionary conceptions in students’ conceptual ecologies (cf. Greene, 1990). That shift may be influenced by cognitive maturation. Indeed, several evolutionary psychologists have suggested that developmental constraints (essentialist, teleological, and intentionality) may lead to intuitive cognitive biases that affect sub-concepts differentially depending on the abstract nature of the concept being employed (Sinatra, Brem, & Evans, 2008). Similarly, the correlated issues of scientific reasoning ability and development may affect the conceptual understanding of evolution (Kwon & Lawson, 2000). The curricula employed in the introductory biology courses at The University of Montana actively and explicitly compelled students to recognize misconceptions, which may be a valuable first step in a cascade of developmental and educational sequences leading to broader understanding of evolution.
I discovered several distinct concepts that warranted specific attention. For example, the use of the verb “adapt” was significant in student responses to the original scenario. Like other studies, these students used the word as part of their environment-caused misconceptions (Bishop & Anderson, 1990; Clough & Wood-Robinson, 1985; Kampourakis & Zogza, 2008b; D. Palmer, 1996; Renner et al., 1981). Specific language in our curriculum influenced student use of the concept, however. A large portion of students included “adapt” in response to Alternative #1, the one alternative that included the word adapt (as well as the word “adept”, which was distasteful to some students). Language in Alternative #4, the alternative including the Lamarckian-laden misconception, also apparently elicited the use of the verb form of “adapt”, but Alternative #2 (the environment-caused misconception) did not. Alternative #2 was a fairly acceptable explanation of evolution (except for the environment-caused misconception), but it included the word “adaptation”. Perhaps students in their re-interpretation did not use the word “adapt” because the language used in this alternative adequately explained the co-evolution of orchids and pollinators to them. Similarly, time was an issue for most students. Rarely was the concept of time longer than generations, even hundreds of generations. Clearly, most were missing major conceptual understanding of the abstract, random appearance of traits, their survival within the population, and the quantity of time necessary for those changes to take place.

Diversity of Students’ Conceptual Ecologies

Teasing apart what students “know” and how they express what they know is difficult from interview data, let alone short answer questions. The responses to four
alternative explanations of a particular phenomena allowed us to examine how students transferred their thinking to different, but highly similar, situations and, in effect, to examine the grain size of working conceptual ecologies. Several recent studies highlight that students provide different types of explanations for the same evolutionary processes when asked to respond to different tasks with different content (Kampourakis & Zogza, 2008b; Nehm & Reilly, 2007; D. H. Palmer, 1999). Because our approach required students to respond to four alternative explanations of the same evolutionary event, we were able to examine the contextual application of concepts at a grain size that reflected understanding and coherence (diSessa, 2008). Our results indicate that students’ conceptual ecologies are diverse, and they include both a variety of non-scientific and scientific conceptions. These pieces of knowledge can be applied differently in different contexts, even when they are very small transfer events. Nevertheless, this curriculum may produce new insights to how students progress in their conceptual understanding; students with at least a grasp of some of the more abstract evolutionary concepts associated with evolutionary theory were less likely to include misconceptions in their responses. Indeed, students’ conceptual ecologies may experience a fundamental shift in the relative frequency of misconceptions and proximate explanations as they begin to grasp evolutionary explanations.

Demastes et al. (1996) describe four patterns of conceptual change within a cohesive framework approach (cascade, wholesale, incremental, and dual constructions), each of which could be an outcome given the relationships we found. In fact, dual constructions are an obvious possibility in our approach. The nature program served as a surrogate, and students were asked specifically to respond in terms of what they believed
an evolutionary biologist would think of explanations for phenomena depicted in the program. Considering conceptual ecologies as fluid bodies engaging different pieces of knowledge in different contexts also may explain the conceptual diversity of students’ response to highly similar explanations for natural phenomena, however. Therefore, based on our results and evidence in the literature, a transitional, contextual framework may be the most applicable approach to teaching for conceptual change.

Using Nature Films as a Tool

A number of science educators have developed curricula using nature programs to help students understand the biological sciences, recognizing the poor representation of the science. Their approaches have involved addressing the plausibility of the narrative (Rose, 2003) or deconstructing the video (B. K. Smith & Resier, 1997). Our approach was to embrace the narrative as a surrogate for poor quality explanations of evolutionary processes. Not only are evolutionary concepts abstract, the language used to represent them is distinct. For example, explaining differential survival requires language that refers to rates (which are inherently population characteristics), and not just to opportunity (increased survival of an individual). In addition, terms such as “adaptation” and “fitness” have an everyday and a scientific meaning (Bishop & Anderson, 1990), and their casual use by evolutionary biologists or nature program narratives may confound understanding (Sinatra et al., 2008). Just as it is important that students understand what a theory in science is (versus its everyday use), so it also is important to understand how the language we use about evolution can lead to misconceptions about the theory, how evolution functions, and its role in understanding many of the problems our societies face.
(e.g., antibiotic resistance). This conceptual change may begin simply by promoting an understanding of the various meanings associated with words such as “need,” “adapt,” and “theory.”

Narrative stories fit well with personal motivations, and as such, they may be easy to retain (especially if they come with incredible imagery). Although anthropomorphizing evolution may arouse student interest, it also may push students toward attributing the similarities of organisms to some sense of kinship among them (Kampourakis & Zogza, 2008b). It is not surprising that students often give purposeful explanations to animals and plants, whereas humans become more selfish, racist, less spiritual, and with less purpose as a result of evolution (Brem, Ranney, & Schindel, 2003). *Fatal Flower* is not unique in its poor treatment of evolutionary concepts (Dingwall & Aldridge, 2006; Dissertation Appendix 1). Nature programs can provide opportunities for students to recognize misconceptions without feeling attacked for their personal understanding. After all, the goal is to help students dispel cognitive illusions by recognizing the inherent errors of their current understanding.

When students leave academic institutions they are exposed to a variety of messages about evolution, some that are purposefully misleading, but some that may indirectly affect understanding by reinforcing misconceptions. As John Ziman so eloquently wrote “the public receives and uses scientific knowledge that is incoherent, practically inadequate, incredible, and inconsistent” (Ziman, 1992). If, as science educators, we do not address the language used to represent evolution and how it fits with lay theories, we may not be preparing students to adequately navigate these experiences. As adults grapple with creationist and evolutionist ideas, they rely on mental
representations that result from both interpreting and internalizing public or cultural representations and those that result from inferential reasoning (Evans, 2001). As knowledge is constructed and reconstructed in the free-choice learning environment, partially constructed ecologies may “revert” or be re-constructed when constantly exposed to the poor-quality messages delivered in nature programs and other free-choice science education resources.

**Implications**

Today, evolution may be considered a socio-scientific issue (Sadler, 2004), but understanding evolution is vital for citizens to navigate the complex biological world they encounter in democratic societies. There are differences between understanding and accepting evolution, however. Misconceptions arise from several sources: (1) those rooted in experience, (2) those that are taught and learned through informal sources (including religious and myth-based sources), (3) those that result from vernacular issues (e.g., definitions of “theory” and “adaptation”), and (4) those that are constructed by accommodating new knowledge into prior misconceptions (Committee on Undergraduate Science Education, 1997). This classification represents different levels of abstraction that may exist simultaneously in a learner’s mind. These sources can be addressed through practices that consider the different levels of abstraction using nature programs in the classroom. For example, vernacular issues can be dealt with in a straightforward way by exploring word denotations and connotations used in the narrative. Likewise, students can be taught that the virtual experiences we have with media are not always a basis on which to judge evidence. Indeed, broadening the curriculum to include explicit
instruction related to the Nature of Science (e.g., Scharmann et al., 2005) could be a valuable complement to examining nature program narratives. The complexities of dealing with informal sources and conceptual change strategies require that students develop abstract levels of thinking, such as an understanding of deep time and probability. These abstract concepts are the basis of ultimate causes of evolution (cf. Mayr, 1997), but vernacular issues can easily derail evolutionary thinking (cf. Ariew, 2003) resulting in teleological (purposeful) explanations. Nevertheless, conceptual change takes time, learning experiences in many contexts, and assessments that addresses the diversity of conceptions each individual may hold and apply in different contexts (diSessa, 2008). Explicit discussion of and reflection on common misconceptions may be a useful tool for helping students recognize their own errors as errors and reveal some cognitive illusions.

References


CHAPTER 4.
SEEING IS BELIEVING: THE IMPACTS OF NATURE FILM NARRATIVES ON
STUDENT UNDERSTANDING OF EVOLUTION

Abstract:
Informal, or free-choice, science education resources may contribute to
individuals’ understanding of evolution, but direct effects are rarely examined. Despite
the incredible appeal of wildlife and nature programs, evolutionary theory is often treated
poorly, promoting creationist accounts of ecological relationships such as “intelligent
design”. The combination of spectacular footage and poor quality narratives may be
particularly damaging to evolution understanding as viewers “witness” individual
organisms overcoming all odds to survive and reproduce. I examined the effects of
imagery and narrative by revising the narrative of one nature program to more accurately
reflect current scientific understanding. The footage, including incredible close-ups of a
euglossine bee squeezing through the throat of a bucket orchid during pollination, was
replaced by still images and by repeating some of the more generalized scenery from the
original version. I used standardized metrics to assess attitudes, beliefs, and knowledge,
and I revised one measure to reflect the organisms from the nature program for use in the
post-assessment. Generally, evolution understanding scores decreased between pre-
assessment and post-assessment, the version of the nature program had very little effect,
and the relationships between attitudes, beliefs, and understanding were complex. When
students with a moderate understanding of evolution were examined alone, the effects of
different versions of the nature program reflected predictions, but the effects were not
significant. Responses to short-answer questions indicated that students believed the imagery was important to their understanding, and broadly characterizing students according to this factor contributed to understanding outcomes. These results indicated that nature programs may be contributing to the poor public understanding of evolution.

Keywords: evolution education, narrative impact, attitudes toward evolution, nature of science understanding

Basic understanding of evolution is critical to civic and social decisions (Antolin & Herbers, 2001). Antibiotic resistance, gene therapy, disease, food production, environmental quality, and biotechnology are all areas of active biological research where evolution is a fundamental process. Yet many Americans hold serious misconceptions about evolution and the process of science. Indeed, the majority of the public (61%) may accept that humans and other living organism have evolved over time, but only 32% believe this evolution was due to natural processes (Pew Research Center for the People & the Press, 2009). The issue of whether and how evolution is taught in public schools is highly contentious (National Science Foundation, 2006). “Balanced treatment” and “strengths and weakness” legislation are invading public school systems across the country. Both Louisiana and Texas have passed laws that not only erode science teaching, they provide loopholes to advance creationist teaching in the science classroom (National Center for Science Education, http://ncseweb.org/). Under the guise of increasing critical thinking, these bills challenge the kinds of knowledge science generates and the methodological naturalism so important to its epistemology. Science
classes taught without evolution will not only impact future citizenship but a future workforce in biological research as well. Ironically, at the same time legislation is eroding the very principles that have permitted the success we all enjoy, the proportion of science-related discourses in our society is likely to increase (American Association for the Advancement of Science, 1990).

The theory of evolution is highly complex encompassing disciplines from anthropology to zoology. Understanding each of these disciplines entails understanding a host of concepts that can be fairly descriptive (e.g., conceptualizing a population or a species) or highly abstract (e.g., conceptualizing genes or probabilities; Lawson, Alkhoury, Benford, Clark, & Falconer, 2000). When these conceptions do not match scientific conceptions about evolution, for example, they are referred to as misconceptions, alternative conceptions, non-scientific ideas, or limited or inappropriate propositional hierarchies (cf. Novak, 2002). Students may hold highly systematic misconceptions about evolution (Cummins, Demastes, & Hafner, 1994), but whether this knowledge exists as a coherent framework (Vosniadou, Vamvakoussi, & Skopeliti, 2008) or as pieces that can be switched in and out of conceptual ecologies (diSessa, 2008) is unclear. Nevertheless, three broad trends in student thinking about evolution exist: (1) students tend to believe the environment causes traits to change over time (students fail to distinguish between appearance of traits and survival over time); (2) students see evolution as a process that changes the entire species simultaneously (students do not consider the role of variation); and (3) students see gradual changes in the traits themselves (students do not see evolution as the changing proportions of individuals with traits; Bishop & Anderson, 1990). These misconceptions can be tenacious, remaining
part of students’ conceptual ecologies even after significant coursework (Brumby, 1984; Nehm & Reilly, 2007; Wandersee, Mintzes, & Novak, 1994).

Informal resources for learning science outside of school, including museums, science centers, newspapers, magazines, the internet, and television, also may be important to evolution understanding. Certainly, these resources affect the knowledge students bring into the science classroom (Alters & Nelson, 2002), but they may be important in shaping conceptual ecologies once students have left formal schooling as well. Although the learning process is the same outside of the classroom, the social context and underlying motivation of the learner are important factors (Dierking, Falk, Rennie, Anderson, & Ellenbogen, 2003; J. H. Falk, 2001; J. H. Falk & Dierking, 2000; Rennie, 2007). Indeed, “free-choice” may be a more appropriate term than “informal” to describe the unique, intrinsic needs and interests of the learner outside of formal settings (J. H. Falk, 2001).

The role of informal sources in the construction of misconceptions about evolution is unclear. Even with museums, one of the most well-studied free-choice learning environments, relatively little is known about how resources influence conceptual change (Diamond & Evans, 2007). For example, science museums may base exhibits on the National Science Education Standards, employ scientists and science educators, and consider exhibit design and flow to provide an experience close to the scientific explanation of human evolution (see Diamond & Scotchmoor, 2006). Prior knowledge (Mintzes, Wandersee, & Novak, 1997) and intuitive biases (Evans, 2008) that visitors bring to the exhibit affect their interpretation and the learning outcome, however. Moreover, visitors are choosing what they want to learn about, perhaps bypassing
anything that does not fit into their conceptual framework or requires more cognitive resources than they are willing to expend at that moment (J. Falk & Storksdieck, 2005; J. H. Falk, Moussouri, & Coulson, 1998; Rennie & Johnston, 2004). Learning from museums, and other informal science education resources, also may be vulnerable to the effect of other individuals within a social group (Gleason & Schauble, 1999). To be sure, some misconceptions have been categorized as “taught and learned” – these types of misconceptions are the unscientific “facts” that may be taught informally by parents and others (Alters & Nelson, 2002). Nevertheless, individuals have different identity-related motivations for their free-choice learning opportunities, and these motivations can predict learning outcomes (J. H. Falk, Heimlich, & Bronnenkant, 2008). If viewers distinguish between educational and entertainment value, they may approach the knowledge presented differently, being more open to learning from programs that are considered “educational.”

Nature and wildlife programs are considered “educational” by convention, and must be considered a source of free-choice science understanding. Whether these television programs contribute to evolution understanding or misunderstanding is unknown, however. Because the genre is driven by the need for compelling story lines rather than scientific accuracy, several authors suggest embracing a highly skeptical view of the reality presented in wildlife films as well (Bousé, 2000; Mitman, 1999). For example, the nature programs on the Discovery Channel may provide factual information about animals, but they present the information in moral and normative terms that engage viewers on a dramatic and emotional level (Pierson, 2005). Narratives individualize the “struggle for existence” and humanize the dramas (the orphan that struggles to survive.
and returns victorious to breed), misleading viewers to teleological and Lamarckian conceptions about evolution. Indeed, references to evolution in nature programs are often teleological – they imply evolution is driven by some purpose (Aldridge & Dingwall, 2003; Dingwall & Aldridge, 2006). The result is that nature programs may implicitly endorse creationist accounts of life on earth, especially the “blue-chip” sub-genre (a sub-genre with high production values and strong visual appeal, often without a host – the narration is voiced over the production; Dingwall & Aldridge, 2006).

Nature film narratives, therefore, may have a dramatic effect on the public understanding of evolution. Narratives affect memory (Graesser, Hauft-Smith, Cohen, & Pyles, 1980; Shapiro & Fox, 2002), and they can increase the plausibility and persuasiveness of information presented (Voss, Wiley, & Sandak, 1999). We relate to narratives. Because the narrative is the predominant form taught for teaching and reading, the “narrative” experience of our lives may make it easier to comprehend and recall content than expository texts much less related to life experiences (Norris, Guilbert, Smith, Hakimelahi, & Phillips, 2005). Indeed, “transportation into a narrative world” may be a key mechanism of narrative impact (Green & Brock, 2000).

Although audiences process fictionality, external realism (matching with external reality), and narrative realism (coherence within a story) (Busselle & Bilandzic, 2008), external realism may not be essential. Audiences make judgments about the consistency of narratives constructed from a narrative experience (i.e., story world, character models, and situation models) in relation to their own experiences (Busselle, Ryabovolova, & Wilson, 2004). The result is that instead of being concerned with verisimilitude (i.e., the “truth”), audience members are concerned with coherence and logic within a particular
fictional context (Busselle & Bilandzic, 2008; Busselle et al., 2004). Enjoyment is not dependent on how well a television program, for example, reflects real-world truth (Green, Brock, & Kaufman, 2004). In fact, readers, and television viewers, that are “highly transported” maintain beliefs that are consistent with the stories, regardless of their realism (Green, 2004). Prior knowledge and experience affect transportation (Green, 2004) in a counter-intuitive manner, with regards to science. Experience with the relevant themes within the narrative results in a greater likelihood of transportation (Green, 2004) rather than any kind of skepticism. So people with some experience overcoming obstacles, perhaps a sibling that has survived a devastating disease, may be more transported into nature film narratives that portray evolution as an individual struggle. Moreover, “perceived realism” is highly correlated with how typical the event is perceived to be, leading to a “relative” realism (Shapiro & Fox, 2002). Unfortunately, engagement with a story may leave viewers with the sense that that story was authentic (Busselle & Bilandzic, 2008), whether it accurately reflects the current understanding of evolution, or not.

Likewise, video images designed to enhance nature programs may serve as powerful “virtual witnessing” events for viewers (Kirby 2003, see also Graber, 1990), resulting in an epistemological impact difficult to overcome, especially with socially controversial topics such as evolution. The imagery not only alters concepts of time, specific imagery is used to enhance the relationship with the viewer, such as including scenes with eye-contact (Bousé, 2000). Even scientists fall prey to the power of the moving image. Padian (1987) suggests that scientific reconstructions of bat-winged pterosaurs were influenced by “plausibility” of pictorial images. He notes, “a picture is
not only worth a thousand words; however inaccurate, it may be worth a wealth of well-
documented evidence to the contrary” (p. 76). Indeed, research into the effects on
learning from one beautifully crafted nature film suggests that the misconceptions
presented in the narration affect undergraduate students’ understanding of evolution
(Bright et al., abstract; Chapter 3; Dissertation Appendix 1).

Therefore, despite their standing as “educational” programming, nature films
actually may enhance the differences in understanding of evolution between biological
scientists and the general public (Dingwall & Aldridge, 2006). Because the educational
content is integral to the narrative (i.e., explanations of evolution that include design and
advancement that individuals can relate to), the parallel mental processes responsible for
comprehending narrative and educational content complement each other (Fisch, 2000),
enhancing the likelihood of developing misconceptions about evolution. The spectacular
footage, so often associated with series like The Blue Planet and Planet Earth, may add a
level of synergism to the effect. Dingwall and Aldridge (2006) note “it is highly
questionable whether wildlife and nature programming is making an appropriate
contribution to the preparedness of civil society to deal with key issues in biological and
environmental sciences.”

Nevertheless, the relationship between viewing a nature program and evolution
understanding is complex, so I designed an experiment that specifically addressed the
factors related to knowledge about this important theory (Figure 4.1). In this large-scale
design, I examined the effects of nature program narrative and imagery to directly assess
the influence of these programs on evolution understanding. I also attempted to control
for characteristics of the students related to attitudes toward science, attitude toward
evolution, understanding the nature of the scientific endeavor, and beliefs about knowledge. I predicted that misconceptions in nature film narratives were a source of viewer misconceptions. Viewer characteristics, such as positive attitudes toward evolution and science, beliefs about knowledge (personal epistemology) as well as understanding the nature of science, should alter that relationship, however. In addition, narrative alone should have the greatest impact on understanding; imagery should only serve to enhance the effect.

Methods

Manipulating a Movie

*Fatal Flower* (BBC’s Natural World series 1998) uses beautiful imagery in a traditional natural history film that explores the adaptations of different species of orchids that lure insect and bird pollinators. These pollinators in turn have adaptations that allow them to extract the nectar from specific orchids that they are dependent on for resources. Thus, from an educational perspective, the film appears to be an excellent example of co-evolution and natural selection. Unfortunately, the film is full of misconceptions (both intentional and inadvertent) about the evolutionary process and is a poor example of science in nature films (Dissertation Appendix 1). Indeed, other work suggests that the misconceptions in the narration may affect students’ understanding of evolution. Misconceptions about the goals of evolution and transmission of adaptive traits appeared frequently in students’ written responses to questions after watching the program (see Chapter 3). Therefore, I revised the narration to explain the co-evolutionary relationship more accurately than the misconception-laden original. I enlisted the assistance of a local
Figure 4.1. Determining the impact of nature program narratives and imagery on students’ understanding of evolution. Heavy lines indicate the proposed factors addressed within the experimental design.
television personality to narrate the revised version and re-voice the original version to avoid confounding the effects of the narration with the differences in narrators. Because visual experiences may affect evolution understanding through the combined effects of narrative and imagery, I wanted to separate the visual effects on understanding from the narrative effects. I reduced the films visual imagery to still images and/or repeated video segments that did not include the stunning close-ups of actual pollination events. As a result, the experiment had the following treatments:

- original version of the video (re-voiced)
- revised narration to enhance the presentation of evolutionary theory
- original version with revised imagery
- revised narration with revised imagery.

Assessment Instruments

I developed pre- and post-assessments from previously published tools addressing Attitudes toward Science, Personal Epistemology, Attitude toward Evolution, Nature of Science (NOS) Understanding, and evolution knowledge (Chapter Appendix 1). I was looking to explore changes in evolution knowledge as the result of watching one version of _Fatal Flower_ and how these changes were influenced by these variables.

Attitude has always been a difficult concept to assess; its presence can only be detected through the behaviors it manifests (Mueller, 1986). Indeed, Thurstone’s first formulation of the concept was “the sum total of a man’s inclination and feelings, prejudice and bias, preconceived notions, ideas, fears, threats, and convictions about any specified topic” (Thurstone, 1928). Because attitudes toward evolution may carry more
emotional weight than attitudes toward science, a combination of tools was necessary to address this variable.

The Test of Science Related Attitudes (TOSRA) was developed by Fraser (1981) and modified and refined by Adolphe (2002). The multi-dimensional scale measured seven science-related attitudes, including Attitude to Scientific Inquiry, Adoption of Scientific Attitudes, and Social Implication of Science using a number of paired negative and positive statements. Adolphe (2002) recorded moderately high to high reliability among students in two different countries for three of the sub-scales (Career Interest in Science: Cronbach’s alpha = 0.74-0.77; Attitude toward Scientific Inquiry: Cronbach’s alpha = 0.71-0.75; Normality of Scientists: Cronbach’s alpha = 0.59-0.66), as did Joyce & Farenga (1999; Adoption of Scientific Attitudes: Cronbach’s alpha = 0.61; Career Interest in Science: Cronbach’s alpha = 0.90; Enjoyment of Science Lessons: Cronbach’s alpha = 0.93; Attitude toward Scientific Inquiry: Cronbach’s alpha = 0.78; Leisure Interest in Science: Cronbach’s alpha = 0.89; Social Implications of Science; Cronbach’s alpha = 0.83; and Normality of Scientists: Cronbach’s alpha = 0.72). Responses to all 47 items were recoded prior to analyses to reflect similar directions.

Personal epistemology (PE), or students’ underlying beliefs about knowledge and knowing, was operationalized using a modified version of Schommer’s Beliefs about Knowledge and Learning Test, a test with both high validity and reliability (0.74 test-retest and 0.63-0.85 inter-item correlations for items within each belief factor; Duell & Schommer-Atkins, 2001). The test was modified by Schraw, Bendixen, & Dunkle (2002) to create a more efficient instrument that reflected Schommer’s five sub-scales (Innate Ability, Omniscient Authority, Quick Learning, Certain Knowledge, and Simple
Knowledge). The Epistemic Belief Inventory, as it came to be called, had higher test-retest reliability than the original and better predictive ability when correlated with reading comprehension (Schraw et al., 2002). In addition, the five sub-scales reflected the original dimensions of personal epistemology hypothesized by Schommer (1990). Responses to all items were recoded prior to analyses to reflect similar directions.

Attitudes toward evolution suffer from similar difficulties, especially given the perceived threat evolution poses toward religion. Several similar surveys have been developed to evaluate evolution attitudes. Most recently, Ingram & Nelson (2006) modified Brian Alter’s survey measuring student acceptance of evolution and used that scale to assess attitudes toward creationism and evolution. The 12-item scale was highly reliable (Cronbach’s alpha = 0.87-0.88) and used very similar statements to the Measurement of Acceptance of the Theory of Evolution (MATE). MATE also was a particularly reliable scale (Cronbach’s alpha = 0.98) but included 20 items (Rutledge & Warden, 1999). Because of the high correlation between the two scales (Ingram & Nelson, 2006), I used the scale finalized by Ingram & Nelson (2006) to assess students’ acceptance of evolution. Items from this survey included both positive and negative Likert-scale statements such as “over billions of years all plants and animals on Earth (including humans) descended (evolved) from a common ancestor (e.g., a one-celled organism)” (a positive statement) and “there is no real evidence that humans evolved from other animals” (a negative statement). Responses to all items were recoded prior to analyses to reflect similar directions.

NOS Understanding was conceptualized as the level of understanding about the process of science, including the role of evidence, terminology, certainty, and tentative
nature of results. Assessing students’ views of the NOS has been difficult, especially using standardized tests with closed questions (Aikenhead, 1988; Lederman, Wade, & Bell, 1998). Nevertheless, open-ended questions, such as those developed by Lederman, Abd-El-Khalick, Bell, & Schwartz (2002), were not logistically feasible for this research. As a result, I used the Views of Science-Technology-Society (VOSTS) developed by Aikenhead & Ryan (1992). VOSTS is a series of closed questions, the validity of which arises from development of options grounded in student views (Aikenhead & Ryan, 1992). VOSTS, therefore, was a multiple-choice assessment that presented a variety of different viewpoints that likely included most students’ conceptualizations without resorting to written explanations. The original VOSTS questionnaire was quite long, however, and included topics not necessarily appropriate in this research. Therefore, I reduced the 114 questions from the original test to 15 questions I believed addressed the kind of NOS knowledge that may influence evolution understanding and media literacy.

None of these variables was expected to change between pre- and post-assessments. For example, although personal epistemology has been found to change over time (King & Kitchener, 1994), these changes take years. Furthermore, change requires formidable effort (Schommer, 1990). Understanding NOS also was unlikely to change in such a short timeframe; it too, requires explicit instruction to change conceptions (Akerson, Morrison, & McDuffie, 2006).

Prior evolution understanding was determined using the Conceptual Inventory of Natural Selection (CINS; Anderson, Fisher, & Norman, 2002). CINS was a multiple choice test designed with answers known as “distracters” intended to assess the prevalence of misconceptions (Anderson et al., 2002). The assessment focused on 10 key
concepts related to evolution, each with two questions: biotic potential, population stability, natural resources, limited survival, variation within a population, variation inheritable, differential survival, change in a population, origin of species, origin of variation. Previous uses of CINS produced reliable results (Kuder-Richardson 20 = 0.58-0.64) and internal validity (Anderson et al., 2002).

Because the pre- and post-assessments were to be given in close proximity (within two hours of each other originally), I did not want the test questions addressing evolution understanding to be identical. CINS included two questions for each concept and could have been split into pre- and post-assessments. I wanted to maintain maximum reliability, however, because I was looking for as sensitive a tool as possible. In addition, I wanted to use organisms with which students had just had a visual experience. If students had personal experience with the subject, they may have been more interested in answering the questions honestly in the face of testing fatigue during the post-assessment. In addition, using subjects from Fatal Flower may have added sensitivity to the experiment as students transferred knowledge about evolution to organisms they were familiar with after watching the program. Therefore, I substituted organisms in the original CINS questions using subjects similar to those addressed in the nature program Fatal Flower. The wording of the questions in all cases was kept nearly identical to the original CINS questions; only slight modifications were necessary to accommodate the new organisms. The series of questions related to Canary Island Lizards was reformulated around hummingbirds foraging in the Andes (where mountain tops can act as islands), the Venezuelan Guppies questions were replaced with questions referring to Costus plants (pollinated by hummingbirds or bees depending on the species), and the
Galapagos Finch questions were replaced with questions relating to Miami Blue Butterflies (whose populations have been so isolated by development in Florida that they essentially exist on islands).

Open-ended questions were added to the online versions of the assessments to examine some of the complexity associated with individual’s understanding. The pre-assessment included two questions. The first was a widely adopted question from an instrument developed by Bishop & Anderson (1986):

“Cheetahs (large African cats) are able to run faster than 60 miles per hour when chasing prey. How would a biologist explain how the ability to run fast evolved in cheetahs, assuming their ancestors could run only 20 miles per hour?”

The second question came from an instrument developed by the Environmental Literacy Project at Michigan State University (MSU) by C. W. Anderson and others:

“Squirrels have claws that they use to help them climb the bark of trees and jump from branch to branch. They had ancestors that did not have good claws, so they were not as good at climbing and jumping. Explain how modern day squirrels have claws that are good for climbing and jumping even though their ancestors did not.”

The post-assessment included a single open-ended question similarly designed but using an example from Fatal Flower:

“The program showed how some orchids have structures that seem to mimic the females of a species of wasp. Males are attracted to this structure and try to mate with it, and they inadvertently pollinate the flower. How would an evolutionary
biologist explain this type of mimicry, assuming that the orchids’ ancestors did not have these structures?”

In addition, the post-assessment included three questions designed to elicit general information about the interaction of the program with evolution understanding:

- What did watching the video do for your understanding of evolution?
- Was the story particularly important to your understanding? Give specific examples.
- Was the imagery particularly important to your understanding? Give specific examples.

Questions used in the assessments are given in Chapter Appendices 1 and 2.

Implementation

Pre-assessments may sensitize participants and thereby influence how individuals respond to treatments and/or post-assessments. For example, a pre-assessment that focuses on evolution may alert students to cues in the nature program that focus their attention and affect how they respond to the post-assessment follow-up questions addressing evolution understanding. The Solomon four-group design is a quasi-experimental design that permits testing for the effects of the pre-assessment on post-assessment outcomes (Table 4.1). The design can test for effects of the pre-assessment and test for interaction effects between the pre-assessment and treatment that differ from the treatment alone (assuming sensitization did not occur; Frey, Botan, & Kreps, 2000). Indeed, the Solomon four-group design is one of the most powerful experimental designs
in social research, but it clearly requires large sample sizes to isolate causal effects (Frey et al., 2000).

The requisite large sample sizes were obtained by enlisting students from introductory biology courses from several universities in the north and west. Initially, the assessments were designed as paper-and-pencil tests accompanied by a DVD version of the nature program (where applicable). I enlisted the assistance of the professor of the designated non-majors biology course at The University of Montana (UM); 244 students were ultimately enrolled in 12 laboratory sections associated with the lecture. During the fall semester of 2008, I assigned lab sections randomly to one of the treatment groups (two sections each were assigned to groups 1 and 2). Students completed the entire exercise during the course of the 2-hour lab period for extra credit.

The time requirement to conduct the experiment in class was a barrier for many other professors’ participation, however. In addition, logistics for dealing with the large volume of paper required and the distances between universities necessitated a different methodological approach. The assessments were converted to online surveys using Survey Gizmo software (http://www.surveygizmo.com/), and the qualitative questions were added. The four different versions of Fatal Flower also were made available online, each with its own, unique web address. Because some of the treatments did not require pre-assessments and the class sizes of interested professors were small, the plan was to assign different universities treatments with pre/post-assessments or post-assessments only. Unfortunately, the post-assessment only classes did not participate, but students from introductory biology courses at Eastern Washington University (EWU; Fall 2008) and Michigan State University (MSU; Spring 2009) provided valuable additions to
Table 4.1.

Assignment of treatment groups according to the Solomon four-group design.

<table>
<thead>
<tr>
<th>Group</th>
<th>Pre-assessment</th>
<th>Treatment</th>
<th>Post-assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>3&lt;sub&gt;original&lt;/sub&gt;</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>4&lt;sub&gt;original&lt;/sub&gt;</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>5&lt;sub&gt;new images&lt;/sub&gt;</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>6&lt;sub&gt;new images&lt;/sub&gt;</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>7&lt;sub&gt;new narrative&lt;/sub&gt;</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>8&lt;sub&gt;new narrative&lt;/sub&gt;</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>9&lt;sub&gt;narration/images&lt;/sub&gt;</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>10&lt;sub&gt;narration/images&lt;/sub&gt;</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

the sample sizes within the pre/post-assessment cells (Table 4.2). In spring 2009, students from the designated major’s introductory biology course at UM permitted sampling within the remaining cells, however. I designed the survey to randomly assign each student to one version of Fatal Flower and provide the appropriate web address once the student had completed the pre-assessment or pre-assigned students by lab section to a version for those in the post-assessment only cells.

Because I revised the CINS assessment, I also compared the two versions (the original CINS questions versus the modified CINS questions) using students from the Fall 2008 Introduction to Human Form & Function course at UM. Human Form & Function was a beginning biology course, primarily for pre-medical students. As such, these students had a clear interest in biology but were not addressing biological
Table 4.2.

*Realized fulfillment of the Solomon four-group design based on participating classes.*

<table>
<thead>
<tr>
<th>Pre-assessment</th>
<th>Treatmenta</th>
<th>Post-assessment</th>
<th>Participating classes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td></td>
<td>UM Non-majors, UM Majors</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td></td>
<td>UM Non-majors, UM Majors</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td></td>
<td>UM Non-majors, UM Majors</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>UM Non-majors, UM Majors, EWU, MSU</td>
</tr>
</tbody>
</table>

*a Treatment includes watching one of four versions of *Fatal Flower*.

processes, such as evolution. Students were offered extra credit to complete one of the two versions of the full assessment, including the personal epistemology, attitudes, and NOS understanding questions.

All procedures were reviewed and certified by UM’s Institutional Review Board. All participants were over 18 years of age. Paper and pencil tests followed standard confidentiality procedures, and online participation was anonymous.

**Analyses**

**Attitudes and Beliefs Scales**

Two of the knowledge scales were complex, and the data derived from this experiment did not necessarily reflect the published measures of constructs related to attitudes and beliefs. Discarding items from scales that represented theoretical constructs implied that the reliability was a characteristic of the scale rather than the sample (Helms, Henze, Sass, & Mifsud, 2006), so I took two approaches to these problems. For the first approach, I used all the items in previously identified sub-scales unless that set of items
could not be reduced to a single factor with Principle Components Analysis (PCA). For the second approach, I used Principle Axis Factoring (PAF) and the Promax oblique rotation to examine the variance common to multiple variables and identify related items (Kahn, 2006). The oblique rotation allowed assessment of factors that were correlated; for uncorrelated factors, the rotation was equivalent to an orthogonal rotation (Kahn, 2006). My goal was to identify factors that may have predicted the effects of different versions of the nature programs on understanding and not necessarily to devise new latent constructs. Therefore, once I identified new combinations of variables, I used PCA with Varimax rotation to maximize the information retained in the components describing these new factors (Kahn, 2006).

Evolution Understanding

I examined the CINS scores in several forms: (1) total scores from either the Pre-assessment CINS or the Post-assessment CINS, (2) individual score differences between post-assessment and pre-assessment (Differences), (3) the proportion of answers on items that changed between pre-assessment and post-assessment for each individual (Changed Answers), and (4) whether those changes moved in the direction toward more correct answers on the post-assessment than on the pre-assessment (Correction Scale). Correction Scale was calculated as a scale where 1 = correct answer on pre-assessment, changed answer on post-assessment; 2 = incorrect answer on pre-assessment, changed answer (but still incorrect) on post-assessment; 3 = incorrect answer on pre-assessment, correct answer on post-assessment; and 4 = correct answer on pre-assessment, correct
Testing for the effects of the different versions of the nature program on evolution understanding required several different analyses. I began analyses by examining the descriptive statistics of variables, as well as their inter-correlations. I used $t$-tests to examine the differences between scores on the two versions of the evolution understanding tool (CINS). To test for the effects of the pre-assessment on the post-assessment, I used two-way ANOVA to compare evolution understanding at the end of the experiment among those taking the pre-assessment versus those not taking it and the UM biology class (non-majors v. majors).

Using only individuals that experienced both the pre-assessment and the post-assessment, I compared CINS scores among classes using two-way ANOVA. Because the other CINS metrics related post-assessment to pre-assessment, I examined the differences among classes using Welch’s variance-weighted ANOVA to account for unequal error variances coupled with unequal sample sizes (Garson, 2009).

I examined the effects of the different treatments (versions of Fatal Flower) using ANCOVA on the post-assessment scores with the pre-assessment scores as a covariate control. I also used one-way ANCOVA to examine the effects of the covariates describing attitudes and beliefs on the three differences metrics.

**Results**

Over 700 students participated in the experiment. The average age of students was shy of 21 years old, but ages differed among the classes (Table 4.3). Generally,
students at MSU were younger than students in other classes. The majority of students were either freshmen or sophomores. In addition, the number of biology courses students had taken prior to the current course ranged from none to more than six. This question did not specify whether these courses were in college or elsewhere, however, and students at EWU were not asked the question. Nevertheless, students in the consistency test (Human Form & Function) and UM Non-majors Biology reported taking more classes than UM Majors Biology students and students at MSU (Table 4.3).

Table 4.3.

*Descriptive statistics for classes participating in the experimental examination of nature films on evolution understanding.*

<table>
<thead>
<tr>
<th>Class</th>
<th>n</th>
<th>Age (^a)</th>
<th>Biology courses (^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UM Human Form &amp; Function</td>
<td>71</td>
<td>21.2</td>
<td>2.49</td>
</tr>
<tr>
<td>UM Non-majors Biology</td>
<td>210</td>
<td>20.7</td>
<td>2.00</td>
</tr>
<tr>
<td>UM Majors Biology</td>
<td>257</td>
<td>21.0</td>
<td>1.39</td>
</tr>
<tr>
<td>EWU</td>
<td>49</td>
<td>20.9</td>
<td>--- (^c)</td>
</tr>
<tr>
<td>MSU</td>
<td>126</td>
<td>19.4</td>
<td>1.01</td>
</tr>
</tbody>
</table>

\(^a\) \(F = 252.42; 4, 708 \text{ df}; p = 0.001\).

\(^b\) \(F = 43.498; 5, 537 \text{ df}; p < 0.001\).

\(^c\) Students were not asked how many biology course they had taken.
Attitudes toward Science. – Almost all of the seven sub-scales from the published Attitudes toward Science multi-dimensional scale were reliable metrics. Items within each sub-scale generally were reduced to a single linear combination with very little modification. Three sub-scales proved highly reliable and were reduced easily to single components: Career Interest in Science, Enjoyment of Science Lessons, and Leisure Interest in Science (Table 4.4). The single component generated to represent Career Interest in Science explained 59% of the variance of the original items (Table 4.5), the component generated to represent Enjoyment of Science Lessons explained 62% of the variance (Table 4.6), and the component generated to represent Leisure Interest in Science explained 48% of the variance of the original items (Table 4.7).

Table 4.4.

<table>
<thead>
<tr>
<th>Sub-scale</th>
<th>n</th>
<th>No. of items</th>
<th>Cronbach’ s alpha</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Career Interest in Science</td>
<td>655</td>
<td>6</td>
<td>0.86</td>
<td>19.34</td>
<td>5.469</td>
</tr>
<tr>
<td>Enjoyment of Science Lessons</td>
<td>647</td>
<td>6</td>
<td>0.88</td>
<td>21.78</td>
<td>5.018</td>
</tr>
<tr>
<td>Leisure Interest in Science</td>
<td>648</td>
<td>7</td>
<td>0.82</td>
<td>22.33</td>
<td>5.773</td>
</tr>
<tr>
<td>Adoption of Scientific Attitudes</td>
<td>666</td>
<td>6</td>
<td>0.75</td>
<td>24.45</td>
<td>3.375</td>
</tr>
<tr>
<td>Attitude toward Scientific Inquiry</td>
<td>654</td>
<td>6</td>
<td>0.73</td>
<td>21.41</td>
<td>3.914</td>
</tr>
<tr>
<td>Social Implications of Science</td>
<td>541</td>
<td>10</td>
<td>0.81</td>
<td>38.76</td>
<td>5.444</td>
</tr>
<tr>
<td>Normality of Scientists</td>
<td>566</td>
<td>4</td>
<td>0.53</td>
<td>15.29</td>
<td>2.500</td>
</tr>
</tbody>
</table>
Table 4.5.

*Factor coefficients for items in the Career Interest in Science sub-scale.*

<table>
<thead>
<tr>
<th>Items</th>
<th>Component 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>I would like to be a scientist when I leave school.</td>
<td>0.871</td>
</tr>
<tr>
<td>I would dislike being a scientist after I leave school.</td>
<td>0.855</td>
</tr>
<tr>
<td>When I leave school, I would like to work with people who make</td>
<td>0.779</td>
</tr>
<tr>
<td>discoveries in science.</td>
<td></td>
</tr>
<tr>
<td>A career in science would be dull and boring.</td>
<td>0.762</td>
</tr>
<tr>
<td>I would like to teach science when I leave school.</td>
<td>0.653</td>
</tr>
<tr>
<td>I would dislike becoming a scientist because it needs too much</td>
<td>0.646</td>
</tr>
<tr>
<td>education.</td>
<td></td>
</tr>
</tbody>
</table>

Eigenvalue 3.520

Note.  n = 655.

*a* Reverse keyed.

Items within the Adoption of Scientific Attitudes sub-scale proved fairly reliable measures of this construct (Table 4.4) but were slightly more difficult to reduce to a single component. Originally, two components with Eigenvalues > 1.0 were defined, but the second component explained a relatively small amount of the variation and was highly correlated with the first (Table 4.8). Therefore, the second component was eliminated, leaving a single Adoption of Scientific Attitudes component that explained 45% of the variance of the original items.
Table 4.6.

Factor coefficients for items in the Enjoyment of Science Lessons sub-scale.

<table>
<thead>
<tr>
<th>Items</th>
<th>Component 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>I dislike science lessons.(^a)</td>
<td>0.854</td>
</tr>
<tr>
<td>Science is one of the most interesting school subjects.</td>
<td>0.821</td>
</tr>
<tr>
<td>Science lessons are fun.</td>
<td>0.812</td>
</tr>
<tr>
<td>I would enjoy school more if there were no science lessons.(^a)</td>
<td>0.805</td>
</tr>
<tr>
<td>The material covered in science lessons is uninteresting.(^a)</td>
<td>0.741</td>
</tr>
<tr>
<td>School should have more science lessons each week.</td>
<td>0.668</td>
</tr>
<tr>
<td><strong>Eigenvalue</strong></td>
<td><strong>3.707</strong></td>
</tr>
</tbody>
</table>

*Note.* n = 647.

\(^a\) Reverse keyed.

Two items were deleted from the Attitude toward Scientific Inquiry sub-scale after the paper and pencil test because a number of students commented on the redundancy of questions. All of the items refer to the value of conducting experiments versus other forms of discovering information, so two items (one positive and one negative) were deleted in the subsequent online assessments. The reduced sub-scale was still a fairly reliable metric (Table 4.4), however, and a single linear combination described 44% of the variation (Table 4.9).
Table 4.7.

Factor coefficients for items in the Leisure Interest in Science sub-scale.

<table>
<thead>
<tr>
<th>Items</th>
<th>Component 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Listening to talk about science on the radio would be boring.\textsuperscript{a}</td>
<td>0.766</td>
</tr>
<tr>
<td>I dislike reading books about science during my vacations.\textsuperscript{a}</td>
<td>0.740</td>
</tr>
<tr>
<td>I would enjoy visiting a science museum at the weekend.</td>
<td>0.717</td>
</tr>
<tr>
<td>I would like to belong to a science club.</td>
<td>0.708</td>
</tr>
<tr>
<td>I would like to be given a science book or a piece of scientific equipment as a present.</td>
<td>0.679</td>
</tr>
<tr>
<td>I get bored when watching science programs on TV at home.\textsuperscript{a}</td>
<td>0.613</td>
</tr>
<tr>
<td>I dislike reading newspaper articles about science.\textsuperscript{a}</td>
<td>0.604</td>
</tr>
<tr>
<td>Eigenvalue</td>
<td>3.352</td>
</tr>
</tbody>
</table>

Note. \( n = 648 \).

\textsuperscript{a} Reverse keyed.

The Social Implications of Science sub-scale was highly reliable (Table 4.4) but could not be reduced to a single component using PCA. The second component (Table 4.10) was primarily related to a single item (whether public funds for science have been used wisely in the last few years). This item was removed from the scale, improving both the reliability of the sub-scale (Cronbach’s alpha = 0.81, mean = 35.89, SD = 5.159, 9 items) and the number of components that were generated. The resulting single component explained 42% of the variation in the remaining nine items (Eigenvalue = 3.764).
Table 4.8.

Rotated factor loadings for items in the Adoption of Scientific Attitudes sub-scale.

<table>
<thead>
<tr>
<th>Items</th>
<th>Component</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>I find it boring to hear about new ideas.(^a)</td>
<td>1</td>
<td>0.770</td>
<td>0.199</td>
</tr>
<tr>
<td>I dislike listening to other people’s opinions.(^a)</td>
<td>1</td>
<td>0.708</td>
<td>-0.181</td>
</tr>
<tr>
<td>I like to listen to people whose opinions are different from mine.</td>
<td>1</td>
<td>0.701</td>
<td>-0.471</td>
</tr>
<tr>
<td>I am curious about the world in which we live.</td>
<td>1</td>
<td>0.617</td>
<td>0.424</td>
</tr>
<tr>
<td>Finding out about new things is unimportant.(^a)</td>
<td>1</td>
<td>0.603</td>
<td>0.551</td>
</tr>
<tr>
<td>I enjoy reading about things that disagree with my previous ideas.</td>
<td>1</td>
<td>0.590</td>
<td>-0.490</td>
</tr>
<tr>
<td>Eigenvalue</td>
<td></td>
<td>2.68</td>
<td>1.02</td>
</tr>
<tr>
<td>Rotated loading</td>
<td></td>
<td>1.874</td>
<td>1.822</td>
</tr>
</tbody>
</table>

Note. n = 666.

\(^a\) Reverse keyed.

Lastly, the Normality of Scientists sub-scale was much less reliable than other sub-scales (Table 4.4). In addition, PCA could not calculate a single component for the set of items (Table 4.11). Because the second component explained only slightly more of the variance than a single item, only the scores from the first component were saved.

The saved regression scores for the sub-scales describing Attitudes toward Science were highly correlated (Table 4.12), indicating a high degree of overlap in the underlying constructs within this sample. PAF also indicated significant correlations
Table 4.9.

*Factor coefficients for items in the Attitude toward Scientific Inquiry sub-scale.*

<table>
<thead>
<tr>
<th>Items</th>
<th>Component 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>I would rather agree with other people than do experiments and find out</td>
<td>0.750</td>
</tr>
<tr>
<td>for myself.(^a)</td>
<td></td>
</tr>
<tr>
<td>It is better to ask the teacher the answer than to find out by doing</td>
<td>0.731</td>
</tr>
<tr>
<td>experiments.(^a)</td>
<td></td>
</tr>
<tr>
<td>I would rather solve a problem by doing an experiment than be told the</td>
<td>0.715</td>
</tr>
<tr>
<td>answer.</td>
<td></td>
</tr>
<tr>
<td>I would rather find out about things by asking an expert than by doing</td>
<td>0.654</td>
</tr>
<tr>
<td>an experiment.(^a)</td>
<td></td>
</tr>
<tr>
<td>I dislike repeating experiments to check that I get the same results.</td>
<td>0.543</td>
</tr>
<tr>
<td>(^a)</td>
<td></td>
</tr>
<tr>
<td>I would prefer to do experiments than to read about them.</td>
<td>0.542</td>
</tr>
</tbody>
</table>

| Eigenvalue | 2.63 |

*Note.* \(n = 654.\)

\(^a\) Reverse keyed.

among factors and items (Table 4.13). The high correlations between Career Interest in Science, Enjoyment of Science Lessons, and Leisure Interest in Science were apparent in Component 1 of the structure matrix. Items associated with the Social Implications of Science, Attitudes toward Inquiry, and Adoption of Scientific Attitudes appeared to load strongly on single components, whereas items describing the Normality of Scientists did not. Therefore, I removed items with high inter-correlations, items that loaded heavily on more than one factor, and items that did not load on any factor. The final structure matrix
Table 4.10.

Rotated factor coefficients for items in the Social Implications of Science sub-scale.

<table>
<thead>
<tr>
<th>Items</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Science is man’s worst enemy.(^a)</td>
<td>0.680</td>
</tr>
<tr>
<td>Money used on scientific projects is wasted.(^a)</td>
<td>0.643</td>
</tr>
<tr>
<td>Scientific discoveries are doing more harm than good.(^a)</td>
<td>0.638</td>
</tr>
<tr>
<td>This country is spending too much money on science.(^a)</td>
<td>0.612</td>
</tr>
<tr>
<td>Too many laboratories are being built at the expense of the rest of</td>
<td>0.583</td>
</tr>
<tr>
<td>education.(^a)</td>
<td></td>
</tr>
<tr>
<td>Science helps to make life better.</td>
<td>0.450</td>
</tr>
<tr>
<td>Science can help to make the world a better place in the future.</td>
<td>0.426</td>
</tr>
<tr>
<td>Money spent on science is well worth spending.</td>
<td>0.342</td>
</tr>
<tr>
<td>The government should spend more money on scientific research.</td>
<td>0.193</td>
</tr>
<tr>
<td>Public money spent on science in the last few years has been used</td>
<td>-0.165</td>
</tr>
<tr>
<td>wisely.</td>
<td></td>
</tr>
<tr>
<td>Eigenvalue</td>
<td>3.826</td>
</tr>
<tr>
<td>Rotated loading</td>
<td>2.563</td>
</tr>
</tbody>
</table>

\(^a\) Reverse keyed.

Note. \(n = 541\).
Table 4.11.

*Rotated factor coefficients for items in the Normality of Scientist sub-scale.*

<table>
<thead>
<tr>
<th>Items</th>
<th>Component</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Scientists are about as fit and healthy as other people.</td>
<td></td>
<td>0.868</td>
<td>0.032</td>
</tr>
<tr>
<td>Scientists are just as interested in art and music as other people are.</td>
<td></td>
<td>0.806</td>
<td>0.143</td>
</tr>
<tr>
<td>Scientists are less friendly than other people.</td>
<td></td>
<td>0.015</td>
<td>0.831</td>
</tr>
<tr>
<td>Scientists do not have enough time to spend with their families.</td>
<td></td>
<td>0.139</td>
<td>0.694</td>
</tr>
<tr>
<td>Eigenvalue</td>
<td></td>
<td>1.586</td>
<td>1.032</td>
</tr>
<tr>
<td>Rotated loading</td>
<td></td>
<td>1.423</td>
<td>1.194</td>
</tr>
</tbody>
</table>

*Note.*  n = 566.

*Reverse keyed.*
Table 4.12.

*Pearson correlations for the saved regression scores for sub-scales describing Attitudes toward Science.*

<table>
<thead>
<tr>
<th>Sub-scale</th>
<th>Career Interest in Science</th>
<th>Enjoyment of Science Lessons</th>
<th>Leisure Interest in Science</th>
<th>Adoption of Scientific Attitudes</th>
<th>Attitude toward Scientific Inquiry</th>
<th>Social Implications of Science</th>
<th>Normality of Scientists</th>
</tr>
</thead>
<tbody>
<tr>
<td>Career Interest in Science</td>
<td>0.776**</td>
<td>0.732**</td>
<td>0.317**</td>
<td>0.412**</td>
<td>0.443**</td>
<td>0.292**</td>
<td></td>
</tr>
<tr>
<td>Enjoyment of Science Lessons</td>
<td></td>
<td>0.738**</td>
<td>0.403**</td>
<td>0.424**</td>
<td>0.540**</td>
<td>0.339**</td>
<td></td>
</tr>
<tr>
<td>Leisure Interest in Science</td>
<td></td>
<td></td>
<td>0.417**</td>
<td>0.393**</td>
<td>0.470**</td>
<td>0.310**</td>
<td></td>
</tr>
<tr>
<td>Adoption of Scientific Attitudes</td>
<td></td>
<td></td>
<td></td>
<td>0.363**</td>
<td>0.520**</td>
<td>0.318**</td>
<td></td>
</tr>
<tr>
<td>Attitude toward Scientific Inquiry</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.339**</td>
<td>0.303**</td>
<td></td>
</tr>
<tr>
<td>Social Implications of Science</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.454**</td>
<td></td>
</tr>
<tr>
<td>Normality of Scientists</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** p < 0.001.
Table 4.13.

Factor structure matrix for coefficients of all items in the Attitudes toward Science scale and the sub-scale (SS) to which they had been assigned in the literature.

<table>
<thead>
<tr>
<th>Item</th>
<th>SS</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science is one of the most interesting school subjects.</td>
<td>E</td>
<td>0.791</td>
</tr>
<tr>
<td>I dislike science lessons.</td>
<td>E</td>
<td>0.784</td>
</tr>
<tr>
<td>Science lessons are fun.</td>
<td>E</td>
<td>0.784</td>
</tr>
<tr>
<td>I would like to be a scientist when I leave school.</td>
<td>CI</td>
<td>0.779</td>
</tr>
<tr>
<td>A career in science would be dull and boring.</td>
<td>CI</td>
<td>0.768</td>
</tr>
<tr>
<td>I would like to belong to a science club.</td>
<td>LI</td>
<td>0.765</td>
</tr>
<tr>
<td>I would dislike being a scientist after I leave school.</td>
<td>CI</td>
<td>0.741</td>
</tr>
<tr>
<td>I would enjoy school more if there were no science lessons.</td>
<td>E</td>
<td>0.735</td>
</tr>
<tr>
<td>When I leave school, I would like to work with people who make</td>
<td>CI</td>
<td>0.682</td>
</tr>
<tr>
<td>discoveries in science.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The material covered in science lessons is uninteresting.</td>
<td>E</td>
<td>0.633</td>
</tr>
<tr>
<td>School should have more science lessons each week.</td>
<td>E</td>
<td>0.620</td>
</tr>
<tr>
<td>I dislike reading books about science during my vacations.</td>
<td>LI</td>
<td>0.619</td>
</tr>
<tr>
<td>Item</td>
<td>Component</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>-----------</td>
<td></td>
</tr>
<tr>
<td>Listening to talk about science on the radio would be boring.</td>
<td>LI 0.619</td>
<td></td>
</tr>
<tr>
<td>I would enjoy visiting a science museum at the weekend.</td>
<td>LI 0.599</td>
<td></td>
</tr>
<tr>
<td>I would like to be given a science book or a piece of scientific</td>
<td>LI 0.592</td>
<td></td>
</tr>
<tr>
<td>equipment as a present.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I would like to teach science when I leave school.</td>
<td>CI 0.583</td>
<td></td>
</tr>
<tr>
<td>positive - I would dislike becoming a scientist because it needs</td>
<td>CI 0.528</td>
<td></td>
</tr>
<tr>
<td>too much education.</td>
<td>0.458c</td>
<td></td>
</tr>
<tr>
<td>positive - I dislike reading newspaper articles about science.</td>
<td>LI 0.510</td>
<td></td>
</tr>
<tr>
<td>This country is spending too much money on science.</td>
<td>SI 0.421c</td>
<td></td>
</tr>
<tr>
<td>Money used on scientific projects is wasted.</td>
<td>SI 0.599</td>
<td></td>
</tr>
<tr>
<td>Scientists are less friendly than other people.</td>
<td>SI 0.536</td>
<td></td>
</tr>
<tr>
<td>Too many laboratories are being built at the expense of the rest</td>
<td>SI 0.534</td>
<td></td>
</tr>
<tr>
<td>of education.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scientific discoveries are doing more harm than good.</td>
<td>SI 0.485</td>
<td></td>
</tr>
<tr>
<td>Scientists do not have enough time to spend with their families.</td>
<td>SI 0.406</td>
<td></td>
</tr>
</tbody>
</table>

229
<table>
<thead>
<tr>
<th>Item</th>
<th>Component</th>
<th>SS&lt;sup&gt;b&lt;/sup&gt;</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Money spent on science is well worth spending.</td>
<td>SI</td>
<td></td>
<td>0.463&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.662</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The government should spend more money on scientific research.</td>
<td>SI</td>
<td></td>
<td>0.452&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.656</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Science can help to make the world a better place in the future.</td>
<td>SI</td>
<td></td>
<td>0.648</td>
<td>0.475</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Science helps to make life better.</td>
<td>SI</td>
<td></td>
<td>0.620</td>
<td>0.429&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public money spent on science in the last few years has been used wisely.</td>
<td>SI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I find it boring to hear about new ideas.&lt;sup&gt;b&lt;/sup&gt;</td>
<td>A</td>
<td></td>
<td>0.528&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.712</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I dislike listening to other people’s opinions.&lt;sup&gt;b&lt;/sup&gt;</td>
<td>A</td>
<td></td>
<td>0.686</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I like to listen to people whose opinions are different from mine.</td>
<td>A</td>
<td></td>
<td>0.637</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I enjoy reading about things that disagree with my previous ideas.</td>
<td>A</td>
<td></td>
<td>0.452</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I would rather solve a problem by doing an experiment than be told the answer.</td>
<td>I</td>
<td></td>
<td></td>
<td>0.647</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>It is better to ask the teacher the answer than to find out by doing experiments.&lt;sup&gt;b&lt;/sup&gt;</td>
<td>I</td>
<td></td>
<td>0.468&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td>0.645</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I would rather agree with other people than do experiments and find out for myself.&lt;sup&gt;b&lt;/sup&gt;</td>
<td>I</td>
<td></td>
<td>0.511&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td>0.487&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.623</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I would rather find out about things by asking an expert than by doing an experiment.&lt;sup&gt;b&lt;/sup&gt;</td>
<td>I</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.568</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I would prefer to do experiments than to read about them.</td>
<td>I</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.482</td>
<td></td>
</tr>
<tr>
<td>Item</td>
<td>Component</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------------------------------------------------</td>
<td>-----------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scientists are about as fit and healthy as other people.</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scientists are just as interested in art and music as other people</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>are.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am curious about the world in which we live.</td>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I get bored when watching science programs on TV at home.</td>
<td>LI 0.513c</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finding out about new things is unimportant.</td>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I dislike repeating experiments to check that I get the same results.</td>
<td>I</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Note. n = 451. Factor coefficients less than 0.400 are not shown.


b Reverse keyed.

c When the correlations among factors was controlled, relationship between item and factor close to 0.
yielded five factors with high item correlations when the correlation among factors was controlled.

I named the first factor General Interest because it included a combination of 12 items from Career Interest in Science, Enjoyment of Science Lessons, and Leisure Interest in Science. The combination explained the majority of the variance in the sample, and the 12 items were highly reliable (Table 4.14). The remaining factors mirrored sub-scales from the original Attitudes toward Science scale (Social Implications of Science, Adoption of Attitudes, and Attitudes toward Inquiry), each with fewer items. Therefore, I gave the factors new names to reflect these relationships: Factor 2 = New Implications, Factor 3 = New Attitudes, and Factor 4 = New Inquiry. The remaining two factors were excluded from further analyses because they contributed little in terms of explaining the variance or interpretation.

Personal Epistemology. – Students beliefs about knowledge also were difficult to classify according to published sub-scales. Previous researchers had identified five independent sub-scales (Schommer, 1990, Schommer-Aikins, 2004, and Schraw et al., 2002), yet this sample yielded low reliability estimates. Three of the sub-scales (Innate Ability, Omniscient Authority, and Quick Learning) had relatively minor issues to overcome for this analysis. Using the published items, the reliability of the Innate Ability sub-scale was lower than generally considered acceptable (Table 4.15). In addition, describing the variation with this combination of items required more than one factor (Table 4.16). One item seemed to negatively affect the sub-scale (whether individuals are born with special gifts and talents). When this item was not included, reliability
Table 4.14.

*Coefficients and reliability for new factors describing Attitudes toward Science derived from the sample.*

<table>
<thead>
<tr>
<th>Factor</th>
<th>Eigenvalue</th>
<th>% variance</th>
<th>Rotated loading</th>
<th>% variance</th>
<th>n</th>
<th>Items</th>
<th>Cronbach’s alpha</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.985</td>
<td>28.5</td>
<td>5.994</td>
<td>21.4</td>
<td>618</td>
<td>12</td>
<td>0.91</td>
<td>37.18</td>
<td>10.031</td>
</tr>
<tr>
<td>2</td>
<td>2.342</td>
<td>8.4</td>
<td>2.834</td>
<td>10.1</td>
<td>581</td>
<td>5</td>
<td>0.72</td>
<td>18.07</td>
<td>3.108</td>
</tr>
<tr>
<td>3</td>
<td>1.843</td>
<td>6.6</td>
<td>2.792</td>
<td>10.0</td>
<td>671</td>
<td>4</td>
<td>0.72</td>
<td>15.49</td>
<td>2.562</td>
</tr>
<tr>
<td>4</td>
<td>1.546</td>
<td>5.5</td>
<td>2.097</td>
<td>7.5</td>
<td>672</td>
<td>4</td>
<td>0.67</td>
<td>14.59</td>
<td>2.794</td>
</tr>
<tr>
<td>5</td>
<td>1.275</td>
<td>4.6</td>
<td>---(^a)</td>
<td>---(^a)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1.142</td>
<td>4.1</td>
<td>---(^a)</td>
<td>---(^a)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Factors excluded from further analyses.
increased to an acceptable level (Cronbach’s alpha = 0.71, mean = 17.82, SD = 3.689, 5 items), and the remaining five items combined to a single component that described 47% of the variation (Eigenvalue = 2.331). Reliability of the Omniscient Authority sub-scale with all four original items also was moderately unacceptable (Table 4.15). PCA effectively reduced these items to a single component, however, that explained 50% of the variation in the original items (Table 4.17). Similarly, when using all of the items from the published sub-scale designed to describe Quick Learning, reliability was below that considered acceptable for a construct (Table 4.15). Nevertheless, PCA was able to extract a single component describing 39% of the variation in the five items (Table 4.18).

Table 4.15.

Reliability metrics for the five sub-scales measuring students’ beliefs about knowledge.

<table>
<thead>
<tr>
<th>Sub-scale</th>
<th>n</th>
<th>No. of items</th>
<th>Cronbach’s alpha</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Innate Ability</td>
<td>651</td>
<td>6</td>
<td>0.67</td>
<td>19.56</td>
<td>3.888</td>
</tr>
<tr>
<td>Omniscient Authority</td>
<td>661</td>
<td>4</td>
<td>0.65</td>
<td>12.47</td>
<td>3.071</td>
</tr>
<tr>
<td>Quick Learning</td>
<td>677</td>
<td>5</td>
<td>0.57</td>
<td>20.24</td>
<td>2.890</td>
</tr>
<tr>
<td>Certain Knowledge</td>
<td>553</td>
<td>6</td>
<td>-0.16</td>
<td>20.33</td>
<td>2.558</td>
</tr>
<tr>
<td>Simple Knowledge</td>
<td>610</td>
<td>7</td>
<td>0.48</td>
<td>24.63</td>
<td>3.332</td>
</tr>
</tbody>
</table>
Table 4.16.

*Rotated factor coefficients for items in the Innate Ability sub-scale.*

<table>
<thead>
<tr>
<th>Items</th>
<th>Component 1</th>
<th>Component 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smart people are born that way.(^a)</td>
<td>0.763</td>
<td>0.161</td>
</tr>
<tr>
<td>People’s intellectual potential is fixed at birth.(^a)</td>
<td>0.722</td>
<td>-0.195</td>
</tr>
<tr>
<td>How well you do in school depends on how smart you are.(^a)</td>
<td>0.686</td>
<td>-0.073</td>
</tr>
<tr>
<td>Really smart students don’t have to work as hard to do well in school.(^a)</td>
<td>0.640</td>
<td>0.306</td>
</tr>
<tr>
<td>Some people just have a knack for learning and others don’t.(^a)</td>
<td>0.543</td>
<td>0.378</td>
</tr>
<tr>
<td>Some people are born with special gifts and talents.(^a)</td>
<td>-0.031</td>
<td>0.924</td>
</tr>
<tr>
<td><strong>Eigenvalue</strong></td>
<td>2.356</td>
<td>1.082</td>
</tr>
<tr>
<td><strong>Rotated loading</strong></td>
<td>2.279</td>
<td>1.159</td>
</tr>
</tbody>
</table>

*Note.*  \(n = 651\).

\(^a\) Reverse keyed.

Both the Certain Knowledge and Simple Knowledge sub-scales indicated more complex relationships in this sample than had been published previously. The reliability estimate for Certain Knowledge, based on items from the literature, was negative (Table 4.15), due specifically to negative correlations between the items (despite recoding so that all items measured the same direction). Schraw et al. (2002) identified a sub-set of three of the six original items to describe this construct using PAF, but isolating that sub-set with this sample did not improve reliability (Cronbach’s alpha = 0.09). Nor did it
Table 4.17.

*Factor coefficients for items in the Omniscient Authority sub-scale.*

<table>
<thead>
<tr>
<th>Items</th>
<th>Component 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>People should always obey the law.\textsuperscript{a}</td>
<td>0.798</td>
</tr>
<tr>
<td>When someone in authority tells me what to do, I usually do it.\textsuperscript{a}</td>
<td>0.772</td>
</tr>
<tr>
<td>People shouldn’t question authority.\textsuperscript{a}</td>
<td>0.770</td>
</tr>
<tr>
<td>Children should be allowed to question their parents’ authority.</td>
<td>0.429</td>
</tr>
<tr>
<td><strong>Eigenvalue</strong></td>
<td><strong>2.011</strong></td>
</tr>
</tbody>
</table>

*Note.* $n = 661$.

\textsuperscript{a} Reverse keyed.

Table 4.18.

*Factor coefficients for items in the Quick Learning sub-scale.*

<table>
<thead>
<tr>
<th>Items</th>
<th>Component 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>If you don’t learn something quickly, you won’t ever learn it.\textsuperscript{a}</td>
<td>0.752</td>
</tr>
<tr>
<td>Working on a problem with no quick solution is a waste of time.\textsuperscript{a}</td>
<td>0.673</td>
</tr>
<tr>
<td>If you haven’t understood a chapter the first time through, going back over it won’t help.\textsuperscript{a}</td>
<td>0.663</td>
</tr>
<tr>
<td>If a person tries too hard to understand a problem, they will most likely end up being confused.\textsuperscript{a}</td>
<td>0.528</td>
</tr>
<tr>
<td>Students who learn things quickly are the most successful.\textsuperscript{a}</td>
<td>0.481</td>
</tr>
<tr>
<td><strong>Eigenvalue</strong></td>
<td><strong>1.968</strong></td>
</tr>
</tbody>
</table>

*Note.* $n = 677$.

\textsuperscript{a} Reverse keyed.
yield a single principle component. In fact, this sub-set of three items resulted in two components with relatively evenly distributed Eigenvalues (1.07, 1.01, 0.91, respectively), each representing about a third of the variance found in the original three items of the sub-set. PCA highlighted the complex nature of the sub-scale with this sample; the original items represented three linear components that explained 61% of the variation. The rotated matrix indicated that these components split the items into a component that could be considered an idiosyncratic approach to knowledge certainty, a component that isolated the negative relationship between two factors defining “truth”, and a component that identified the role of parents (Table 4.19). Removing the two items that yielded negative correlations and the item comprising the majority of the third component resulted in a single component that described 45% of the variation in the remaining items (Eigenvalue = 1.347). Not surprisingly, the reliability of these three items was low (Cronbach’s alpha = 0.38, mean = 12.00, SD = 1.941, 3 items).

Simple Knowledge also was a poor characterization of students’ understanding (Table 4.15). The complexity was clear when attempting to reduce the sub-scale to a single linear combination of the items (Table 4.20). PCA identified three components in this one sub-scale that explained 59% of the original variance: the first component described the role of theories in science explanations, the second component described the ease of science knowledge, and the third component described the complexity of knowledge. Although the two items comprising the bulk of the third component were both strong contributors (> 0.70), the component only described slightly more variation than a single item. In addition, “the more you know about a topic, the more there is to know” contributed positively and “the best ideas are often the most simple” contributed
Table 4.19.

Rotated factor coefficients for items in the Certain Knowledge sub-scale.

<table>
<thead>
<tr>
<th>Items</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>What is true today will be true tomorrow.(^a)</td>
<td>0.744</td>
</tr>
<tr>
<td>If two people are arguing about something, at least one of them must be wrong.(^a)</td>
<td>0.724</td>
</tr>
<tr>
<td>Absolute moral truth does not exist.</td>
<td>-0.236</td>
</tr>
<tr>
<td>Sometimes there are no right answers to life’s big problems.</td>
<td>0.381</td>
</tr>
<tr>
<td>What is true is a matter of opinion.(^a)</td>
<td>-0.118</td>
</tr>
<tr>
<td>Parents should teach their children all there is to know about life.(^a)</td>
<td>0.131</td>
</tr>
<tr>
<td>Eigenvalue</td>
<td>1.477</td>
</tr>
<tr>
<td>Rotated loading</td>
<td>1.310</td>
</tr>
</tbody>
</table>

Note.  \(n = 553\).

\(^a\) Reverse keyed.

negatively (despite recoding). By removing these two items and the single item negatively correlated with the first component, I was able to reduce the remaining items to a single factor that described 49% of the variation in the remaining items (Eigenvalue = 1.753). Reliability was relatively low, however (Cronbach’s alpha = 0.57, mean = 14.66, SD = 2.557, 4 items). Nevertheless, these four items encompassed the sub-set of items identified by Schraw et al. (2002) (they did not include “things are simpler than
Table 4.20.

Rotated factor coefficients for items in the Simple Knowledge sub-scale.

<table>
<thead>
<tr>
<th>Items</th>
<th>Component</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Too many theories just complicate things.(^a)</td>
<td></td>
<td>0.772</td>
<td>0.053</td>
<td>0.089</td>
</tr>
<tr>
<td>Things are simpler than most professors would have you believe.(^a)</td>
<td></td>
<td>0.689</td>
<td>-0.094</td>
<td>-0.019</td>
</tr>
<tr>
<td>Instructors should focus on facts instead of theories.(^a)</td>
<td></td>
<td>0.592</td>
<td>0.432</td>
<td>-0.074</td>
</tr>
<tr>
<td>Science is easy to understand because it contains so many facts.(^a)</td>
<td></td>
<td>-0.182</td>
<td>0.849</td>
<td>-0.141</td>
</tr>
<tr>
<td>Most things worth knowing are easy to understand.(^a)</td>
<td></td>
<td>0.356</td>
<td>0.601</td>
<td>0.250</td>
</tr>
<tr>
<td>The more you know about a topic, the more there is to know.</td>
<td></td>
<td>0.171</td>
<td>0.155</td>
<td>0.707</td>
</tr>
<tr>
<td>The best ideas are often the most simple.(^a)</td>
<td></td>
<td>0.158</td>
<td>0.175</td>
<td>-0.748</td>
</tr>
<tr>
<td>Eigenvalue</td>
<td></td>
<td>1.874</td>
<td>1.211</td>
<td>1.041</td>
</tr>
<tr>
<td>Rotated loading</td>
<td></td>
<td>1.634</td>
<td>1.335</td>
<td>1.156</td>
</tr>
</tbody>
</table>

*Note.* n = 610.

\(^a\) Reverse keyed.

most professors would have you believe” in their sub-set), indicating some consistency within this theoretical construct.

Because the Personal Epistemology sub-scales identified in the literature were less than ideal for use with these data, I used PAF to explore the relationships among items and to identify new related factors. Although seven factors were identified, the final two contributed little to the overall analysis (Table 4.21). The first factor described
Table 4.21.

*Factor structure matrix for coefficients of all items in the Personal Epistemology scale and the sub-scale (SS) to which they had been assigned in the literature.*

<table>
<thead>
<tr>
<th>Item</th>
<th>SS</th>
<th>Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working on a problem with no quick solution is a waste of time.</td>
<td>QL</td>
<td>0.674</td>
</tr>
<tr>
<td>Too many theories just complicate things.</td>
<td>SK</td>
<td>0.639</td>
</tr>
<tr>
<td>If you don’t learn something quickly, you won’t ever learn it.</td>
<td>QL</td>
<td>0.598</td>
</tr>
<tr>
<td>Most things worth knowing are easy to understand.</td>
<td>SK</td>
<td>0.583</td>
</tr>
<tr>
<td>If you haven’t understood a chapter the first time through, going back over it won’t help.</td>
<td>QL</td>
<td>0.577</td>
</tr>
<tr>
<td>Instructors should focus on facts instead of theories.</td>
<td>SK</td>
<td>0.553</td>
</tr>
<tr>
<td>If two people are arguing about something, at least one of them must be wrong.</td>
<td>CK</td>
<td>0.474</td>
</tr>
<tr>
<td>Smart people are born that way.</td>
<td>IA</td>
<td>0.699</td>
</tr>
<tr>
<td>Really smart students don’t have to work as hard to do well in school.</td>
<td>IA</td>
<td>0.596</td>
</tr>
<tr>
<td>Students who learn things quickly are the most successful.</td>
<td>QL</td>
<td>0.580</td>
</tr>
<tr>
<td>Item</td>
<td>Components</td>
<td>SS</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>------------</td>
<td>------</td>
</tr>
<tr>
<td>How well you do in school depends on how smart you are.(^b)</td>
<td>IA</td>
<td>0.576</td>
</tr>
<tr>
<td>People’s intellectual potential is fixed at birth.(^b)</td>
<td>IA</td>
<td>0.420</td>
</tr>
<tr>
<td>Some people just have a knack for learning and others don’t.(^b)</td>
<td>IA</td>
<td>0.487</td>
</tr>
<tr>
<td>People should always obey the law.(^b)</td>
<td>OA</td>
<td>0.726</td>
</tr>
<tr>
<td>When someone in authority tells me what to do, I usually do it.(^b)</td>
<td>OA</td>
<td>0.655</td>
</tr>
<tr>
<td>People shouldn’t question authority.(^b)</td>
<td>OA</td>
<td>0.441</td>
</tr>
<tr>
<td>Sometimes there are no right answers to life’s big problems.</td>
<td>CK</td>
<td>0.560</td>
</tr>
<tr>
<td>The more you know about a topic, the more there is to know.</td>
<td>SK</td>
<td>0.404</td>
</tr>
<tr>
<td>What is true is a matter of opinion.(^b)</td>
<td>CK</td>
<td>0.513</td>
</tr>
<tr>
<td>Things are simpler than most professors would have you believe.(^b)</td>
<td>SK</td>
<td></td>
</tr>
<tr>
<td>Science is easy to understand because it contains so many facts.(^b)</td>
<td>SK</td>
<td>0.496</td>
</tr>
<tr>
<td>Parents should teach their children all there is to know about life.(^b)</td>
<td>CK</td>
<td></td>
</tr>
</tbody>
</table>
### Components

<table>
<thead>
<tr>
<th>Item</th>
<th>Item Description</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Some people are born with special gifts and talents.(^b)</td>
<td>IA</td>
<td>0.489</td>
</tr>
<tr>
<td>Absolute moral truth does not exist.</td>
<td>CK</td>
<td></td>
</tr>
<tr>
<td>The best ideas are often the most simple.(^b)</td>
<td>SK</td>
<td></td>
</tr>
<tr>
<td>Children should be allowed to question their parents’ authority.</td>
<td>OA</td>
<td></td>
</tr>
<tr>
<td>If a person tries too hard to understand a problem, they will most likely end up being confused.(^b)</td>
<td>QL</td>
<td></td>
</tr>
<tr>
<td>What is true today will be true tomorrow.(^b)</td>
<td>CK</td>
<td></td>
</tr>
</tbody>
</table>

| Eigenvalue | 4.986 | 2.294 | 1.901 | 1.626 | 1.428 | 1.113 | 1.041 |

*Note.* n = 476. Factor coefficients less than 0.400 are not shown.

\(^a\) SS: IA = Innate Ability, OA = Omniscient Authority, QL = Quick Learning, CK = Certain Knowledge, SK = Simple Knowledge.

\(^b\) Reverse keyed.

\(^c\) When the correlations among factors was controlled, relationship between item and factor close to 0.
Table 4.22.

*Coefficients and reliability for new factors describing Personal Epistemology derived from the sample.*

<table>
<thead>
<tr>
<th>Factor</th>
<th>Eigenvalue</th>
<th>% variance</th>
<th>Rotated loading</th>
<th>% variance</th>
<th>Items</th>
<th>Cronbach’s alpha</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.986</td>
<td>17.807</td>
<td>3.452</td>
<td>12.330</td>
<td>7</td>
<td>0.75</td>
<td>28.30</td>
<td>3.911</td>
</tr>
<tr>
<td>2</td>
<td>2.294</td>
<td>8.194</td>
<td>2.889</td>
<td>10.319</td>
<td>6</td>
<td>0.74</td>
<td>21.32</td>
<td>4.352</td>
</tr>
<tr>
<td>3</td>
<td>1.901</td>
<td>6.789</td>
<td>2.127</td>
<td>7.597</td>
<td>3</td>
<td>0.72</td>
<td>9.32</td>
<td>2.628</td>
</tr>
<tr>
<td>4</td>
<td>1.626</td>
<td>5.809</td>
<td>1.652</td>
<td>5.900</td>
<td>2</td>
<td>0.34</td>
<td>7.66</td>
<td>1.538</td>
</tr>
<tr>
<td>5</td>
<td>1.428</td>
<td>5.102</td>
<td>1.526</td>
<td>5.449</td>
<td>2</td>
<td>0.31</td>
<td>6.75</td>
<td>1.645</td>
</tr>
<tr>
<td>6</td>
<td>1.113</td>
<td>3.977</td>
<td>1.431</td>
<td>5.110</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>7</td>
<td>1.041</td>
<td>3.718</td>
<td>1.314</td>
<td>4.691</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

---

*Factors excluded from further analyses.*
Quick & Easy Knowledge. Factor 1 included seven items uncorrelated with other factors with loadings > 0.4 that represented a combination of the original Quick Learning and the Simple Knowledge sub-scales from the literature. The reliability of this new sub-scale was relatively high (Table 4.22). Factors 2 and 3 were nearly identical to the two sub-scales describing Innate Ability and Omniscient Authority, respectively. Variable names, New Innate and New Omniscient, were designated to reflect this similarity. The reliability of items comprising these two factors also was acceptable. The fourth factor, Complex Knowledge, included items that caused difficulties in the previous analyses, but with only two items comprising the component, reliability was low. The last factor considered was Idiosyncratic Knowledge, which also yielded fairly low reliability for the two items. Scores from a PCA were saved for these five factors.

Attitudes toward Evolution. – The scale describing students’ acceptance of evolution was highly reliable (Cronbach’s alpha = 0.90, 12 items, mean = 46.73, SD = 9.118, n = 474), but one item was problematic. One third of students did not answer the item that stated “The Second Law of Thermodynamics shows that evolution could not have happened.” On the paper and pencil version, many students commented that they did not even know what the law was, so this item was excluded from analyses. The final sub-scale was still highly reliable (Cronbach’s alpha = 0.89, 11 items; mean = 42.74, SD = 8.587, n = 520) and reduced to a single component (Table 4.23) that explained 49% of the variation in the original items.
Table 4.23.

*Factor coefficients for items in the Attitudes toward Evolution scale.*

<table>
<thead>
<tr>
<th>Items</th>
<th>Component 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>A supreme being (e.g., God) created humans pretty much in their present form; humans did not evolve from other forms of life (e.g., fish and/or reptiles).(^a)</td>
<td>0.840</td>
</tr>
<tr>
<td>There is no real evidence that humans evolved from other animals.(^a)</td>
<td>0.825</td>
</tr>
<tr>
<td>There is no fossil evidence supporting that humans and apes evolved from a common ancestor.(^a)</td>
<td>0.782</td>
</tr>
<tr>
<td>The Earth is not old enough for evolution to have taken place.(^a)</td>
<td>0.762</td>
</tr>
<tr>
<td>Over billions of years all plants and animals on Earth (including humans) descended (evolved) from a common ancestor (e.g., a one-celled organism).</td>
<td>0.718</td>
</tr>
<tr>
<td>Scientists who believe in evolution do so mainly because they want to, not because of any evidence.(^a)</td>
<td>0.685</td>
</tr>
<tr>
<td>There is scientific evidence supporting that humans were supernaturally created.(^a)</td>
<td>0.621</td>
</tr>
<tr>
<td>Mutations are never beneficial to animals.(^*)</td>
<td>0.477</td>
</tr>
<tr>
<td>It is statistically impossible that life arose by chance.(^a)</td>
<td>0.467</td>
</tr>
</tbody>
</table>

Eigenvalue 5.41

*Note:* n = 520.

\(^a\) Reverse keyed.
Understanding. NOS Understanding was measured with multiple choice answers that reflected a variety of students’ ideas. Although a single choice could be made for each question that reflected how most educators would view the NOS, several questions had numerous choices that indicated partial understanding of the topic and not necessarily a misunderstanding. I scored each “correct” answer with one point and each partial answer with 0.5 points. I summed points across all 15 questions. The resulting variable appeared relatively normally distributed (Figure 4.2), however Shapiro-Wilk indicated it was not ($W = 0.990; 713$ df; $p < 0.001$). The difference was due to the right skew (mean ± SE: -0.194 ± 0.092) and somewhat leptokurtotic distribution (mean ± SE: 0.019 ± 0.183). Standard transformations failed to improve normality issues, however.

*Figure 4.2. Distribution of students’ NOS Understanding scores (n = 714).*
Consistency of the Two Versions of CINS

I examined the mean total scores for the two versions of CINS (the original and the post-assessment version that had been modified with new organisms) to look for consistency between the two measures of evolution understanding using students not involved in the experimental manipulation. The distribution of scores indicated that the two versions might not be comparable metrics (Figure 4.3). In fact, the mean score for students taking the original CINS assessment was higher than the mean score for students taking the modified CINS assessment (10.9 ± 0.53 [mean ± SE] v. 9.4 ± 0.56; $t = 1.985$; 67 df; $p = 0.05$).

![Distribution of CINS scores for the original version of the CINS tool and the new, revised version used in the post-assessment (original: n = 36; modified: n = 33).](image)

*Figure 4.3.* Distribution of CINS scores for the original version of the CINS tool and the new, revised version used in the post-assessment (original: n = 36; modified: n = 33).
Effects of the Pre-assessment

The Post-assessment CINS scores did not differ among individuals taking the pre-assessment and individuals taking the post-assessment only (Table 4.24). Scores of UM Non-majors Biology students taking the post-assessment only were lower than those that had taken both the pre-assessment and post-assessment, as would be predicted if the pre-assessment had a positive priming effect. Conversely, the scores of UM Majors Biology students were opposite of that predicted given a positive priming effect. Although the error variances were not equal among the groups (Levene’s statistic = 8.142; 3, 452 df; \( p < 0.001 \)), the ratio of the largest to smallest variance was less than 3:1 and two-way ANOVA is less sensitive to issues of heterogeneity of variance than one-way ANOVA (Garson, 2009).

Table 4.24.

Mean post-assessment Total Scores of evolution understanding for individuals experiencing both the pre- and post-assessments versus the post-assessment only.

<table>
<thead>
<tr>
<th>Class</th>
<th>Pre-/Post-Assessment</th>
<th>Post-Assessment only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean</td>
</tr>
<tr>
<td>UM Non-majors Biology</td>
<td>99</td>
<td>10.3</td>
</tr>
<tr>
<td>UM Majors Biology</td>
<td>127</td>
<td>10.1</td>
</tr>
</tbody>
</table>

Note. \( F = 0.983; \ 3, 452 \text{ df}; \ p = 0.401 \).
Effects of *Fatal Flower* on Evolution Understanding

**Treatment Effects:** With the Solomon four-group design, some students taking both the pre-assessment and the post-assessment in classes at UM did not view any version of *Fatal Flower*. ANCOVA using Pre-assessment CINS scores as the covariate indicated that treatment did indeed have an effect ($F = 2.444; 4, 420 \text{ df}; p = 0.048$; Table 4.25). Students not watching any version of *Fatal Flower* had higher Post-Assessment CINS scores than those watching all versions of the nature program except for the New Imagery version. Parameter estimates indicated that both No Treatment and New Imagery had significant effects on the model, but the observed power was lower than the 0.80 considered acceptable to avoid a Type II error (0.714 and 0.615, respectively).

I also examined the three difference metrics using one-way ANOVA because pre-assessment and post-assessment scores were highly correlated ($r = 0.904$). Although differences (post-assessment score - pre-assessment score) did not differ (Table 4.26), the proportion of Changed Answers and the Correction Scale did vary among students experiencing the different treatments of *Fatal Flower*. These differences were driven by students watching the New Narrative/Imagery version who tended to change answers more often and to less correct responses more often than students watching other versions or none at all.

**Differences among Classes:** For students taking both the pre-assessment and the post-assessment, Pre-assessment and Post-assessment CINS scores differed among classes (assessment: $F = 4.227; 1, 776; p = 0.040$; class: $F = 35.726; 3, 776; p < 0.001$). The differences were due to lower scores on the post-assessment than on the pre-
Table 4.25.

*Estimated marginal means of Post-Assessment CINS using Pre-Assessment CINS as a covariate for each of the five treatments examining the effect of Fatal Flower on evolution understanding.*

<table>
<thead>
<tr>
<th>Treatment</th>
<th>n</th>
<th>Mean</th>
<th>SE</th>
<th>Lower bound</th>
<th>Upper bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Treatment</td>
<td>37</td>
<td>11.12</td>
<td>0.532</td>
<td>10.07</td>
<td>12.17</td>
</tr>
<tr>
<td>Original</td>
<td>48</td>
<td>10.39</td>
<td>0.467</td>
<td>9.47</td>
<td>11.31</td>
</tr>
<tr>
<td>New Narrative</td>
<td>48</td>
<td>9.70</td>
<td>0.468</td>
<td>8.78</td>
<td>10.63</td>
</tr>
<tr>
<td>New Imagery</td>
<td>43</td>
<td>10.82</td>
<td>0.499</td>
<td>9.83</td>
<td>11.80</td>
</tr>
<tr>
<td>New Narrative/Imagery</td>
<td>50</td>
<td>9.28</td>
<td>0.458</td>
<td>8.38</td>
<td>10.18</td>
</tr>
</tbody>
</table>

assessment, and higher scores on both assessments for the class at MSU than other classes (Figure 4.4). The effect of class also was significant when examining the difference scores (Table 4.27). Likewise, the proportion of changed answers between pre- and post-assessments differed among classes, as did the Correction Scale (Table 4.27). Students in UM Majors Biology tended to have a higher proportion of changed answers between the pre- and post-assessment, and students in the MSU class a lower proportion, than students in either UM Non-majors Biology or the EWU class. Despite changing answers frequently, UM Majors Biology students generally did not change to correct responses in the post-assessment; MSU students generally changed to correct answers (Table 4.27).
Table 4.26.

Mean Difference, Changed Answers, and Correction Scale for tests of evolution understanding of students experiencing both the pre-assessment and the post-assessment and different versions of Fatal Flower.

<table>
<thead>
<tr>
<th>Class</th>
<th>n</th>
<th>Mean</th>
<th>SE</th>
<th>Changed Answers</th>
<th>Mean</th>
<th>SE</th>
<th>Correction Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Treatment</td>
<td>37</td>
<td>0.27</td>
<td>0.440</td>
<td>0.35</td>
<td>0.029</td>
<td>0.72</td>
<td>0.018</td>
</tr>
<tr>
<td>Original</td>
<td>48</td>
<td>-0.38</td>
<td>0.494</td>
<td>0.45</td>
<td>0.034</td>
<td>0.68</td>
<td>0.020</td>
</tr>
<tr>
<td>New Narrative</td>
<td>48</td>
<td>-1.02</td>
<td>0.453</td>
<td>0.48</td>
<td>0.029</td>
<td>0.65</td>
<td>0.018</td>
</tr>
<tr>
<td>New Imagery</td>
<td>43</td>
<td>-0.26</td>
<td>0.580</td>
<td>0.39</td>
<td>0.037</td>
<td>0.72</td>
<td>0.022</td>
</tr>
<tr>
<td>New Narrative/Imagery</td>
<td>50</td>
<td>-1.52</td>
<td>0.467</td>
<td>0.51</td>
<td>0.032</td>
<td>0.64</td>
<td>0.018</td>
</tr>
</tbody>
</table>

\(^a\) F = 1.969; 4, 221; p = 0.100.

\(^b\) F = 3.617; 4, 221; p = 0.007.

\(^c\) F = 3.359; 4, 221; p = 0.011.
Differences among Versions: No differences among versions were detected when Post-assessment CINS scores were examined using ANCOVA and Pre-assessment Scores as the covariate ($F = 0.609; 3, 338 \text{ df}; p = 0.610$). Classes differed significantly, however ($F = 3.992; 3, 338 \text{ df}; p = 0.008$). Graphing the estimated marginal means indicated that indeed evolution understanding may have been changing differently among classes (Figure 4.5). MSU students scored better on the Post-assessment CINS after watching the versions with new narrative and poorer after watching versions with the original narrative. Students at UM, however, seemed to perform better on the Post-assessment CINS after watching versions with the original narrative (Original and New Imagery) and worse after watching versions with the revised narrative (New Narrative...
Table 4.27.

*Mean Difference, Changed Answers, and Correction Scale for tests of evolution understanding of students experiencing both the pre-assessment and the post-assessment.*

<table>
<thead>
<tr>
<th>Class</th>
<th>n</th>
<th>Mean</th>
<th>SE</th>
<th>Mean</th>
<th>SE</th>
<th>Mean</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>UM Non-majors Biology</td>
<td>99</td>
<td>-0.4</td>
<td>0.28</td>
<td>0.39</td>
<td>0.018</td>
<td>0.69</td>
<td>0.012</td>
</tr>
<tr>
<td>UM Majors Biology</td>
<td>127</td>
<td>-0.8</td>
<td>0.33</td>
<td>0.48</td>
<td>0.022</td>
<td>0.67</td>
<td>0.013</td>
</tr>
<tr>
<td>EWU</td>
<td>49</td>
<td>-1.2</td>
<td>0.37</td>
<td>0.43</td>
<td>0.029</td>
<td>0.69</td>
<td>0.018</td>
</tr>
<tr>
<td>MSU</td>
<td>117</td>
<td>-0.1</td>
<td>0.23</td>
<td>0.29</td>
<td>0.017</td>
<td>0.79</td>
<td>0.011</td>
</tr>
</tbody>
</table>

\(^a\) Welch’s statistic = 2.807; 3, 173.042; \(p > 0.041\).

\(^b\) Welch’s statistic = 16.710; 3, 170.026; \(p > 0.001\).

\(^c\) Welch’s statistic = 19.849; 3, 170.080; \(p > 0.001\).

and New Narrative/Imagery). Students at EWU scored higher after watching any of the revised versions of the program than the original version.

Using the difference metrics with two-way ANOVA supported the idea that class was differentially affecting evolution understanding. Differences between the two assessments for each individual did not vary among class or version (class: \(F = 2.033; 3, 339\) df; \(p = 0.109\); version: \(F = 0.486; 3, 339\) df; \(p = 0.692\)), but the proportion of Changed Answers was lower (\(F = 16.984; 3, 339\) df; \(p < 0.001\); Figure 4.6) and the Correction Scale was higher (\(F = 19.535; 3, 339\) df; \(p < 0.001\); Figure 4.7) for students at Michigan State than in other classes. Homogeneity of variances was an issue with these
Figure 4.5. Estimated marginal means of Post-assessment CINS scores for each class and version of *Fatal Flower*.

Figure 4.6. Estimated marginal means of Changed Answer scores for each class and version of *Fatal Flower*.
analyses, but the ratio of the largest to smallest variance was relatively small in all cases (Garson, 2009).

Effects of Attitudes and Beliefs

The covariates addressing attitudes and beliefs affected outcomes of the experimental treatments differently. The class at MSU was examined separately because previous analyses indicated students may have been responding differently there than in the other classes. Difference metrics for students from the class at MSU rarely were influenced by any of the attitudes and beliefs scales, however.

Figure 4.7. Estimated marginal means of Correction Scale scores for each class and version of Fatal Flower.
**Attitudes toward Science**: Neither the original Attitudes toward Science sub-scales (Table 4.28) nor the sub-scales derived from the data (Table 4.29) were significant predictors of evolution understanding for students at MSU. For students in the other classes, variation was evident. Career Interest was a significant predictor of Difference scores between post-assessment and pre-assessment scores, and Adoption of Attitudes was a significant predictor of both the proportion of Changed Answers and Correction Scale (Table 4.30), as were General Interest, New Implications, and New Attitudes from the sub-scales derived from the data (Table 4.31). In addition, these covariates affected the outcomes of the different versions of the nature program. Difference scores became more positive for students watching the New Imagery version and more negative for students watching other versions, indicating a decrease in post-assessment scores from pre-assessment scores (Table 4.32). The effect was similar when the sub-scales derived from the data were used as covariates (Table 4.33). Correction Scale of students watching the version New Narrative/Imagery version increased after adjustment for the derived attitudes toward science sub-scales, whereas scores of students watching other versions decreased (Table 4.34).
Table 4.28.

Results of ANCOVA using the Attitudes toward Science sub-scales to predict difference metrics for evolution understanding for students in the MSU class taking both the pre-assessment and the post-assessment.

<table>
<thead>
<tr>
<th>Sub-scale</th>
<th>Difference</th>
<th></th>
<th></th>
<th></th>
<th>Changed Answers</th>
<th></th>
<th></th>
<th></th>
<th>Correction Scale</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$r^2$</td>
<td>$F$</td>
<td>$p$</td>
<td>$r^2$</td>
<td>$F$</td>
<td>$p$</td>
<td>$r^2$</td>
<td>$F$</td>
<td>$p$</td>
<td>$r^2$</td>
<td>$F$</td>
</tr>
<tr>
<td>Career Interest</td>
<td></td>
<td>0.021</td>
<td>0.959</td>
<td>0.333</td>
<td>0.001</td>
<td>0.055</td>
<td>0.816</td>
<td>0.011</td>
<td>0.509</td>
<td>0.480</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enjoyment</td>
<td></td>
<td>0.065</td>
<td>3.075</td>
<td>0.086</td>
<td>0.002</td>
<td>0.079</td>
<td>0.780</td>
<td>0.040</td>
<td>1.843</td>
<td>0.182</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leisure Interest</td>
<td></td>
<td>0.002</td>
<td>0.073</td>
<td>0.788</td>
<td>0.034</td>
<td>1.535</td>
<td>0.222</td>
<td>0.007</td>
<td>0.308</td>
<td>0.582</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adoption of Attitudes</td>
<td></td>
<td>0.017</td>
<td>0.772</td>
<td>0.384</td>
<td>0.000</td>
<td>0.021</td>
<td>0.885</td>
<td>0.000</td>
<td>0.001</td>
<td>0.972</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attitudes toward Inquiry</td>
<td></td>
<td>0.012</td>
<td>0.514</td>
<td>0.477</td>
<td>0.006</td>
<td>0.251</td>
<td>0.619</td>
<td>0.005</td>
<td>0.200</td>
<td>0.657</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social Implications</td>
<td></td>
<td>0.008</td>
<td>0.341</td>
<td>0.562</td>
<td>0.070</td>
<td>3.332</td>
<td>0.075</td>
<td>0.034</td>
<td>1.557</td>
<td>0.219</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normality of Scientists</td>
<td></td>
<td>0.033</td>
<td>1.487</td>
<td>0.229</td>
<td>0.001</td>
<td>0.046</td>
<td>0.831</td>
<td>0.003</td>
<td>0.121</td>
<td>0.730</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Version</td>
<td></td>
<td>0.088</td>
<td>1.409</td>
<td>0.253</td>
<td>0.067</td>
<td>1.048</td>
<td>0.381</td>
<td>0.054</td>
<td>0.832</td>
<td>0.484</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. 1, 44 df.
Table 4.29.

*Results of ANCOVA using the sub-scales derived from the data describing attitudes toward science to predict difference metrics for evolution understanding for students in the MSU class taking both the pre-assessment and the post-assessment.*

<table>
<thead>
<tr>
<th>Sub-scale</th>
<th>Difference</th>
<th>Changed Answers</th>
<th>Correction Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$r^2$</td>
<td>F</td>
<td>p</td>
</tr>
<tr>
<td>General Interest</td>
<td>0.000</td>
<td>0.023</td>
<td>0.880</td>
</tr>
<tr>
<td>New Implications</td>
<td>0.020</td>
<td>1.160</td>
<td>0.286</td>
</tr>
<tr>
<td>New Attitudes</td>
<td>0.001</td>
<td>0.037</td>
<td>0.849</td>
</tr>
<tr>
<td>New Inquiry</td>
<td>0.045</td>
<td>2.627</td>
<td>0.111</td>
</tr>
<tr>
<td>Version</td>
<td>0.055</td>
<td>1.090</td>
<td>0.361</td>
</tr>
</tbody>
</table>

*Note.* 1, 56 df.
Table 4.30.

*Results of ANCOVA using the Attitudes toward Science sub-scales to predict difference metrics for evolution understanding for students at UM and EWU classes taking both the pre-assessment and the post-assessment.*

<table>
<thead>
<tr>
<th>Sub-scale</th>
<th>Difference</th>
<th></th>
<th></th>
<th></th>
<th>Changed Answers</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Correction Scale</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r²</td>
<td>F</td>
<td>p</td>
<td></td>
<td>r²</td>
<td>F</td>
<td>p</td>
<td></td>
<td>r²</td>
<td>F</td>
<td>p</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Career Interest</td>
<td>0.043</td>
<td>5.728</td>
<td>0.018</td>
<td></td>
<td>0.016</td>
<td>2.142</td>
<td>0.146</td>
<td></td>
<td>0.027</td>
<td>3.507</td>
<td>0.063</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enjoyment</td>
<td>0.009</td>
<td>1.194</td>
<td>0.277</td>
<td></td>
<td>0.002</td>
<td>0.206</td>
<td>0.651</td>
<td></td>
<td>0.004</td>
<td>0.554</td>
<td>0.458</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leisure Interest</td>
<td>0.005</td>
<td>0.605</td>
<td>0.438</td>
<td></td>
<td>0.002</td>
<td>0.252</td>
<td>0.616</td>
<td></td>
<td>0.000</td>
<td>0.004</td>
<td>0.949</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adoption of Attitudes</td>
<td>0.000</td>
<td>0.001</td>
<td>0.970</td>
<td></td>
<td>0.103</td>
<td>14.682</td>
<td>&lt;0.001</td>
<td></td>
<td>0.061</td>
<td>8.309</td>
<td>0.005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attitudes toward Inquiry</td>
<td>0.000</td>
<td>0.025</td>
<td>0.876</td>
<td></td>
<td>0.001</td>
<td>0.090</td>
<td>0.764</td>
<td></td>
<td>0.000</td>
<td>0.063</td>
<td>0.802</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social Implications</td>
<td>0.006</td>
<td>0.819</td>
<td>0.367</td>
<td></td>
<td>0.001</td>
<td>0.137</td>
<td>0.712</td>
<td></td>
<td>0.001</td>
<td>0.154</td>
<td>0.696</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normality of Scientists</td>
<td>0.011</td>
<td>1.370</td>
<td>0.244</td>
<td></td>
<td>0.011</td>
<td>1.410</td>
<td>0.237</td>
<td></td>
<td>0.011</td>
<td>1.407</td>
<td>0.238</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Version</td>
<td>0.075</td>
<td>3.469</td>
<td>0.018</td>
<td></td>
<td>0.042</td>
<td>1.873</td>
<td>0.137</td>
<td></td>
<td>0.048</td>
<td>2.129</td>
<td>0.100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* 1, 128 df.
Table 4.31.

Results of ANCOVA using the sub-scales derived from the data describing attitudes toward science to predict difference metrics for evolution understanding for students at UM and EWU classes taking both the pre-assessment and the post-assessment.

<table>
<thead>
<tr>
<th>Sub-scale</th>
<th>Difference</th>
<th></th>
<th></th>
<th></th>
<th>Changed Answers</th>
<th></th>
<th></th>
<th></th>
<th>Correction Scale</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$r^2$</td>
<td>$F$</td>
<td>$p$</td>
<td>$r^2$</td>
<td>$F$</td>
<td>$p$</td>
<td>$r^2$</td>
<td>$F$</td>
<td>$p$</td>
<td>$r^2$</td>
<td>$F$</td>
</tr>
<tr>
<td>General Interest</td>
<td>0.008</td>
<td>1.046</td>
<td>0.308</td>
<td>0.038</td>
<td>5.462</td>
<td>0.021</td>
<td>0.063</td>
<td>9.311</td>
<td>0.003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Implications</td>
<td>0.001</td>
<td>0.110</td>
<td>0.741</td>
<td>0.052</td>
<td>7.495</td>
<td>0.007</td>
<td>0.050</td>
<td>7.319</td>
<td>0.008</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Attitudes</td>
<td>0.002</td>
<td>0.278</td>
<td>0.599</td>
<td>0.090</td>
<td>13.687</td>
<td>&lt;0.001</td>
<td>0.053</td>
<td>7.676</td>
<td>0.006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Inquiry</td>
<td>0.000</td>
<td>0.042</td>
<td>0.838</td>
<td>0.002</td>
<td>0.256</td>
<td>0.614</td>
<td>0.002</td>
<td>0.261</td>
<td>0.610</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Version</td>
<td>0.069</td>
<td>3.384</td>
<td>0.020</td>
<td>0.046</td>
<td>2.234</td>
<td>0.087</td>
<td>0.065</td>
<td>3.184</td>
<td>0.026</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. 1, 138 df.
Table 4.32.
Unadjusted and estimated marginal means adjusted by the Attitudes toward Science sub-scales for Difference scores for students in classes at UM and EWU.

<table>
<thead>
<tr>
<th>Version</th>
<th>n</th>
<th>Unadjusted Mean</th>
<th>Unadjusted SE</th>
<th>Adjusted Mean</th>
<th>Adjusted SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>40</td>
<td>-0.750</td>
<td>0.619</td>
<td>-0.889</td>
<td>0.518</td>
</tr>
<tr>
<td>New Narrative</td>
<td>34</td>
<td>-1.029</td>
<td>0.507</td>
<td>-1.007</td>
<td>0.559</td>
</tr>
<tr>
<td>New Imagery</td>
<td>24</td>
<td>1.083</td>
<td>0.586</td>
<td>1.359</td>
<td>0.685</td>
</tr>
<tr>
<td>New Narrative/Imagery</td>
<td>41</td>
<td>-1.195</td>
<td>0.442</td>
<td>-1.240</td>
<td>0.505</td>
</tr>
</tbody>
</table>

Table 4.33.
Unadjusted and estimated marginal means adjusted by the sub-scales derived from the data describing attitudes toward science for Difference scores for students in classes at UM and EWU.

<table>
<thead>
<tr>
<th>Version</th>
<th>n</th>
<th>Unadjusted Mean</th>
<th>Unadjusted SE</th>
<th>Adjusted Mean</th>
<th>Adjusted SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>40</td>
<td>-0.683</td>
<td>0.597</td>
<td>-0.720</td>
<td>0.503</td>
</tr>
<tr>
<td>New Narrative</td>
<td>34</td>
<td>-1.250</td>
<td>0.465</td>
<td>-1.244</td>
<td>0.536</td>
</tr>
<tr>
<td>New Imagery</td>
<td>24</td>
<td>0.962</td>
<td>0.556</td>
<td>0.985</td>
<td>0.630</td>
</tr>
<tr>
<td>New Narrative/Imagery</td>
<td>41</td>
<td>-1.395</td>
<td>0.447</td>
<td>-1.380</td>
<td>0.488</td>
</tr>
</tbody>
</table>
Table 4.34.

*Unadjusted and estimated marginal means adjusted by the sub-scales derived from the data describing attitudes toward science for Correction Scale for students in classes at UM and EWU.*

<table>
<thead>
<tr>
<th>Version</th>
<th>n</th>
<th>Unadjusted Mean</th>
<th>SE</th>
<th>Adjusted Mean</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>40</td>
<td>0.664</td>
<td>0.020</td>
<td>0.662</td>
<td>0.018</td>
</tr>
<tr>
<td>New Narrative</td>
<td>34</td>
<td>0.669</td>
<td>0.018</td>
<td>0.667</td>
<td>0.019</td>
</tr>
<tr>
<td>New Imagery</td>
<td>24</td>
<td>0.746</td>
<td>0.023</td>
<td>0.745</td>
<td>0.023</td>
</tr>
<tr>
<td>New Narrative/Imagery</td>
<td>41</td>
<td>0.671</td>
<td>0.021</td>
<td>0.675</td>
<td>0.018</td>
</tr>
</tbody>
</table>

**Personal Epistemology:** The Personal Epistemology sub-scales derived from the literature generally were not important predictors of evolution understanding for students in the MSU class (Table 4.35). The Simple Knowledge sub-scale was related to Correction Scale, however. Quick Learning affected Difference scores for students in the classes at UM and EWU, and Simple Knowledge was an important predictor for Changed Answers and Correction Scale (Table 4.36).

Moreover, several of the Personal Epistemology sub-scales interacted with the factor Version. For example, Innate Authority had a steeper slope when examining Correction Scale scores of students at UM and EWU watching the New Narrative version than other versions. The difference was relatively small, however, and was likely not reflected in the full factorial ANCOVA. This type of interaction was more common.
using the sub-scales for personal epistemology derived from the data, and several had to be examined independently.

The sub-scales describing personal epistemology that were derived from the sample data were not important predictors of Difference scores for students from MSU (Table 4.37) nor UM and EWU (Table 4.38). Quick & Easy Knowledge was an important predictor for both the proportion of Changed Answers and Correction Scale for both the class at MSU and classes at UM and EWU, but with the MSU sample, this covariate violated assumptions about the homogeneity of regression slopes among versions of the nature program. Regression using the Quick & Easy Knowledge sub-scale indicated a more positive relationship with Changed Answers for students at MSU watching the New Narrative/Imagery version than with other versions. Those students changed answers more frequently than students watching other versions (Table 4.39), indicating that the more they accepted that knowledge was not quickly and easily obtained, the more likely they were to change answers given a correct presentation of evolution. Correction Scale scores also were more positively related to the Quick & Easy Knowledge sub-scale for versions including the new narrative, indicating more advanced thinking about knowledge for both New Narrative and New Narrative/Imagery than versions with the old narrative (Table 4.40). Although ANCOVA indicated New Innate, New Omniscient, and Certain Knowledge interacted significantly with Version, they were not important in the full factorial model and their slopes were not significant when examined separately.
Table 4.35.

Results of ANCOVA using the Personal Epistemology sub-scales to predict difference metrics for evolution understanding for students at MSU classes taking both the pre-assessment and the post-assessment.

<table>
<thead>
<tr>
<th>Sub-scale</th>
<th>Difference</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r²</td>
<td>F</td>
<td>p</td>
<td>r²</td>
</tr>
<tr>
<td>Innate Ability</td>
<td>0.013</td>
<td>1.009</td>
<td>0.319</td>
<td>0.004</td>
</tr>
<tr>
<td>Omniscient Authority</td>
<td>0.006</td>
<td>0.440</td>
<td>0.509</td>
<td>0.007</td>
</tr>
<tr>
<td>Quick Learning</td>
<td>0.001</td>
<td>0.077</td>
<td>0.782</td>
<td>0.026</td>
</tr>
<tr>
<td>Certain Knowledge</td>
<td>0.014</td>
<td>1.059</td>
<td>0.307</td>
<td>0.000</td>
</tr>
<tr>
<td>Simple Knowledge</td>
<td>0.029</td>
<td>2.183</td>
<td>0.144</td>
<td>0.017</td>
</tr>
<tr>
<td>Version</td>
<td>0.018</td>
<td>0.440</td>
<td>0.725</td>
<td>0.022</td>
</tr>
</tbody>
</table>

Note. 1, 74 df
Table 4.36.

Results of ANCOVA using the Personal Epistemology sub-scales to predict difference metrics for evolution understanding for students in classes at UM and EWU taking both the pre-assessment and the post-assessment.

<table>
<thead>
<tr>
<th>Sub-scale</th>
<th>Difference</th>
<th>Changed Answers</th>
<th>Correction Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r²</td>
<td>F</td>
<td>p</td>
</tr>
<tr>
<td>Innate Ability</td>
<td>0.002</td>
<td>0.350</td>
<td>0.555</td>
</tr>
<tr>
<td>Omniscient Authority</td>
<td>0.000</td>
<td>0.063</td>
<td>0.802</td>
</tr>
<tr>
<td>Quick Learning</td>
<td>0.029</td>
<td>5.392</td>
<td>0.021</td>
</tr>
<tr>
<td>Certain Knowledge</td>
<td>0.001</td>
<td>0.232</td>
<td>0.631</td>
</tr>
<tr>
<td>Simple Knowledge</td>
<td>0.011</td>
<td>2.029</td>
<td>0.156</td>
</tr>
<tr>
<td>Version</td>
<td>0.038</td>
<td>2.373</td>
<td>0.072</td>
</tr>
</tbody>
</table>

Note. 1, 178 df.
Table 4.37.

*Results of ANCOVA using the sub-scales derived from the data to describe personal epistemology to predict difference metrics for evolution understanding for students at MSU classes taking both the pre-assessment and the post-assessment.*

<table>
<thead>
<tr>
<th>Sub-scale</th>
<th>Difference</th>
<th></th>
<th>Changed Answers</th>
<th></th>
<th>Correction Scale</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$r^2$</td>
<td>$F$</td>
<td>$p$</td>
<td>$r^2$</td>
<td>$F$</td>
<td>$p$</td>
</tr>
<tr>
<td>Quick &amp; Easy Knowledge</td>
<td>0.019</td>
<td>1.086</td>
<td>0.302</td>
<td>0.160</td>
<td>10.471$^a$</td>
<td>0.002</td>
</tr>
<tr>
<td>New Innate</td>
<td>0.000</td>
<td>0.005</td>
<td>0.944</td>
<td>0.002</td>
<td>0.097</td>
<td>0.756</td>
</tr>
<tr>
<td>New Omniscient</td>
<td>0.007</td>
<td>0.360</td>
<td>0.551</td>
<td>0.015</td>
<td>0.842</td>
<td>0.363</td>
</tr>
<tr>
<td>Certain Knowledge</td>
<td>0.028</td>
<td>1.561</td>
<td>0.217</td>
<td>0.045</td>
<td>2.583</td>
<td>0.114</td>
</tr>
<tr>
<td>Idiosyncratic Knowledge</td>
<td>0.010</td>
<td>0.566</td>
<td>0.455</td>
<td>0.008</td>
<td>0.442</td>
<td>0.509</td>
</tr>
<tr>
<td>Version</td>
<td>0.023</td>
<td>0.430</td>
<td>0.732</td>
<td>0.011</td>
<td>0.212</td>
<td>0.887</td>
</tr>
</tbody>
</table>

*Note.* 1, 55 df.

$^a$ Significant covariate-factor interaction.
Table 4.38.

Results of ANCOVA using the sub-scales derived from the data to describe personal epistemology to predict difference metrics for evolution understanding for students in classes at UM and EWU taking both the pre-assessment and the post-assessment.

<table>
<thead>
<tr>
<th>Sub-scale</th>
<th>Difference</th>
<th></th>
<th></th>
<th>Changed Answers</th>
<th></th>
<th></th>
<th>Correction Scale</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r²</td>
<td>F</td>
<td>p</td>
<td>r²</td>
<td>F</td>
<td>p</td>
<td>r²</td>
<td>F</td>
<td>p</td>
</tr>
<tr>
<td>Quick &amp; Easy Knowledge</td>
<td>0.016</td>
<td>2.470</td>
<td>0.118</td>
<td>0.111</td>
<td>19.178</td>
<td>&lt;0.001</td>
<td>0.075</td>
<td>12.491</td>
<td>0.001</td>
</tr>
<tr>
<td>New Innate</td>
<td>0.001</td>
<td>0.226</td>
<td>0.635</td>
<td>0.004</td>
<td>0.588</td>
<td>0.445</td>
<td>0.002</td>
<td>0.302</td>
<td>0.583</td>
</tr>
<tr>
<td>New Omniscient</td>
<td>0.001</td>
<td>0.103</td>
<td>0.749</td>
<td>0.024</td>
<td>3.837</td>
<td>0.052</td>
<td>0.037</td>
<td>5.808</td>
<td>0.017</td>
</tr>
<tr>
<td>Certain Knowledge</td>
<td>0.001</td>
<td>0.145</td>
<td>0.704</td>
<td>0.003</td>
<td>0.409</td>
<td>0.523</td>
<td>0.003</td>
<td>0.487</td>
<td>0.487</td>
</tr>
<tr>
<td>Idiosyncratic Knowledge</td>
<td>0.001</td>
<td>0.144</td>
<td>0.705</td>
<td>0.024</td>
<td>3.827</td>
<td>0.052</td>
<td>0.016</td>
<td>2.444</td>
<td>0.120</td>
</tr>
<tr>
<td>Version</td>
<td>0.035</td>
<td>1.830</td>
<td>0.144</td>
<td>0.024</td>
<td>1.254</td>
<td>0.292</td>
<td>0.033</td>
<td>1.749</td>
<td>0.159</td>
</tr>
</tbody>
</table>

*Note.* 1, 178 df.

* Significant covariate-factor interaction.
Table 4.39.

Regression analysis using Quick & Easy Knowledge to predict Changed Answer scores for students in the MSU class.

<table>
<thead>
<tr>
<th>Version</th>
<th>F</th>
<th>df</th>
<th>p</th>
<th>r²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>0.163</td>
<td>1, 17</td>
<td>0.692</td>
<td>0.010</td>
</tr>
<tr>
<td>New Narrative</td>
<td>3.432</td>
<td>1, 13</td>
<td>0.089</td>
<td>0.222</td>
</tr>
<tr>
<td>New Imagery</td>
<td>2.777</td>
<td>1, 17</td>
<td>0.115</td>
<td>0.148</td>
</tr>
<tr>
<td>New Narrative/Imagery</td>
<td>6.057</td>
<td>1, 13</td>
<td>0.030</td>
<td>0.335</td>
</tr>
</tbody>
</table>

Table 4.40.

Regression analysis using Quick & Easy Knowledge to predict Correction Scale scores for students in the MSU class.

<table>
<thead>
<tr>
<th>Version</th>
<th>F</th>
<th>df</th>
<th>p</th>
<th>r²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>2.332</td>
<td>1, 17</td>
<td>0.146</td>
<td>0.127</td>
</tr>
<tr>
<td>New Narrative</td>
<td>5.859</td>
<td>1, 13</td>
<td>0.032</td>
<td>0.328</td>
</tr>
<tr>
<td>New Imagery</td>
<td>4.453</td>
<td>1, 17</td>
<td>0.051</td>
<td>0.218</td>
</tr>
<tr>
<td>New Narrative/Imagery</td>
<td>11.794</td>
<td>1, 13</td>
<td>0.005</td>
<td>0.496</td>
</tr>
</tbody>
</table>
Attitude towards Evolution: As with other covariates, Attitude toward Evolution did not seem to affect Difference scores for either the MSU class or the UM and EWU classes (Table 4.41). Attitude towards Evolution was an important predictor for both the proportion of Changed Answers and the Correction Scale for students in the MSU class, however. Similarly, for students in classes at UM and EWU, this scale also was important for Changed Answers and Correction Scale, but not for Difference scores. In addition, the covariate influenced the relationships between Correction Scale scores and version. Post-assessment evolution understanding scores were more incorrect for students watching the New Imagery version than for other versions (Table 4.42).

NOS Understanding: Likewise, NOS Understanding was not an important predictor for Difference scores for either set of classes, but served to predict both Changed Answers and Correction Scale for students in both the MSU class and students in classes at UM and EWU (Table 4.43). Adjusting for the covariates did not affect the influence of Version on student understanding, however.

Open-ended Questions and Evolution Understanding

Responses to the open-ended evolution questions were classified according to a framework developed by Perkins (unpubl., see Chapter 3). Students’ answers were often quite short and usually represented a single concept. Not all students answered all questions, nor did they necessarily include similar concepts among questions. As a result, analysis was limited to broad generalizations designed to provide some insight to student thinking.
Table 4.41.

*Results of ANCOVA using the Attitude toward Evolution scale to predict difference metrics for evolution understanding for students in classes taking both the pre-assessment and the post-assessment.*

<table>
<thead>
<tr>
<th>Class</th>
<th>Difference</th>
<th></th>
<th></th>
<th>Changed Answers</th>
<th></th>
<th></th>
<th>Correction Scale</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>df</td>
<td>p</td>
<td>r²</td>
<td>F</td>
<td>df</td>
<td>p</td>
<td>r²</td>
<td>F</td>
</tr>
<tr>
<td>MSU</td>
<td>2.013</td>
<td>1, 58</td>
<td>0.161</td>
<td>0.034</td>
<td>12.881</td>
<td>1, 58</td>
<td>0.001</td>
<td>0.182</td>
<td>19.657</td>
</tr>
<tr>
<td>UM &amp; EWU</td>
<td>0.531</td>
<td>1, 170</td>
<td>0.467</td>
<td>0.003</td>
<td>15.672</td>
<td>1, 170</td>
<td>&lt;0.001</td>
<td>0.084</td>
<td>16.634</td>
</tr>
</tbody>
</table>
Table 4.42.

Unadjusted and estimated marginal means adjusted by Attitude towards Evolution for Correction Scale for students in classes at UM and EWU.

<table>
<thead>
<tr>
<th>Version</th>
<th>n</th>
<th>Unadjusted Mean</th>
<th>Unadjusted SE</th>
<th>Adjusted Mean</th>
<th>Adjusted SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>40</td>
<td>0.665</td>
<td>0.019</td>
<td>0.675</td>
<td>0.019</td>
</tr>
<tr>
<td>New Narrative</td>
<td>34</td>
<td>0.671</td>
<td>0.019</td>
<td>0.668</td>
<td>0.019</td>
</tr>
<tr>
<td>New Imagery</td>
<td>24</td>
<td>0.751</td>
<td>0.021</td>
<td>0.740</td>
<td>0.021</td>
</tr>
<tr>
<td>New Narrative/Imagery</td>
<td>41</td>
<td>0.667</td>
<td>0.020</td>
<td>0.669</td>
<td>0.018</td>
</tr>
</tbody>
</table>

The open-ended evolution questions indicated that students held a diversity of concepts about the evolutionary process, including misconceptions, proximate conceptions (less abstract, individual-level concepts), and evolutionary concepts (more abstract, population-level concepts; see Chapter 3 for more details). Generally, a greater number of each kind of concept, on average, was included in response to the post-assessment question related to Fatal Flower than the literature-based pre-assessment questions (Table 4.44). Misconceptions increased between pre- and post-assessments for all individuals, but evolutionary conceptions seemed to increase more for students that watched the new narrative version of the program than other versions.

In addition to the open-ended evolution questions, students were asked whether the imagery or story had a particular effect on their understanding. Broadly grouping individuals into “yes” and “no” permitted another approach to determining the effect of
Table 4.43.

Results of ANCOVA using the NOS Understanding scale to predict difference metrics for evolution understanding for students in classes taking both the pre-assessment and the post-assessment.

<table>
<thead>
<tr>
<th>Class</th>
<th>Difference</th>
<th></th>
<th></th>
<th>Changed Answers</th>
<th></th>
<th></th>
<th></th>
<th>Correction Scale</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>df</td>
<td>p</td>
<td>r²</td>
<td>F</td>
<td>df</td>
<td>p</td>
<td>r²</td>
<td>F</td>
<td>df</td>
</tr>
<tr>
<td>MSU</td>
<td>1.658</td>
<td>1, 112</td>
<td>0.201</td>
<td>0.015</td>
<td>15.563</td>
<td>1, 112</td>
<td>&lt;0.001</td>
<td>0.122</td>
<td>21.305</td>
<td>1, 112</td>
</tr>
<tr>
<td>UM &amp; EWU</td>
<td>3.790</td>
<td>1, 233</td>
<td>0.053</td>
<td>0.016</td>
<td>46.126</td>
<td>1, 233</td>
<td>&lt;0.001</td>
<td>0.165</td>
<td>45.480</td>
<td>1, 233</td>
</tr>
</tbody>
</table>
viewing on evolution understanding. Students’ responses to the effect of imagery significantly contributed to the model of evolution understanding ($F = 4.258; 1, 269 \text{ df}; p = 0.040$). In addition, students that believed the imagery helped their understanding tended to have higher assessment scores than those who did not.

**Discussion**

**Attitudes and Beliefs**

Clearly, examining attitudes, beliefs, and understanding is a complex process not easily addressed with standardized instruments. My goal was not to develop scales, but to use previously published metrics addressing attitudes and beliefs about science. Nevertheless, this research provides some insight to the consistency of several metrics important in the literature, the relationships among these metrics, and their value as predictors related to evolution understanding. These scales are not without their criticism, especially the examination of NOS Understanding (e.g., Aikenhead, Ryan, & Fleming, 1989; Lederman & O’Malley, 1990). The means used to construct scales are critical to their validity (Aikenhead, 1988). Because these scales are supposed to describe theoretical constructs, part of the intrigue of using tried and tested metrics in educational research is to predict outcomes of experimental treatment, not just to describe student thinking.

This research supported several theory-bound scales but highlighted difficulties with others. Helms et al. (2006) urged that items from theoretical constructs be dropped only after careful consideration because dropping items implies that reliability is a characteristic of the scale rather than the sample, and it encourages heavy reliance on
Table 4.44.

The mean number of misconceptions, proximate conceptions (less abstract individual-level concepts), and evolutionary concepts (more abstract, population-level concepts) found in students’ short answers to standard open-ended questions about the evolutionary process.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>n</th>
<th>Misconceptions</th>
<th>Proximate Conceptions</th>
<th>Evolutionary Conceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Difference</td>
</tr>
<tr>
<td>Original</td>
<td>70</td>
<td>0.8</td>
<td>1.0</td>
<td>0.2</td>
</tr>
<tr>
<td>New Narrative</td>
<td>61</td>
<td>0.7</td>
<td>1.1</td>
<td>0.3</td>
</tr>
<tr>
<td>New Imagery</td>
<td>69</td>
<td>0.6</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>New Narrative/Imagery</td>
<td>69</td>
<td>0.8</td>
<td>1.0</td>
<td>0.2</td>
</tr>
</tbody>
</table>
these point estimates of reliability in judging the data’s worthiness. As a result, I took two approaches to scale analyses. The first used the scales and sub-scales as they were originally described. The second examined the relationships within this particular sample.

Several scales describing Attitudes toward Science, Personal Epistemology, Attitudes toward Evolution, and NOS Understanding were employed to examine the effects of watching a nature program on subsequent evolution understanding. The scales served to characterize students participating in the experiment based on the assumption that these characteristics would not change during its short duration. The Attitudes toward Science (Adolphe, 2002; Fraser, 1981) and its seven sub-scales proved quite dependable (one sub-scale was not), with generally high reliability and strong suites of items that could be reduced to a single component fairly easily. These components were highly intercorrelated, and PAF indicated that the broad, general theoretical constructs were the same, but their detection was somewhat different for this sample. Indeed, three of the seven constructs (Career Interest, Enjoyment of Science, and Leisure Interest) were effectively reduced to a single sub-scale. Other sub-scales constructed from the sample mirrored the original constructs but with fewer items.

The Personal Epistemology scale was not reliable with this sample. Few of the sub-scales describing Personal Epistemology as originally described seemed to consistently measure their intended constructs. The subsets of items measuring Innate Ability and Omniscient Authority were fairly reliable, however, and lost very little cohesiveness when the items from all five sub-scales were exposed to PAF. Other authors have attempted to resolve issues with the theoretical constructs of these personal
epistemology sub-scales. In fact, one aspect of Schraw et al.’s (2002) efforts with the Epistemic Belief Inventory had been to remove ambiguity from the Omniscient Authority sub-scale. The three sub-scales addressing Quick Learning, Certain Knowledge and Simple Knowledge were totally inadequate metrics for this sample. In fact, defining any components that described the data related to items from these sub-scales was difficult.

Ironically, students’ responses toward two theoretical scales, Quick & Easy (a derived sub-scale of personal epistemology) and Attitude toward Evolution (a previously published scale), may have been a function of popular discourses. One noticeable influence during the construction of the Personal Epistemology sub-scales seemed to be items that used the word “theory”. Understanding that knowledge does not come in neat little packets called “facts” is important to the Simple/Complex Knowledge component of most Personal Epistemology research, let alone the nature of scientific knowledge. After all, the theory of evolution is one of the most important organizing principles in biology. In this study, students’ beliefs about knowledge primarily scaled along a quick-and-easy to slow-and-complex axis, largely affected by how they responded to the influence of theories. In fact, PAF indicated that the relatively high loadings (> 0.55) associated with the two items that included the word “theory” were important components of the first factor of the Personal Epistemology sub-scale derived from the data. Indeed, recent arguments to challenge evolution have stressed that evolution is “just a theory”.

Formerly, the fashionable persuasive campaign to “disprove” evolution addressed the “failure” of the 2nd Law of Thermodynamics to explain how “order” could be an outcome of evolution. In this application, the item related to the 2nd Law of Thermodynamics in the Attitude toward Evolution scale (Ingram & Nelson, 2006) had to be deleted because
so few students understood its meaning. Therefore, the older scale construction that reflected historic arguments against evolution may need to be revised to reflect the effects of current rhetorical tactics on attitudes toward knowledge and evolution.

Not surprising, then, NOS Understanding was clearly an important covariate in the analyses, despite the crude measure using only a fraction of the original VOSTS scale items (Aikenhead & Ryan, 1992). Numerous authors have argued for enhancing NOS knowledge as a means to increase understanding and acceptance of evolutionary concepts (Abd-El-Khalick & Lederman, 2000; Alters & Nelson, 2002; Scharmann, Smith, James, & Jenson, 2005). Results of studies designed to improve the relationship have been equivocal, however (e.g., Akerson et al., 2006; Johnson & Peebles, 1987; Sadler, Chambers, & Zeidler, 2004), because of the complexity of teaching both the philosophical NOS and evolutionary theory. Results from the experimental manipulation of *Fatal Flower* indicated that NOS Understanding played a central role in the outcomes of evolution understanding assessments. Even though the effect was indirect, it strongly advocates teaching NOS to enhance understanding of evolution.

**Effects of Modifying CINS**

The Conceptual Inventory of Natural Selection (CINS; Anderson et al., 2002) was developed as a tool for describing evolution understanding. The multiple-choice assessment used distracters (or commonly held misconceptions) to gain insight to students’ complex conceptual diversities. Although the value of the type of information gained through CINS may be of some concern (Nehm & Schonfeld, 2008), the reliability was important if I hoped to find effects given the experimental design. CINS consisted of
only 20 questions, and despite arguments that the paired questions for the 10 key concepts could be separated, I chose to modify the tool and maintain 20 questions in both the pre- and post-assessments. Unfortunately, the modified tool may have confounded the results of the study because an unrelated sample of students scored lower on the modified version than on the original version. The impact on evolution understanding of changing organisms with very minor changes in wording raised interesting questions about revisiting the Disney Effect (Jensen, Settlage, & Odem, 1996), knowledge transfer, and evolution understanding, however.

Effects of Fatal Flower on Evolution Understanding

The experimental design to determine the impact of viewing a nature program on evolution understanding was complex by necessity. Understanding what students know is not a simple and straightforward task (see Pellegrino, Chudowsky, & Glaser, 2001), especially on a large scale, but the attitudes and beliefs sub-scales were included to account for at least some of the variance among individuals. Moreover, significant results were expected after a single viewing. Stocklmayer & Gilbert (2002) suggested that for a one-time event, such as viewing a nature program, to have an effect required the following conditions were important: (1) an intrinsically engaging component, either through appeal, need, or interest; (2) drawing powerfully on prior experiences; and (3) demonstrating an apparent relationship to the viewer. Obviously, viewing in this case had an intrinsically engaging component (course credit of some kind) and, perhaps, built on prior experiences in the classroom. It is possible that many participating students did not see an apparent relationship to themselves. Furthermore, most students participated
online, viewing the nature program at their leisure in their own personal environment.

The original experimental design intended viewing in the classroom to control for a suite of effects associated with leisure television viewing (Chen, 1994). In addition, the strong difference between students in the MSU class and other students was unexpected. Partitioning classes, therefore, affected sample size and likely, effect sizes. Nevertheless, the trends apparent in the experiment suggested some disturbing results.

Evolution understanding was relatively low overall; MSU students scored just under 70%, and UM and EWU students scored 55% – essentially “C”s and “F”s. Although the differences among treatments with the MSU students were not significant, these were the individuals influenced by the different versions of the nature program in the manner predicted. The revised narrative appeared to positively affect evolution understanding, and the original, misconception-laden narrative seemed to negatively influence understanding, especially when it was coupled with poor imagery. Differences in CINS assessments were not an influence because MSU student scores differed very little on the original and modified assessments (13.8 ± 0.34 [mean ± SE] and 13.7 ± 0.37, respectively). The lack of consistent patterns in the outcomes for students in the UM and EWU classes likely reflected guesswork associated with their very poor understanding of evolution.

The timing of the assessments relative to the presentation of evolution in the classroom may have played a role in the observed differences. Because this was a voluntary experiment, professors participated when they felt participation would be appropriate. MSU had just completed a discussion of evolution (at least comments from students indicated that was the case), whereas students at UM had completed their
evolution unit weeks prior to the experiment. As a result, students at MSU may have
seen the relevance of the assignment to their own understanding more so than students at
the other universities. Although purely speculative at this stage of research, the issue of
relevance and the influence of poor presentation of science may be profoundly important
as interested viewers seek out free-choice science education opportunities (Chapter 5).

Adding the covariates to the models rarely influenced the effect of the
experimental treatments. Nor were the influences of particular attitudes and beliefs
scales consistent across classes or variables. Attitude toward Evolution and NOS
Understanding were strongly related to Changed Answers and Correction Scales,
however. Students with a more positive attitude toward evolution were likely to change
more answers between the pre- and post-assessments, and those answers were more
likely to be correct in the post-assessment. NOS Understanding had a similar influence
on post-assessment evolution understanding. These relationships were consistent
whether students had a generally better understanding of evolution (MSU class) or a
generally poorer understanding of evolution (UM and EWU classes).

In sum, this experiment indicates that free-choice science learning opportunities
indeed influence evolution understanding (Figure 4.8). The outcomes, however, may
depend more upon knowledge development in a broad sense. Evolution understanding is
clearly influenced by attitudes toward science and evolution, as well as beliefs about
knowledge and the kinds of knowledge science produces. These factors may dampen any
influence a single viewing of a nature program, for example, may have. In addition,
other factors, such as the rhetoric of the marketplace of ideas, may have indirect
influences on the relationship between free-choice opportunities and understanding.
Figure 4.8. Outcomes of the experimental manipulation of a nature program on evolution understanding. Heavy lines indicated consistent, significant relationships.
Unfortunately, effect sizes likely were too small to detect differences because of the sample size partitioning. Although the logistics of a large-scale assessment may seem daunting, that kind of sample size may be necessary to adequately determine the relationships between attitudes and beliefs and knowledge acquisition from nature programs.

The Fate of Fatal Flower

Research with science fiction movies has found negative impacts on science understanding with single-viewing events (Barnett et al., 2006). Whether viewing the different versions of Fatal Flower resulted in long-term conceptual change, for better or worse, is unknown. Any patterns could result from shifting relevance of concepts in the learners’ mind or increased access to concepts as a result of viewing (Keil & Newman, 2008). The effect ultimately depends on elaboration by students. For example, if elaboration is minimal, effects may reflect priming and a shift in relevance. More engaged students motivated to learn may experience greater elaboration (Dole & Sinatra, 1998; Keil & Newman, 2008), especially as they apply principles of evolution, NOS Understanding, and beliefs about knowledge, thereby representing something closer to a conceptual change. Indeed, the qualitative data lend support to potential differences in engaged students (those that found the narrative and/or imagery important to their understanding) versus those less inclined. Fatal Flower, and other blue-chip nature programs, incorporate striking and memorable imagery. In fact, these images may be more memorable than science courses and lab experiments (Aikenhead, 1988; Barnett et al., 2006). Indeed, recall of television news is related to images through “explanation”
and the “emotional bond” they add (Graber, 1990; Zhou, 2005). If “the experience is everything” (Stocklmayer & Gilbert, 2002), this research indicates that nature programs may in fact be doing more harm to evolution understanding than good.

Poor presentation of science is common in nature programs (Chapter 6; Dissertation Appendix 1). In addition, evolution is rarely treated accurately (Aldridge & Dingwall, 2003; Dingwall & Aldridge, 2006; Dissertation Appendix 1) The results from this experiment suggest that students leaving universities with an “average” understanding of evolution (like students from MSU) are likely to be negatively influenced by these poor presentations of nature; students with even less of a grasp of the theory may be influenced by these programs interacting with the dominant discourse in popular deconstructions of evolution. MSU is a hub for research in science teaching and likely represents an upper bound for evolution understanding by non-majors. The outcome for public understanding of evolution is bleak given that the great majority of students is not exposed to that level of teaching and experience a very limited number of biology courses in general.

References


http://faculty.chass.ncsu.edu/garson/pa765/statnote.htm


Green, M. C. (2004). Transportation into narrative worlds: The role of prior knowledge and perceived realism. Discourse Processes, 38(2), 247-266.


Appendix 1. The Knowing the Natural World Pre-assessment.

KNOWING THE NATURAL WORLD

How many courses have you taken that included biology, ecology, or the natural sciences, not counting this course?

- none
- 1-2
- 3-4
- 5-6
- More than 6

How old are you? ________ years

Year in school:

- Freshman
- Sophomore
- Junior
- Senior
- Other/Please specify: ____________

Who is your professor for this course? ______________________

Circle the number that represents your belief on a scale from 1 = strongly disagree to 5 = strongly agree.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th></th>
<th></th>
<th></th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I would prefer to do experiments than to read about them.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I would like to be given a science book or a piece of scientific equipment as a present.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Too many laboratories are being built at the expense of the rest of education.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I dislike reading newspaper</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Strongly Disagree</td>
<td>Strongly Agree</td>
<td></td>
<td></td>
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<td>--------------------------------</td>
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<tr>
<td>articles about science.</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scientists who believe in evolution do so mainly because they want to, not because of any evidence.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Scientists are less friendly than other people.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Science is man’s worst enemy</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
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<tr>
<td>I dislike reading books about science during my vacations.</td>
<td>1 2 3 4 5</td>
<td></td>
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<tr>
<td>Absolute moral truth does not exist.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>The material covered in science lessons is uninteresting.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
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<tr>
<td>The Second Law of Thermodynamics shows that evolution could not have happened.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
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<tr>
<td>I would rather find out about things by asking an expert than by doing an experiment.</td>
<td>1 2 3 4 5</td>
<td></td>
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<tr>
<td>Mutations are never beneficial to animals.</td>
<td>1 2 3 4 5</td>
<td></td>
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<tr>
<td>There is scientific evidence supporting that humans were supernaturally created.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
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<tr>
<td>Things are simpler than most professors would have you believe.</td>
<td>1 2 3 4 5</td>
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<tr>
<td>Scientific discoveries are doing more harm than good.</td>
<td>1 2 3 4 5</td>
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</tbody>
</table>
For the following questions, some of the answers are grouped. Read all the possibilities, and circle the answer that best fits your thinking.

**When developing new theories or laws, scientists need to make certain assumptions about nature (for example, matter is made up of atoms). These assumptions must be true in order for science to progress properly. Your position, basically (please read from A to I, and then choose one):**

Assumptions MUST be true in order for science to progress:

A. because correct assumptions are needed for correct theories and laws. Otherwise scientists would waste a lot of time and effort using wrong theories and laws.

B. otherwise society would have serious problems, such as inadequate technology and dangerous chemicals.

C. because scientists do research to prove their assumptions true before going on with their work.

D. It depends. Sometimes science needs true assumptions in order to progress. But sometimes history has shown that great discoveries have been made by disproving a theory and learning from its false assumptions.

E. It doesn’t matter. Scientists have to make assumptions, true or not, in order to get started on a project. History has shown that great discoveries have been made by disproving a theory and learning from its false assumptions.

F. Scientists do not make assumptions. They research an idea to find out if the idea is true. They don’t assume it is true.

G. I don’t understand.
H. I don’t know enough about this subject to make a choice.
I. None of these choices fits my basic viewpoint.

For this statement, assume that a gold miner “discovers” gold while an artist “invents” a sculpture. Some people think that scientists discover scientific THEORIES. Others think that scientists invent them. What do you think? Your position, basically (please read from A to I, and then choose one):

Scientists discover a theory:
A. because the idea was there all the time to be uncovered.
B. because it is based on experimental facts.
C. but scientists invent the methods to find the theories.
D. Some scientists may stumble onto a theory by chance, thus discovering it. But other scientists may invent the theory from facts they already know.

Scientists invent a theory:
E. because a theory is an interpretation of experimental facts which scientists have discovered.
F. because inventions (theories) come from the mind — we create them.
G. I don’t understand.
H. I don’t know enough about this topic to make a choice.
I. None of these choices fits my basic viewpoint.

When scientists classify something (for example, a plant according to its species, an element according to the periodic table, energy according to its source, or a star according to its size), scientists are classifying nature according to the way nature really is; any other way would simply be wrong. Your position, basically (please read from A to I, and then choose one):

Classifications match the way nature really is,
A. since scientists have proven them over many years of work.

B. since scientists use observable characteristics when they classify.

C. Scientists classify nature in the most simple and logical way, but their way isn’t necessarily the only way.

D. There are many ways to classify nature, but agreeing on one universal system allows scientists to avoid confusion in their work.

E. There could be other correct ways to classify nature, because science is liable to change and new discoveries may lead to different classifications.

F. Nobody knows the way nature really is. Scientists classify nature according to their perceptions or theories. Science is never exact, and nature is so diverse. Thus, scientists could correctly use more than one classification scheme.

G. I don’t understand.

H. I don’t know enough about this subject to make a choice.

I. None of these choices fits my basic viewpoint.

Scientific ideas develop from hypotheses to theories, and finally, if they are good enough, to being scientific laws. Your position, basically (please read from A to H, and then choose one):

Hypotheses can lead to theories which can lead to laws:

A. because an hypothesis is tested by experiments, if it proves correct, it becomes a theory. After a theory has been proven true many times by different people and has been around for a long time, it becomes a law.

B. because an hypothesis is tested by experiments, if there is supporting evidence, it’s a theory. After a theory has been tested many times and seems to be essentially correct, it’s good enough to become a law.

C. because it is a logical way for scientific ideas to develop.

D. Theories can’t become laws because they both are different types of ideas. Theories are based on scientific ideas which are less than 100% certain, and so theories can’t be proven true. Laws, however, are based on facts only and are 100% sure.
E. Theories can’t become laws because they both are different types of ideas. Laws describe things in general. Theories explain these laws. However, with supporting evidence, hypotheses may become theories (explanations) or laws (descriptions).

F. I don’t understand.

G. I don’t know enough about this subject to make a choice.

H. None of these choices fits my basic viewpoint.

Some cultures have a particular viewpoint on nature and man. Scientists and scientific research are affected by the religious or ethical views of the culture where the work is done. Your position, basically (please read from A to J, and then choose one):

Religious or ethical views DO influence scientific research:

A. because some cultures want specific research done for the benefit of that culture.

B. because scientists may unconsciously choose research that would support their culture’s views.

C. because most scientists will not do research which goes against their upbringing or their beliefs.

D. because everyone is different in the way they react to their culture. It is these individual differences in scientists that influence the type of research done.

E. because powerful groups representing certain religious, political or cultural beliefs will support certain research projects, or will give money to prevent certain research from occurring.

Religious or ethical views do NOT influence scientific research:

F. because research continues in spite of clashes between scientists and certain religious or cultural groups (for example, clashes over evolution and creation).

G. because scientists will research topics which are of importance to science and scientists, regardless of cultural or ethical views.

H. I don’t understand.

I. I don’t know enough about this subject to make a choice.

J. None of these choices fits my basic viewpoint
Circle the number that represents your belief on a scale from 1 = strongly disagree to 5 = strongly agree.

<table>
<thead>
<tr>
<th>Statement</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<tbody>
<tr>
<td>Scientists do not have enough time to spend with their families.</td>
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<tr>
<td>Students who learn things quickly are the most successful.</td>
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<tr>
<td>School should have more science lessons each week.</td>
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<tr>
<td>I dislike science lessons.</td>
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<tr>
<td>If you don’t learn something quickly, you won’t ever learn it.</td>
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<tr>
<td>If a person tries too hard to understand a problem, they will most likely end up being confused.</td>
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<tr>
<td>Really smart students don’t have to work as hard to do well in school.</td>
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<tr>
<td>I would dislike being a scientist after I leave school.</td>
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<tr>
<td>When I leave school, I would like to work with people who make discoveries in science.</td>
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</table>

**Canary Island Lizards**

The Canary Islands are seven islands just west of the African continent. The islands gradually became colonized with life: plants, lizards, birds, etc. Three different species of lizards found on the islands are similar to one species found on the African continent (Thorpe & Brown 1989). Because of this, scientists assume that the lizards traveled from Africa to the Canary Islands by floating on tree trunks washed out to sea.
Choose the answer that best reflects how an evolutionary biologist would answer.

**Lizards eat a variety of insects and plants. Which statement describes the availability of food for lizards on the Canary Islands?**

a. Finding food is not a problem since food is always in abundant supply.
b. Since lizards can eat a variety of foods, there is likely to be enough food for all of the lizards at all times.
c. Lizards can get by on very little food, so the food supply does not matter.
d. It is likely that sometimes there is enough food, but at other times there is not enough food for all of the lizards.

**What do you think happens among the lizards of a certain species when the food supply is limited?**

a. The lizards cooperate to find food and share what they find.
b. The lizards fight for the available food and the strongest lizards kill the weaker ones.
c. Genetic changes that would allow lizards to eat new food sources are likely to be induced.
d. The lizards least successful in the competition for food are likely to die of starvation and malnutrition.

**Populations of lizards are made up of hundreds of individual lizards. Which statement describes how similar they are likely to be to each other?**

a. All lizards in the population are likely to be nearly identical.
b. All lizards in the population are identical to each other on the outside, but there are differences in their internal organs such as how they digest food.
c. All lizards in the population share many similarities, but there are differences in features like body size and claw length.
d. All lizards in the population are completely unique and share no features with other lizards.

**Which statement could describe how traits in lizards pass from one generation of lizards to the next generation?**

a. Lizards that learn to catch a particular type of insect will pass the new ability to offspring.
b. Lizards that are able to hear but have no survival advantage because of hearing, will eventually stop passing on the “hearing” trait.
c. Lizards with stronger claws that allow for catching certain insects have offspring whose claws gradually get even stronger during their lifetime.

d. Lizards with a particular coloration and pattern are likely to pass the same trait on to offspring.

Fitness is a term often used by biologists to explain the evolutionary success of certain organisms. Below are descriptions of four fictional female lizards. Which lizard might a biologist consider to be the “most fit”?

<table>
<thead>
<tr>
<th></th>
<th>Lizard A</th>
<th>Lizard B</th>
<th>Lizard C</th>
<th>Lizard D</th>
</tr>
</thead>
<tbody>
<tr>
<td>body length</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 cm</td>
<td>12 cm</td>
<td>10 cm</td>
<td>15 cm</td>
<td></td>
</tr>
<tr>
<td>offspring surviving to adulthood</td>
<td>19</td>
<td>28</td>
<td>22</td>
<td>26</td>
</tr>
<tr>
<td>age at death</td>
<td>4 years</td>
<td>5 years</td>
<td>4 years</td>
<td>6 years</td>
</tr>
<tr>
<td>comments</td>
<td>Lizard A is very healthy, strong, and clever</td>
<td>Lizard B has mated with many lizards</td>
<td>Lizard C is dark colored and very quick</td>
<td>Lizard D has the largest territory of all the lizards</td>
</tr>
</tbody>
</table>

a. Lizard A  
b. Lizard B  
c. Lizard C  
d. Lizard D

According to the theory of natural selection, where did the variations in body size in the three species of lizards most likely come from?

a. The lizards needed to change in order to survive, so beneficial new traits developed.  
b. The lizards wanted to become different in size, so beneficial new traits gradually appeared in the population.  
c. Random genetic changes and sexual recombination both created new variations.  
d. The island environment caused genetic changes in the lizards.

What could cause one species to change into three species over time?

a. Groups of lizards encountered different island environments so the lizards needed to become new species with different traits in order to survive.
b. Groups of lizards must have been geographically isolated from other groups and random genetic changes must have accumulated in these lizard populations over time.

c. There may be minor variations, but all lizards are essentially alike and all are members of a single species.

d. In order to survive, different groups of lizards needed to adapt to the different islands, and so all organisms in each group gradually evolved to become a new lizard species.

Circle the number that represents your belief on a scale from 1 = strongly disagree to 5 = strongly agree.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>If two people are arguing about something, at least one of them must be wrong.</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>The more you know about a topic, the more there is to know.</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>Scientists are just as interested in art and music as other people are.</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>Sometimes there are no right answers to life’s big problems.</td>
<td>1 2 3 4 5</td>
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<tr>
<td>Science helps to make life better.</td>
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<tr>
<td>The Earth is not old enough for evolution to have taken place.</td>
<td>1 2 3 4 5</td>
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<tr>
<td>Listening to talk about science on the radio would be boring.</td>
<td>1 2 3 4 5</td>
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<tr>
<td>Too many theories just complicate things.</td>
<td>1 2 3 4 5</td>
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<tr>
<td>If you haven’t understood a chapter the first time through, going back over it won’t help.</td>
<td>1 2 3 4 5</td>
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</table>
For the following questions, some of the answers are grouped. Read all the possibilities, and circle the answer that best fits your thinking.

**Good scientific theories explain observations well. But good theories are also simple rather than complex. Your position, basically (please read from A to I, and then choose one):**

A. Good theories are simple. The best language to use in science is simple, short, direct language.

B. It depends on how deeply you want to get into the explanation. A good theory can explain something either in a simple way or in a complex way.

C. It depends on the theory. Some good theories are simple, some are complex.

D. Good theories can be complex, but they must be able to be translated into simple language if they are going to be used.

E. Theories are usually complex. Some things cannot be simplified if a lot of details are involved.
F. Most good theories are complex. If the world was simpler, theories could be simpler.

G. I don’t understand.

H. I don’t know enough about this subject to make a choice.

I. None of these choices fits my basic viewpoint.

**For this statement, assume that a gold miner “discovers” gold while an artist “invents” a sculpture. Some people think that scientists discover scientific LAWS. Others think that scientists invent them. What do you think? Your position, basically (please read from A to H, and then choose one):**

Scientists discover scientific laws:

A. because the laws are out there in nature and scientists just have to find them.

B. because laws are based on experimental facts.

C. but scientists invent the methods to find those laws.

D. Some scientists may stumble onto a law by chance, thus discovering it. But other scientists may invent the law from facts they already know.

E. Scientists invent laws, because scientists interpret the experimental facts which they discover. Scientists don’t invent what nature does, but they do invent the laws which describe what nature does.

F. I don’t understand.

G. I don’t know enough about this topic to make a choice.

H. None of these choices fits my basic viewpoint.

Science rests on the assumption that the natural world CANNOT be altered by a supernatural being (for example, a deity). Your position, basically (please read from A to H, and then choose one):

Scientists assume that a supernatural being will NOT alter the natural world:

A. because the supernatural is beyond scientific proof. Other views, outside the realm
of science, may assume that a supernatural being can alter the natural world.

B. because if a supernatural being did exist, scientific facts could change in the wink of an eye. BUT scientists repeatedly get consistent results.

C. It depends. What scientists assume about a supernatural being is up to the individual scientist.

D. Anything is possible. Science does not know everything about nature. Therefore, science must be open-minded to the possibility that a supernatural being could alter the natural world.

E. Science can investigate the supernatural and can possibly explain it. Therefore, science can assume the existence of supernatural beings.

F. I don’t understand.

G. I don’t know enough about this topic to make a choice.

H. None of these choices fits my basic viewpoint.

If scientists find that people working with asbestos have twice as much chance of getting lung cancer as the average person, this must mean that asbestos causes lung cancer. Your position, basically (please read from A to H, and then choose one):

A. The facts obviously prove that asbestos causes lung cancer. If asbestos workers have a greater chance of getting lung cancer, then asbestos is the cause.

The facts do NOT necessarily mean that asbestos causes lung cancer:

B. because more research is needed to find out whether it is asbestos or some other substance that causes the lung cancer.

C. because asbestos might work in combination with other things, or may work indirectly (for example, weakening your resistance to other things which cause you to get lung cancer).

D. because if it did, all asbestos workers would have developed lung cancer.

E. Asbestos cannot be the cause of lung cancer because many people who don’t work with asbestos also get lung cancer.

F. I don’t understand.
G. I don’t know enough about this subject to make a choice.
H. None of these choices fits my basic viewpoint.

Scientists should NOT make errors in their work because these errors slow the advance of science. Your position basically (please read from A to H, and then choose one):

Errors slow the advance of science:
A. because misleading information can lead to false conclusions. If scientists don’t immediately correct the errors in their results, then science is not advancing.
B. because new technology and equipment reduce errors by improving accuracy and so science will advance faster.

Errors CANNOT be avoided:
C. so scientists reduce errors by checking each others’ results until agreement is reached.
D. some errors can slow the advance of science, but other errors can lead to a new discovery or breakthrough. If scientists learn from their errors and correct them, science will advance.
E. Errors most often help the advance of science. Science advances by detecting and correcting the errors of the past.
F. I don’t understand.
G. I don’t know enough about this subject to make a choice.
H. None of these choices fits my basic viewpoint.
Galapagos Finches

Scientists have long believed that the 14 species on the Galapagos Islands evolved from a single species of finch that migrated to the islands one to five million years ago (Lack 1940). Recent DNA analyses support the conclusion that all of the Galapagos finches evolved from the warbler finch (Grant et al. 2001; Petren et al. 1999). Different species live on different islands. For example, the medium ground finch and the cactus finch live on one island. The large cactus finch occupies another island. One of the major changes in the finches in their beak sizes and shapes, as shown in this figure.

Choose the one answer that best reflects how an evolutionary biologist would answer.

**What would happen if a breeding pair of finches was placed on an island under ideal conditions with no predators and unlimited food so that all individuals survived?**

**Given enough time**

a. the finch population would stay small because birds only have enough babies to replace themselves.

b. the finch population would double and then stay relatively stable.

c. the finch population would increase dramatically.

d. the finch population would grow slowly and then level off.

**Finches on the Galapagos Islands require food to eat and water to drink.**

a. When food and water are scarce, some birds may be unable to obtain what they need to survive.

b. When food and water are limited, the finches will find other food sources, so there is always enough.

c. When food and water are scarce, the finches all eat and drink less so that all birds survive.

d. There is always plenty of food and water on the Galapagos Islands to meet the finches’ needs.

**Once a population of finches has lived on a particular island for many years,**

a. the population continues to grow rapidly.

b. the population remains relatively stable, with some fluctuations.

c. the population dramatically increases and decreases each year.
d. the population will decrease steadily.

In the finch population, what are the primary changes that occur gradually over time?

a. The traits of each finch within a population gradually change.
b. The proportions of finches having different traits within a population change.
c. Successful behaviors learned by finches are passed on to offspring.
d. Mutations occur to meet the needs of the finches as the environment changes.

Depending on their beak size and shape, some finches get nectar from flowers, some eat grubs from bark, some eat small seeds, and some eat large nuts. Which statement best describes the interactions among the finches and the food supply?

a. Most of the finches on an island cooperate to find food and share what they find.
b. Many of the finches on an island fight with one another and the physically strongest ones win.
c. There is more than enough food to meet all the finches’ needs so they don’t need to compete for food.
d. Finches compete primarily with closely related finches that eat the same kinds of food, and some may die from lack of food.

How did the different beak types first arise in the Galapagos finches?

a. The changes in the finches’ beak size and shape occurred because of their need to be able to eat different kinds of food to survive.
b. Changes in the finches’ beaks occurred by chance, and when there was a good match between beak structure and available food, those birds had more offspring.
c. The changes in the finches’ beaks occurred because the environment induced the desired genetic changes.
d. The finches’ beaks changed a little bit in size and shape with each successive generation, some getting larger and some getting smaller.

What type of variation in finches is passed to the offspring?

a. Any behaviors that were learned during a finch’s lifetime.
b. Only characteristics that were beneficial during a finch’s lifetime.
c. All characteristics that were genetically determined.

d. Any characteristics that were positively influenced by the environment during a finch’s lifetime.

**What caused populations of birds having different beak shapes and sizes to become distinct species distributed on the various islands?**

a. The finches were quite variable, and those whose features were best suited to the available food supply on each island reproduced most successfully.

b. All finches are essentially alike and there are not really fourteen different species.

c. Different foods are available on different islands and for that reason, individual finches on each island gradually developed the beaks they needed.

d. Different lines of finches developed different beak types because they needed them in order to obtain the available food.

Circle the number that represents your belief on a scale from 1 = strongly disagree to 5 = strongly agree.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Strongly Agree</th>
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<td>1 2 3 4 5</td>
<td>1 2 3 4 5</td>
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</table>

There is no fossil evidence supporting that humans and apes evolved from a common ancestor.

I would rather solve a problem by doing an experiment than be told the answer.

Finding out about new things is unimportant.

People’s intellectual potential is fixed at birth.

It is statistically impossible that life arose by chance.
<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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</thead>
<tbody>
<tr>
<td>A supreme being (e.g., God) created humans pretty much in their present form; humans did not evolve from other forms of life (e.g., fish and/or reptiles).</td>
<td>1</td>
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<tr>
<td>Money used on scientific projects is wasted.</td>
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<tr>
<td>Some people just have a knack for learning and others don’t.</td>
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<tr>
<td>This country is spending too much money on science.</td>
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<tr>
<td>Science is one of the most interesting school subjects.</td>
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<tr>
<td>Money spent on science is well worth spending.</td>
<td>1</td>
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<tr>
<td>What is true today will be true tomorrow.</td>
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</tr>
<tr>
<td>Over billions of years all plants and animals on Earth (including humans) descended (evolved) from a common ancestor (e.g., a one-celled organism).</td>
<td>1</td>
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<tr>
<td>I like to listen to people whose opinions are different from mine.</td>
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</tr>
<tr>
<td>How well you do in school depends on how smart you are.</td>
<td>1</td>
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<tr>
<td>I would enjoy school more if there were no science lessons.</td>
<td>1</td>
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<tr>
<td>I would enjoy visiting a science museum on the weekend.</td>
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</tbody>
</table>
There is no real evidence that humans evolved from other animals.

I dislike listening to other people’s opinions.

I find it boring to hear about new ideas.

There is no real evidence that humans evolved from other animals.

I dislike listening to other people’s opinions.

I find it boring to hear about new ideas.

Venezuelan Guppies

Guppies are small fish found in streams in Venezuela. Male guppies are brightly colored, with black, red, blue and iridescent (reflective) spots. Males cannot be too brightly colored or they will be seen and consumed by predators, but if they are too plain, females will choose other males. Natural selection and sexual selection push in opposite directions. When a guppy population lives in a stream in the absence of predators, the proportion of males that are bright and flashy increases in the population. If a few aggressive predators are added to the same stream, the proportion of bright-colored males decreases within about five months (3-4 generations). The effects of predators on guppy coloration have been studied in artificial ponds with mild, aggressive, and no predators, and by similar manipulations of natural stream environments (Endler 1980).

Choose the one answer that best reflects how an evolutionary biologist would answer.

A typical natural population of guppies consists of hundreds of guppies. Which statement best describes the guppies of a single species in an isolated population?

a. The guppies share all of the same characteristics and are identical to each other.

b. The guppies share all of the essential characteristics of the species; the minor variations they display don’t affect survival.

c. The guppies are all identical on the inside, but have many differences in appearance.

d. The guppies share many essential characteristics, but also vary in many features.

Fitness is a term often used by biologists to explain the evolutionary success of certain organisms. Which feature would a biologist consider to be most important in determining which guppies were the “most fit”? 
a. Large body size and ability to swim quickly away from predators.
b. Excellent ability to compete for food.
c. High number of offspring that survived to reproductive age.
d. High number of matings with many different females.

Assuming ideal conditions with abundant food and space and no predators, what would happen if a pair of guppies was placed in a large pond?

a. The guppy population would grow slowly, as guppies would have only the number of babies that are needed to replenish the population.
b. The guppy population would grow slowly at first, then would grow rapidly, and thousands of guppies would fill the pond.
c. The guppy population would never become very large, because only organisms such as insects and bacteria reproduce in that manner.
d. The guppy population would continue to grow slowly over time.

Once a population of guppies has been established for a number of years in a real (not ideal) pond with other organisms including predators, what will likely happen to the population?

a. The guppy population will stay about the same size.
b. The guppy population will continue to rapidly grow in size.
c. The guppy population will gradually decrease until no more guppies are left.
d. It is impossible to tell because populations do not follow patterns.

In guppy populations, what are the primary changes that occur gradually over time?

a. The traits of each individual guppy within a population gradually change.
b. The proportions of guppies having different traits within a population change.
c. Successful behaviors learned by certain guppies are passed on to offspring.
d. Mutations occur to meet the needs of the guppies as the environment changes.
For the following questions, some of the answers are grouped. Read all the possibilities, and circle the answer that best fits your thinking.

**Even when people use mathematics accurately in science and engineering, they can only predict what will probably happen. They can never conclude with 100% certainty. Your position, basically (please read from A to G, and then choose one):**

Predictions are never 100% certain:

A. because there is always measurement error or human error.

B. because there are always unknown or unforeseen events which will affect a result.

C. Predictions with mathematics are usually 100% certain, because they are based on tested results.

D. Predictions with mathematics are always 100% certain because mathematics itself is certain.

E. I don’t understand.

F. I don’t know enough about this subject to make a choice.

G. None of these choices fits my basic viewpoint.

**In spite of their knowledge and training, scientists and technologists can be fooled by what they see on TV or read in newspapers. Your position, basically (please read from A to H, and then choose one):**

Scientists and technologists CAN BE fooled by the media:

A. because they are so open-minded and always accept new ideas.

B. because their special knowledge doesn’t help them detect errors in the media.

C. because they are only human. Like everyone, they are influenced by the media (except when the topic is in their field of specialization).

Scientists and technologists are NOT fooled by the media:

D. because they know the facts. Knowledge of science tells them what is correct.

E. because they are trained to look at things logically. They know the correct information or they know how to check it out.
F. I don’t understand.

G. I don’t know enough about this subject to make a choice.

H. None of these choices fits my basic viewpoint.

**Even when making predictions based on accurate knowledge, scientists and engineers can tell us only what probably might happen. They cannot tell what will happen for certain.** Your position basically (please read from A to H, and then choose one):

Predictions are NEVER certain:

A. because there is always room for error and unforeseen events which will affect a result. No one can predict the future for certain.

B. because accurate knowledge changes as new discoveries are made, and therefore predictions will always change.

C. because a prediction is not a statement of fact. It is an educated guess.

D. because scientists never have all the facts. Some data are always missing.

E. It depends. Predictions are certain, only as long as there is accurate knowledge and enough information.

F. I don’t understand.

G. I don’t know enough about this subject to make a choice.

H. None of these choices fits my basic viewpoint.

**Many scientific models used in research laboratories (such as the model of heat, the neuron, DNA, or the atom) are copies of reality.** Your position, basically (please read from A to J, and then choose one):

Scientific models ARE copies of reality:

A. because scientists say they are true, so they must be true.

B. because much scientific evidence has proven them true.

C. because they are true to life. Their purpose is to show us reality or teach us
something about it.

D. Scientific models come close to being copies of reality, because they are based on scientific observations and research.

Scientific models are NOT copies of reality:

E. because they are simply helpful for learning and explaining, within their limitations.

F. because they change with time and with the state of our knowledge, like theories do.

G. because these models must be ideas or educated guesses, since you can’t actually see the real thing.

H. I don’t understand.

I. I don’t know enough about this subject to make a choice.

J. None of these choices fits my basic viewpoint.

Even when scientific investigations are done correctly, the knowledge that scientists discover from those investigations may change in the future. Your position, basically (please read from A to G, and then choose one):

Scientific knowledge changes:

A. because new scientists disprove the theories or discoveries of old scientists. Scientists do this by using new techniques or improved instruments, by finding new factors overlooked before, or by detecting errors in the original “correct” investigation.

B. because the old knowledge is reinterpreted in light of new discoveries. Scientific facts can change.

Scientific knowledge APPEARS to change:

C. because the interpretation or the application of the old facts can change. Correctly done experiments yield unchangeable facts.

D. because new knowledge is added on to old knowledge; the old knowledge doesn’t change.

E. I don’t understand.
F. I don’t know enough about this subject to make a choice.

G. None of these choices fits my basic viewpoint.

Circle the number that represents your belief on a scale from 1 = strongly disagree to 5 = strongly agree.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>1</th>
<th>2</th>
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<tbody>
<tr>
<td>I would dislike becoming a scientist because it needs too much education.</td>
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<tr>
<td>What is true is a matter of opinion.</td>
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<td>The government should spend more money on scientific research.</td>
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<td>The methods used to determine the age of fossils and rocks are not accurate.</td>
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<td>Science is easy to understand because it contains so many facts.</td>
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<td>Instructors should focus on facts instead of theories.</td>
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<tr>
<td>A career in science would be dull and boring.</td>
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<td>Science lessons are fun.</td>
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<td>The best ideas are often the most simple.</td>
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<td>It is better to ask the teacher the answer than to find out by doing experiments.</td>
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<tr>
<td>Statement</td>
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<td>Strongly Agree</td>
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<tr>
<td>Public money spent on science in the last few years has been used wisely.</td>
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<tr>
<td>Science can help to make the world a better place in the future.</td>
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<tr>
<td>Working on a problem with no quick solution is a waste of time.</td>
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<tr>
<td>Most things worth knowing are easy to understand.</td>
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<tr>
<td>I would like to belong to a science club.</td>
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<tr>
<td>Smart people are born that way.</td>
<td>1</td>
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<tr>
<td>There is fossil evidence supporting that animals, including humans, did not evolve.</td>
<td>1</td>
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<td>5</td>
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<tr>
<td>Children should be allowed to question their parents’ authority.</td>
<td>1</td>
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<tr>
<td>I would like to teach science when I leave school.</td>
<td>1</td>
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<tr>
<td>I would like to be a scientist when I leave school.</td>
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<tr>
<td>I get bored when watching science programs on TV at home.</td>
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<tr>
<td>I am curious about the world in which we live.</td>
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</table>
Cheetahs (large African cats) are able to run faster than 60 miles per hour when chasing prey. How would a biologist explain how the ability to run fast evolved in cheetahs, assuming their ancestors could run only 20 miles per hour?

Squirrels have claws that they use to help them climb the bark of trees and jump from branch to branch. They had ancestors that did not have good claws, so they were not as good at climbing and jumping. Explain how modern day squirrels have claws that are good for climbing and jumping even though their ancestors did not.
Appendix 2. The Knowing the Natural World Post-assessment.

[Note. These questions were substituted for the original CINS questions in the pre-assessment for students completing the post-assessment only]

**Knowing the Natural World**

**Hummingbirds**

Hummingbirds are small birds with long, thin beaks. They are known for their ability to hover in mid-air by rapidly flapping their wings from 15-80 times per second! Hummingbirds feed on nectar and insects. The long thin beak allows birds to feed on nectar stored deep within flowers. The beak also can be opened wide, and the lower half has the ability to flex downward to create an even wider opening, which facilitates the capture of flying insects. Hummingbirds are native only to the Americas, with more species of hummingbirds found in the tropical Andes Mountains of South America than any other place.

Choose the answer that best reflects how an evolutionary biologist would answer.

**Hummingbirds eat insects as well as nectar. Which statement describes the availability of food for hummingbirds in the Andes?**

a. Finding food is not a problem since food is always in abundant supply.

b. Since hummingbirds can eat a variety of foods, there is likely to be enough food for all of the hummingbirds at all times.

c. Hummingbirds can get by on very little food, so the food supply does not matter.

d. It is likely that sometimes there is enough food, but at other times there is not enough food for all of the hummingbirds.

**What do you think happens among the hummingbirds of a certain species when the food supply is limited?**

a. The hummingbirds cooperate to find food and share what they find.

b. The hummingbirds fight for the available food and the strongest hummingbirds chase the weaker ones away.

c. Genetic changes that would allow hummingbirds to eat new food sources are likely to be induced.

d. The hummingbirds least successful in the competition for food are likely to die of starvation and malnutrition.
Populations of hummingbirds are made up of hundreds of individual hummingbirds. Which statement describes how similar they are likely to be to each other?

a. All hummingbirds in the population are likely to be nearly identical.
b. All hummingbirds in the population are identical to each other on the outside, but there are differences in their internal organs such as how they digest food.
c. All hummingbirds in the population share many similarities, but there are differences in features like body size and bill length.
d. All hummingbirds in the population are completely unique and share no features with other hummingbirds.

Which statement could describe how traits in hummingbirds pass from one generation of hummingbirds to the next generation?

a. Hummingbirds that learn to nectar from a particular type of orchid will pass the new ability to offspring.
b. Hummingbirds that are able to hear, but have no survival advantage because of hearing, will eventually stop passing on the “hearing” trait.
c. Hummingbirds with longer bills that allow for obtaining nectar from certain orchids have offspring whose bills gradually get even longer during their lifetime.
d. Hummingbirds with a particular coloration and bill length are likely to pass the same trait on to offspring.

Fitness is a term often used by biologists to explain the evolutionary success of certain organisms. Below are descriptions of four fictional male hummingbirds. Which hummingbird might a biologist consider to be the “most fit”?

<table>
<thead>
<tr>
<th></th>
<th>Hummingbird A</th>
<th>Hummingbird B</th>
<th>Hummingbird C</th>
<th>Hummingbird D</th>
</tr>
</thead>
<tbody>
<tr>
<td>beak length</td>
<td>20 cm</td>
<td>12 cm</td>
<td>10 cm</td>
<td>15 cm</td>
</tr>
<tr>
<td>offspring</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>surviving to</td>
<td>19</td>
<td>28</td>
<td>22</td>
<td>26</td>
</tr>
<tr>
<td>adulthood</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>age at death</td>
<td>4 years</td>
<td>5 years</td>
<td>4 years</td>
<td>6</td>
</tr>
<tr>
<td>comments</td>
<td>Hummingbird A is very healthy, strong, and clever</td>
<td>Hummingbird B has mated with many hummingbirds</td>
<td>Hummingbird C has a long bill and is very quick</td>
<td>Hummingbird D has the largest territory of all the hummingbirds</td>
</tr>
</tbody>
</table>
According to the theory of natural selection, where did the variations in Andean species of hummingbirds most likely come from?

a. The hummingbirds needed to change in order to survive, so beneficial new traits developed.

b. The hummingbirds wanted to eat different foods, so beneficial new traits gradually appeared in the population.

c. Random genetic changes and sexual recombination both created new variations.

d. The environment of the Andes caused genetic changes in the hummingbirds.

What could cause one species to change into so many species over time?

a. Groups of hummingbirds encountered different mountain environments so the hummingbirds needed to become new species with different traits in order to survive.

b. Groups of hummingbirds must have been geographically isolated from other groups and random genetic changes must have accumulated in these hummingbird populations over time.

c. There may be minor variations, but all hummingbirds are essentially alike and all are members of a single species.

d. In order to survive, different groups of hummingbirds needed to adapt to the different types of flowers, and so all organisms in each group gradually evolved to become a new hummingbird species.
Costus

Many flowers can be classified as having either a bee- or hummingbird-pollination syndrome based on distinct suites of floral characters. For example, flowers of bee-pollinated Costus (ginger plants) have broad, pale tubes that are white or yellow and often striped with red or purple, and the floral bracts are green. Flowers of hummingbird-pollinated species have a narrow, tubular form, and the floral bracts are yellow, orange, or red. Flowers in both pollination categories are odorless and diurnal, and they produce relatively large quantities of nectar. Geological uplift in the Andes Mountains caused range shifts and occasionally isolated populations of Costus, resulting in “islands” of this rich food resource. Bees are less active in the cool, wet weather that is common at higher elevations in the tropics and are rarely found above 2000 m.

Choose the one answer that best reflects how an evolutionary biologist would answer.

What would happen if several Costus were placed on a mountain in the Andes under ideal conditions with no predators and unlimited light and water so that all individuals survived? Given enough time

a. the Costus population would stay small because plants only have enough babies to replace themselves.

b. the Costus population would double and then stay relatively stable.

c. the Costus population would increase dramatically.

d. the Costus population would grow slowly and then level off.

Costus in the Andes Mountains require cross-fertilization (pollen from other individuals) to produce vigorous offspring.

a. When bees are scarce, some Costus may be unable to obtain the pollinators they need to reproduce.

b. When bees are limited, the Costus will attract other pollinators, so there is always enough.

c. When bees are scarce, the Costus all reproduced less so they all survive.

d. There are always plenty of bees in the Andes to meet the Costus’ needs.
Once a population of *Costus* has lived in a particular area for many years,

a. the population continues to grow rapidly.

b. the population remains relatively stable, with some fluctuations.

c. the population dramatically increases and decreases each year.

d. the population will decrease steadily.

In the *Costus* population, what are the primary changes that occur gradually over time?

a. The traits of each *Costus* within a population gradually change.

b. The proportions of *Costus* having different traits within a population change.

c. Successful behaviors learned by *Costus* (such as cheating) are passed on to offspring.

d. Mutations occur to meet the needs of the *Costus* as the environment changes.

Depending on their tube size and shape, some *Costus* are pollinated by bees, some by gnats, and some by hummingbirds. Which statement best describes the interactions among the *Costus* and their pollinators?

a. Most of the *Costus* in the Andes cooperate to find pollinators.

b. Many of the *Costus* in the Andes compete with one another for pollinators and the strongest ones win.

c. There are more than enough pollinators to meet all the *Costus*' needs so they don’t need to compete for pollinators.

d. *Costus* compete primarily with closely related species that require the same kinds of pollinators, and some may not reproduce from lack of pollinators.

How did the different tube types first arise in the Andean *Costus*?

a. The changes in the *Costus*’ tube size and shape occurred because of their need to be able to attract different kinds of pollinators to reproduce.

b. Changes in the *Costus*’ tube occurred by chance, and when there was a good match between tube structure and available pollinators, those *Costus* produced more seeds.

c. The changes in the *Costus*’ tube occurred because the environment induced the desired genetic changes.
d. The *Costus*’ tube changed a little bit in size and shape with each successive generation, some getting larger and some getting smaller.

**What type of variation in the bees is passed to the offspring?**

a. Any behaviors that were learned during the bee’s lifetime.
b. Only characteristics that were beneficial during a bee’s lifetime.
c. All characteristics that were genetically determined.
d. Any characteristics that were positively influenced by the environment during the bee’s lifetime.

**What caused populations of *Costus* having different flower shapes and sizes to become distinct species distributed on the various mountains of the Andes?**

a. The *Costus* were quite variable, and those whose features were best suited to the available pollinators on each mountain reproduced most successfully.
b. All *Costus* are essentially alike and there are not really different species.
c. Different pollinators are available on different mountains and for that reason, individual *Costus* on each mountain gradually developed the tubes they needed to attract pollinators.
d. Different lines of *Costus* developed different tube types because they needed them in order to attract pollinators.

**Miami Blue Butterflies**

The Miami Blue, *Cyclargus thomasi bethunbakeri*, is a small, brightly colored butterfly endemic to Florida; additional subspecies occur in the Bahamas and Hispaniola. The butterfly inhabits tropical hardwood hammocks (closed canopy forests) and their associated margins, beachside scrub and tropical pine rocklands. Once widespread and locally abundant, the Miami blue has been eliminated from much of its former range due to ever-expanding urbanization and the associated loss of coastal habitat. It is now one of Florida’s most endangered insects with a single remaining extant population supporting less than 100 individuals.

Choose the one answer that best reflects how an evolutionary biologist would answer.
A typical natural population of butterflies consists of hundreds of butterflies. Which statement best describes the butterflies of a single species in an isolated population?

a. The butterflies share all of the same characteristics and are identical to each other.

b. The butterflies share all of the essential characteristics of the species; the minor variations they display don’t affect survival.

c. The butterflies are all identical on the inside, but have many differences in appearance.

d. The butterflies share many essential characteristics, but also vary in many features.

Fitness is a term often used by biologists to explain the evolutionary success of certain organisms. Which feature would a biologist consider to be most important in determining which butterflies were the “most fit”?

a. Large body size and ability to fly quickly away from predators.

b. Excellent ability to compete for food.

c. High number of offspring that survived to reproductive age.

d. High number of matings with many different females.

Assuming ideal conditions with abundant food and space and no predators, what would happen if a pair of Miami Blues were placed on an island off the coast of Florida?

a. The Miami blue population would grow slowly, as butterflies would have only the number of babies that are needed to replenish the population.

b. The Miami blue population would grow slowly at first, then would grow rapidly, and thousands of butterflies would fill the hammock.

c. The Miami blue population would never become very large, because only organisms such as weeds and bacteria reproduce in that manner.

d. The Miami blue population would continue to grow slowly over time.

Once a population of butterflies has been established for a number of years in a real (not ideal) tropical hardwood hammock with other organisms including predators, what will likely happen to the population?

a. The butterfly population will stay about the same size.

b. The butterfly population will continue to rapidly grow in size.
c. The butterfly population will gradually decrease until no more butterflies are left.
der. It is impossible to tell because populations do not follow patterns.

In butterfly populations, what are the primary changes that occur gradually over time?

a. The traits of each individual butterfly within a population gradually change.
b. The proportions of butterflies having different traits within a population change.
c. Successful behaviors learned by certain butterflies are passed on to offspring.
d. Mutations occur to meet the needs of the butterflies as the environment changes.

What did watching the video do for your understanding of evolution?

Was the story particularly important to your understanding? Give specific examples.

Was the imagery particularly important to your understanding? Give specific examples.

The program showed how some orchids have structures that seem to mimic the females of a species of wasp. Males are attracted to this structure and try to mate with it, and they inadvertently pollinate the flower. How would an evolutionary biologist explain this type of mimicry, assuming that the orchids’ ancestors did not have these structures?
CHAPTER 5.
WHAT IS “EDUCATIONAL” IN A FREE-CHOICE SCIENCE WORLD?
DETERMINING WHAT AUDIENCES BELIEVE ABOUT THE EDUCATIONAL
VALUE OF NATURE PROGRAMS

Abstract:
Wildlife and nature programs have the potential to engage and teach large
audiences about the natural world in free-choice learning environments, but they also
may be complicit in the public’s misunderstanding of basic scientific principles such as
evolution. Theory suggests that epistemological beliefs and cognitive dispositions affect
when and what individuals learn, especially for socio-scientific topics such as evolution.
As a result, audiences may look to descriptors like “educational” as they consider free-
choice learning experiences without any prior knowledge of the content value. This
paper reports on a study conducted to determine what audiences believe to be the
“educational value” of wildlife and other nature films. Results indicated that 95.9% (n =
294) of respondents believed nature films were “educational,” while slightly fewer
(87.4%) agreed that the primary goal for these programs is to teach about nature. Indeed,
the more respondents believed nature programs were designed to be educational, the
more they believed that both the science ($p < 0.001$) and nature ($p < 0.001$) were
portrayed accurately. In terms of the public understanding of science, audiences clearly
treat nature programs as credible and authoritative sources of information, a significant
issue given that they are expecting to learn from a source that often provides inaccurate
and misleading explanations of important processes such as evolution.
How educational are free-choice science learning opportunities? This question is difficult to answer because it first requires a definition of “educational” in an out-of-school context. From the perspective of those who produce science information for the public, the question may seem relatively straightforward. An “educational” opportunity would be one that is specifically designed to teach about a subject and is grounded in some disciplinary standards. In fact, key formal education resources, including Project 2061 (American Association for the Advancement of Science, 1990) and the National Science Education Standards (NSES; National Research Council, 1996), can be used to assess the adequacy of the information presented in resources outside of formal environments (Bybee, 2001). For example, Yager & Falk (2007) showcase a variety of successful examples of how the NSES can and should be applied to learning opportunities outside of school.

Educators differ about the labels applied in these environments, however; non-formal, informal, and free-choice have all been used to describe the distinction from structured school environments. According to Falk (2001), the term “informal” (and similarly non-formal) implies a difference in the process of learning as a function of the physical setting. On the other hand, “free-choice” implicates the social context and underlying motivation of the learner; a free-choice learning environment describes the unique, intrinsic needs and interests of the learner (Falk, 2001). In a free-choice context, therefore, individuals are free to choose when, where, and what they want to learn, and
those choices may or may not include resources guided by the NSES, for example. Obviously, examinations or other tests of understanding are not a component of the free-choice environment. Moreover, in free-choice contexts learners are not segregated by age or achievement like they may be in formal environments, and opportunities to learn science are generally designed for broad audiences. So, by assuming the actual learning process is the same across environments, defining “educational” from a producer’s perspective in a free-choice context may overlook the diversity and motivation of individuals approaching these educational opportunities. This paper explores the educational value of science knowledge in the free-choice environment from the perspective of the consumer.

From a consumer’s perspective, the free-choice science world is full of learning opportunities, including museums, zoos, local parks, science centers, news, documentaries, science- and non-science-fiction films, popular television, and the internet (Bates, 2005; Falk, Storksdieck, & Dierking, 2007). It is a “marketplace of ideas,” to borrow a metaphorical model of free-speech (see also Bartley III, 1987) which, in theory, allows for the open sharing of diverse ideas that leads ultimately to “truth.” Oliver Wendell Holmes, when he coined the metaphor, argued that “the best test of truth is the power of the thought to get itself accepted in the competition of the market” (Abrams v. United States, 250 U.S. 616, 1919). From a democratic theory perspective, the marketplace focuses on maximum idea exchange in the context of effective self-government, whereas the economic perspective of this free-speech model focuses on maximizing consumer welfare and competition (Napoli, 1999). These two theoretical perspectives combine to idealize the marketplace as a source of competitive, efficient,
and unregulated ideas, highly sensitive to consumer preferences, that yields informed
decision-making and a well-functioning democracy (Napoli, 1999). In fact, the
marketplace of ideas metaphor is most often used in the context of consumers’ and
citizens’ rights to receive information (Sweeney, 1984 in Napoli, 1999), but it is
criticized for its unwarranted broad application in jurisprudence (Hopkins, 1996).
Criticisms also have focused on issues of ontology associated with the “truth” to which
Holmes refers, as well as cognitive dissonance (Ingber, 1984; Baker, 1989), but can just
as easily include epistemology. Nevertheless, the metaphor serves as a useful model to
begin exploring how consumers approach educational opportunities related to science
outside of formal school contexts.

Why should science educators be concerned about the consumer’s perspective for
defining resources as “educational”? In the marketplace of ideas, the learning process
may be the same as formal learning environments, but marketplace influences, not
standards-based influences, visibly dominate. The marketplace is full of competing ideas
all vying for some competitive grasp of the public opinion of “truth.” Consumers must
choose among competing claims, but acceptance and rejection is rarely straightforward
(Locke, 1999); the processing of these diverse experiences is complex (Bates, 2005). As
Locke (1999) noted, the degree of acceptance and rejection of claims is a balance of
specific circumstances, experience, and other possible sources of assumed authoritative
knowledge. Therefore, the rhetorical organization of scientific discourse in the
marketplace of ideas may have a huge affect on consumer’s perspectives.

However, not all of the competing ideas in the free-choice marketplace are of
equal “educational” value. Knowledge constructed from poor sources obtained in the
marketplace can lead to misconceptions that can be very difficult to alter (Wandersee, Mintzes, & Novak, 1994), especially when adults are no longer influenced by formal learning environments. In addition, individuals motivated to learn are most likely to incorporate the broad knowledge messages communicated through free-choice venues (Falk, Heimlich, & Bronnenkant, 2008; Maurer & Reinemann, 2006). So, if messages that portray science poorly are common in the marketplace, motivated learners (i.e., those most likely to engage in science and society debates) will learn incorrect conceptions about key scientific processes, such as evolution.

Science educators need to understand all of the opportunities available to consumers of science as we address the public understanding of science and science literacy because both science in general, and evolution in particular, are being challenged in the marketplace for their “truth” value. Although philosophical discussions about ontology, axiology, and epistemology are enormously fruitful in a “metacognitive” sense, ultimately we need to return to an understanding of shared, public knowledge and its role in the scientific enterprise (Chalmers, 1999). For example, antibiotic resistance, gene therapy, disease, food production, environmental quality, and biotechnology are all areas of active biological research at the interface with society. While they are topics that clearly involve multiple ways of knowing, truly understanding the science underlying these topics requires a fundamental understanding of the theory of evolution (Antolin & Herbers, 2001). Knowing that antibiotics affect only bacteria, not viruses, is one level of understanding; understanding that time-honored drugs are no longer effective, perhaps a result of the overuse of antibiotics in everyday life, is another level of understanding; and
understanding that antibiotics are strong selective agents that act on the incomplete eradication of populations is yet another.

In the marketplace of ideas, scientists and non-scientists (e.g., creationists) present different versions of the world in rhetorical terms of competing reasoning of an argument; they use similar argumentative modes and techniques (Locke, 1999). Purveyors of messages in the marketplace often use discrepant or inconsistent information with the purpose of bringing about attitude change (Baker, 1989). Consumers may be unaware that museums, websites, and nature programs may be misused by groups with a particular agenda who manipulate these different media to compete for some “truth” value or credibility. For example, creationists may want to persuade the “uncertain” public to question the fundamentals of evolution, and science as a whole (Clark, Foster, & York, 2007; Scott & Matzke, 2007). Their goal is to return our society to its fundamentalist roots – to “defeat scientific materialism and its destructive moral, cultural and political legacies and to replace materialistic explanations with the theistic understanding that nature and human beings are created by God” (www.antievolution.org, also see Forrest & Gross, 2004) through a deliberate attack in the marketplace of ideas. Indeed, one part of their persuasion strategy includes the tactic of arguing for “equal time” for the “alternative theory” of intelligent design (Forrest, 2007).

More than any other, this strategy to invoke “equal time” appeals to people’s sense of reciprocity (Cialdini, 1993). It also plays well with journalists trying to meet some semblance of “balance,” and the appeal to “fairness” creates additional uncertainty by casting doubt on the credibility of anyone who will not “play by the rules.” As a
result, dissonance purveyors with a message perceived as strong by the uncertain consumer in the marketplace may be afforded the same credibility as an evolutionary scientist despite differences in information and knowledge provided. In this free-for-all marketplace of ideas, acceptance and rejection depend on consumers’ levels of understanding, their experiences, their culture, and the rhetorical organization that influences their responses to authoritative knowledge (Locke, 1999).

This is particularly true with media, like wildlife and nature programs, already considered “educational” by convention. While nature programs have the potential to engage and teach large audiences about the natural world in free-choice learning environments, they also may be complicit in the public’s misunderstanding of evolution. Both Mitman (1999) and Bousé (2000) clearly have endorsed embracing a highly skeptical view of reality presented in wildlife films, warning that this genre is driven by the need for compelling story lines rather than scientific accuracy. Dingwall & Aldridge (2006) suggest that nature film narratives implicitly endorse creationist accounts of life on earth, especially in the “blue-chip” sub-genre, a sub-genre with high production values and strong visual appeal, often without a host – the narration is voiced over the production.

The producers of these programs clearly represent different worldviews, but the information they add to the marketplace of ideas calls into question how to navigate through resources that have different connotations of “educational.” Ironically, a learner motivated to seek a free-choice science learning experience may have little information to assess the quality of the experience sought. From a consumer’s perspective, individuals must either already possess the knowledge to assess the quality of the experience or rely
on an assessment applied by some other source. Yet, awards and the credibility of the awarding institutions, accreditation, and sponsorships may not always be obvious, or straightforward characteristics.

Theoretical Underpinning and Research Questions

Television Audiences

Understanding how audiences approach free-choice science learning opportunities begins with new conceptualizations of these important consumers. Communication is not a linear model. No longer are studies of mass communication based on content-analysis (an assessment from producers’ perspectives) assuming a linear flow of information that audiences acquire (see Bates, 2005). For example, visitors to museums actively engage prior experiences in their interpretation of exhibits (Stocklmayer & Gilbert, 2002). Television, on the other hand, has a long history of considering audiences as passive receptacles of the medium’s account of the world (Wilson, 1993), but free-choice audiences do not just passively consume materials they find in the marketplace. Indeed, recent media-effects models incorporate audience engagement, using prior knowledge as a predictor of how media messages are internalized (Busselle, Ryabovolova, & Wilson, 2004; Potter, Pashupati, Pekurny, Hoffman, & Davis, 2002). Likewise, researchers exploring the public understanding of science suggest that future work should attend more fully to audience processing of science-related media along with their content analyses of texts (Bates, 2005).

Uses-and-gratifications research approaches television as a source of influence on conceptual understanding within the context of other possible influences (Rubin, 2004).
Audiences purposefully seek out programs from a diverse selection of television programs, as well as competing forms of media, with a specific goal in mind (Rubin, 2004). The consumer is an active viewer. The content alone may be less important to the meaning that is ultimately constructed than the media experiences audiences bring, the context in which they use media, and how and why they use the medium (Brown 1998).

What then is the influence of nature programming on knowledge development related to the understanding of evolution? Ultimately, two kinds of information are needed: (1) whether viewers possess, and use, the kinds of knowledge provided to them by the nature program, and (2) what kinds of knowledge viewers actually possess and use when understanding the nature program (Livingstone, 1998). Whether or not viewers can use the information depends in part on the conceptual understanding of science and, in the analysis that follows, evolution. In addition, the prior experiences audiences have with specific genres are critical in their textual readings and interpretation of new experiences (Bates, 2005; Busselle and Bilandzic, 2008; Livingstone, 1998).

Wildlife and nature programs that present evolutionary science poorly may be particularly insidious if audiences perceive the genre as “educational.” For example, audiences expect certain types of character and plot development in soap operas because of past experiences with soap operas, and they interpret these elements in light of those past experiences (Livingstone, 1998). Moreover, emotional connections affect recall and memory (Fujioka, 2005). Thus, past experiences with educational programming may leave audiences unaware that narratives in wildlife and nature programs are shaped from dramatic perspectives rather than educational perspectives. For example, wildlife programs often feature orphans as the main characters, but life history evolution predicts
that in species with high parental care (most charismatic megafauna), orphans will rarely survive to adulthood. Narration that incorporates teleology as a mechanism may not directly promote alternative “theories” to evolution, such as intelligent design (Dingwall and Aldridge 2006), but it can promote alternative conceptions nonetheless.

**Personal Epistemology**

Personal epistemology, or the beliefs an individual holds about knowledge and its production, may provide the theoretical grounding to predict media influences, and more broadly, the learning outcomes about science in the marketplace of ideas. Specifically, personal epistemology may be closely tied to the kind of knowledge viewers use when understanding a nature program. Numerous models are available that address how individuals’ beliefs about the certainty, source, justification, acquisition, and structure of knowledge affect learning (see Duell & Schommer-Atkins, 2001). Multi-dimensional models predict that these dimensions develop independently, whereas uni-dimensional models hypothesize that if one dimension develops the other dimensions also develop (Duell & Schommer-Atkins, 2001). Using a multi-dimensional approach, Schommer (1990) and Schraw et al. (2002) characterize personal epistemology along five axes: (1) the stability of knowledge, ranging from knowledge being unchanging to knowledge being tentative; (2) the source of knowledge, ranging from omniscient authority to reason and empirical evidence; (3) the structure of knowledge, ranging from isolated bits and pieces to integrated concepts; (4) the speed of learning, ranging from quick to not-at-all to gradual; and (5) the ability to learn ranging from being fixed at birth to being able to change.
The Reflective Judgment Model takes a uni-dimensional approach to personal epistemology. With extensive study, King & Kitchener (1994) describe seven stages in the development of complex reasoning about ill-structured problems (problems that cannot be solved with a high degree of certainty). These stages can be grouped into three levels: pre-reflective, quasi-reflective, and reflective thinking (King & Kitchener, 2004). Pre-reflective thinking is characterized by judgments that knowledge is certain and single correct answers exist that usually come from authority figures. Quasi-reflective thinking is characterized by judgments that uncertainty is part of the process of knowing, understanding that knowledge is an abstraction, and that it is constructed – not simply accepted from others. Individuals recognize different types and rules of evidence. Their judgments, however, indicate a tenuous relationship between gathering evidence and drawing conclusions, resulting in idiosyncratic views of knowledge claims. Reflective thinking is characterized by judgments that consistently use evidence and reason. Reflective thinkers are metacognitive thinkers, aware of the context dependency of knowledge and the need to revisit and re-evaluate conclusions and knowledge claims (King & Kitchener, 2004).

Although psychologists disagree about the independence of the development, the dimensions of most personal epistemology models generally fall into two classes (Hofer, 2004):

1. the nature of knowledge (what one believes knowledge is), including dimensions of certainty of knowledge and simplicity of knowledge; and
2. the nature or process of knowing (how one comes to know), including dimensions such as source of knowledge and justification for knowing (a dimension specific
to the Reflective Judgment Model that describes how individuals evaluate knowledge; King & Kitchener, 1994).

In addition, researchers generally agree that these beliefs play an important role in learning. For example, if people believe knowledge is certain and passed down by authority figures, they are less likely to question authority in the classroom (Schommer-Aikins, 2004) or in free-choice learning environments. This can be particularly worrisome with regards to “ill-structured” problems and controversial or socioscientific issues (Sadler, 2004) because the marketplace is full of authority-driven resources that derive their credibility from little more than name recognition (e.g., The Center for Science and Culture). Personal epistemology may be especially important in a broad cultural acceptance of evolution (Sinatra, Southerland, McConaughy, & Demastes, 2003).

The challenge, then, is that people continue to learn outside of the classroom, and they may be incorporating mixed messages into their understanding depending on the free-choice science resources from which they draw their knowledge. Therefore, understanding the educational beliefs audiences may have about nature films may be a key first step in improving evolution education in a broad context. Individuals motivated to learn may choose resources based on some unknown assessment of the “educational” value. If audiences generally consider wildlife and nature films to be educational, then the film’s flawed representation of science may not only be overlooked, but the misconceptions portrayed may be incorporated into viewers’ conceptualizations.

This study attempts to determine audience’s views of the educational value of wildlife and nature films. Personal epistemology may play an important role in the impact wildlife and nature programs have on the viewing public’s understanding of
evolution. If viewers believe knowledge is certain, then they may accept the information presented in wildlife and nature films without question. Similarly, if they believe knowledge is passed down from authority figures, they may be even less likely to question the authority of free-choice learning environments. Individuals with higher levels of education in general, and the natural sciences in particular, should be more wary of nature films than less well-educated individuals because of both advanced understanding of scientific processes and advanced development of personal epistemology. They should have less of an expectation for an “educational” experience.

A more subtle distinction lies with how educational audiences believe nature programs are designed to be. Addressing the design aspect may remove some bias associated with interest in nature programs in general. Indeed, audiences that believe wildlife and nature films are designed to be educational may be more likely accept the content as an accurate portrayal of natural processes, like evolution, than audiences that do not (Figure 5.1).

Materials and Methods

Developing the Instrument

I designed a survey (Chapter Appendix 1) using principles outlined in Dillman (2007). Twenty closed questions (e.g., Likert-scale, yes/no) intended to assess different aspects about beliefs about the educational value of nature programs or characteristics of the respondents were developed. These items were designed to elicit individuals’ beliefs about nature programs and the information used to make those judgments.
Figure 5.1. The research approach for determining audiences beliefs about the educational value of nature programs. Heavy arrows indicate the variables addressed with the audience survey.
Because defining the educational value of a television program was potentially problematic, the dependent variable, *educational*, was operationalized in the survey in a variety of forms. The first form was a direct question: “Do you believe that nature films are educational?” The second form was the development of a scale designed to identify the qualities respondents associate with the word. Participants were asked whether they agreed or disagreed with a series of statements (e.g., “If a nature film is educational, then it is accurate, the content has been reviewed/approved by scientists, and it presents the most current scientific understanding) scored on Likert-type scales from strongly agree to strongly disagree (Chapter Appendix 1).

Determining whether a nature film was “educational” was only one approach to the problem; determining whether audiences believed films were designed to be educational added a dimension that extended beyond whether an individual liked “educational” programs. In general, if a wildlife/nature film was designed to be educational, then by definition, one would expect the primary goal for the program to be teaching about wildlife and nature. Similarly, one would expect that the narration was written to explain and clarify the scientific understanding of the wildlife and/or the ecology of the topic. A subtler distinction was the expectation that the producers have advanced knowledge about wildlife and natural sciences. Therefore, *designed to be educational* was operationalized using several items that produced straightforward, nominal answers: (1) do you believe the primary goal of most nature films is to teach about nature, (2) do you believe the narration for nature films is written to explain and clarify what we know about nature, and (3) do you believe the producers for nature films are experts in the natural sciences. A second item addressed the knowledge respondents
believed producers had with regard to science. “Do you believe the producers for nature films know more about wildlife and natural sciences than you do?” was a Likert-scale item ranging from producers know significantly more to significantly less than the respondent (Rank Knowledge). A third form questioned whether respondents believed that science and nature were portrayed accurately (Portrayal of Science, Portrayal of Nature).

Two different metrics were used as independent variables: descriptive characteristics and epistemological characteristics. These variables were operationalized in several forms. Descriptive characteristics included gender, the highest level of education the participant had achieved, the number of courses respondents had taken that included biology, ecology, or the natural sciences, and the respondents’ self-reported interest in biology, ecology, or the natural sciences. Epistemological characteristics were based on recent assessments developed in personal epistemology (e.g., Hofer, 2000; King & Kitchener, 1994; Schommer, 1990; Schraw, Bendixen, & Dunkle, 2002) relating to the nature of knowledge (certainty and simplicity of knowledge) and the nature and the process of knowing (sources of knowledge and justification for knowing). People that believe knowledge is certain should be more likely to believe nature films are educational, and people that believe knowledge is passed down from omniscient authority should believe nature films are designed to be educational. Addressing how individuals related the structure of knowledge to their beliefs may not be as generalizable because some nature films clearly approach the story from an integrated standpoint. Nevertheless, understanding the complexity of knowledge should influence beliefs about the educational value of nature films.
The personal epistemology characteristics defined here are likely related to the descriptive characteristics (King & Kitchener, 1994), but personal epistemology metrics are subtle and require extensive questioning to obtain measurements. Therefore, I choose to include personal epistemology items specific to issues regarding evolution education as proxies for larger, more complex metrics. Nominal items included asking whether respondents believed nature films should only include facts about nature not theories, whether theories were important in nature films, whether trustworthy narrators are an important component of the educational experience, and whether issues have more than one side. Respondents also were asked about the influence of fact-based stories on knowledge simplicity, whether knowledge changed over time, and whether most things worth knowing are simple to understand (Chapter Appendix 1).

Items were tested in three phases to improve clarity and assess the information being collected. The first test included a group of five professionals with experience in education, evolution, and television production. These individuals spoke openly about their thinking as they answered each survey item. This initial testing indicated that some items required revision to clarify objectives, but all five professionals agreed in the value of the research. In addition, time to completion during this initial testing was measured.

The second phase was a “beta-test” with the revised items using students in an upper division forest ecology course taught at the University of Montana. This sample was selected specifically to determine how adults with an advanced knowledge of the natural processes portrayed in nature programs might think about the educational value of those programs. Results from this second phase indicated that some of the items were still not addressing their intended goals (e.g., the acceptability of faking situations in
nature films), so the survey was offered to ecologists and science educators at a national meeting of the Ecological Society of America as a third phase. Visitors to a scientific poster presenting the results from the beta-test of the instrument were solicited for their responses. Several open-ended items were included in this version of the instrument to determine whether concepts were being addressed adequately with other items. Reviewers were very helpful with their input, and the open-ended items were converted to closed items based on their responses. The final survey included 28 items, taking less than 10 minutes to complete (Chapter Appendix 1).

Implementing the Survey

The ideal survey population for this research is adults who may or may not watch nature films. This population does not include homeless individuals, but it does not exclude individuals that do not own television sets. This survey population would be the most broadly representative in assessing how one defines nature films as educational and who has thought about the educational value of these films. Alternatively, a population exposed to nature films frequently should represent the uppermost bounds of the variables being tested. The city of Missoula, Montana, annually hosts an international wildlife film festival, and the festival organizers actively involve the Missoula community, through citizen judging panels, parades, and/or public viewings. A major goal for the organizers is, in fact, promoting the educational value of these types of films. Moreover, Missoula is a community with close ties to the ecological world around it; a large proportion of the community lives there to experience the outdoors. Therefore, the likelihood of individuals thinking about the educational value of nature films in this
community is high. Indeed, this population should provide more illuminating results than a broad US survey population. Therefore, the sample frame was limited to Missoula County.

Participants were selected systematically from the most recent local telephone book using a randomly generated starting number. Only home addresses or individuals listing their business address as their sole address (e.g., lawyers) were included. The number of respondents required was derived from the amount of sampling error tolerated, the population size from which the sample was drawn, the variation in response characteristics, and the confidence interval desired for the estimates according to:

\[ N_s = \frac{N_p p(1-p)}{(N_p - 1)(B/C)^2 + p(1-p)} \]

where \( N_s \) is the completed sample size, \( N_p \) is the population size, \( p \) is the proportion of the population expected to choose one of two response categories, \( B \) is the accepted sampling error, and \( C \) is the Z statistic corresponding to the confidence level desired (Dillman, 2007). Using a 95% confidence interval, an 80/20 split (an homogenous response level), and a population of 35,000 households in the telephone book, the sample size calculated was 243 respondents. Dillman’s (2007) Tailored Design Method suggested that upwards of a 60% response rates could be expected, so a total of 480 respondents were contacted with a pre-notice postcard explaining the research and indicating the survey would be arriving shortly. Only one adult per household was directed to respond to the survey. A confidentiality agreement was in place per Institutional Review Board specifications at The University of Montana.

Roughly 30% of surveys were returned within 10 days of being sent. The 2006 American Community Survey (http://factfinder.census.gov/servlet/ADPTable?_bm=y&-
geo_id=05000US30063&-qr_name=ACS_2006_EST_G00_DP5&-ds_name=ACS_2006_EST_G00_&_lang=en&-redoLog=false&-_sse=on) provided a breakdown of the adult population of Missoula County. Early analyses confirmed predictions that the sample would represent an older segment of the population than census data would indicate; the mail sample was significantly short on individuals 40 years old and younger. Rather than continue on with an expensive method designed to elicit a greater response rate from this segment of the population, efforts were re-directed towards younger members of the Missoula community. A single reminder/thank-you letter was sent to all participants (which elicited an additional 75 responses), and that aspect of the survey was closed.

Although the population at The University of Montana may not have represented the entire missing age group, it was chosen as the most likely source for a large number of “younger” respondents. Invitations to complete surveys were solicited at different times of day at several different locations around the campus, targeting individuals that likely did not live on campus (parking lots, main points of entry/exit, and the “mall” between the library and the University Center) and thus, respondents tended to be older than students living in on-campus residences. To enhance the likelihood of broad representation, participants were offered the opportunity to enter a drawing for a $50 gift card for the university’s bookstore.

Analyses

Likert-scale variables: All of the 7-item Likert-scale variables were highly skewed with generally high kurtosis and consequently very little variability (Table 5.1).
Transformations did not improve the distributions of the responses. As a result, responses to these items were reclassified to reflect more even distributions than the original scale variables without losing much of the diversity of original data. The Likert-scale variable describing how educational respondents believed nature films actually are required additional re-coding. Initial examination of this variable indicated incongruities with other measures of this concept; respondents seemed to believe that nature films were less educational than they had indicated previously. Only 53% ranked the educational value at 5 or greater (of 7 possible), and 35% ranked it 3 or less. This ranking likely reflected an error in survey design, however. On the survey form, the item about the educational value of nature programs appeared immediately after the item asking respondents how educational they believed nature films were designed to be, but the two items scaled in opposite directions. As a result, respondents may have used the same scale on both items in their assessments, that is, inadvertently reversing the scale for their thoughts about the educational value of nature films. The item addressing design was highly skewed toward “designed to be educational”. In fact, the modal response was 2 (on a scale from 1 = designed to be educational to 7 = not designed to be educational), and 80% of respondents ranked the variable 3 or above. Respondents that did reverse scales should have been most apparent for those selecting the same numerical value for each item; someone that ranked the design of nature films as a “2” would have selected “2” for the educational value rather than “6” if they had reversed the scale. Indeed, 84 individuals selected identical values for the two items (20 of which were “4” or the equivalent of “no opinion”). When those respondents’ scores were reversed (i.e., “2”
Table 5.1.

*Measures of the shape of the distributions of Likert-scale items obtained from the audience survey.*

<table>
<thead>
<tr>
<th>Likert-scale Item</th>
<th>n</th>
<th>Skewness</th>
<th>SE</th>
<th>Kurtosis</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designed to be Educational</td>
<td>293</td>
<td>-0.917</td>
<td>0.142</td>
<td>0.651</td>
<td>0.284</td>
</tr>
<tr>
<td>Educational Value</td>
<td>295</td>
<td>-0.615</td>
<td>0.142</td>
<td>-0.543</td>
<td>0.283</td>
</tr>
<tr>
<td>Interest</td>
<td>297</td>
<td>-0.703</td>
<td>0.141</td>
<td>-0.273</td>
<td>0.282</td>
</tr>
<tr>
<td>Portrayal of Science</td>
<td>293</td>
<td>-0.556</td>
<td>0.142</td>
<td>0.158</td>
<td>0.284</td>
</tr>
<tr>
<td>Portrayal of Nature</td>
<td>293</td>
<td>-0.901</td>
<td>0.142</td>
<td>0.928</td>
<td>0.284</td>
</tr>
</tbody>
</table>

replaced with “6”), the distribution reflected the skewed distribution apparent in the variable “designed to be educational” (Figure 5.3).

Responses to 7-item Likert scales were converted from interval data by recoding them as three or four relatively equally distributed categories that varied depending on the original distribution of the data (Table 5.2). For example, responses of 1, 2, 3, and 4 on the Designed to be Educational Likert scale were recoded as “1”, 5 was recoded as “2”, 6 as “3”, and 7 as “4” to represent those who did not feel strongly about the design, those that were almost neutral, those that strongly believed, and those that very strongly believed that nature films were designed to be educational (the scale was reversed to reflect a similar direction in responses). Similarly, Interest was recoded to three categories representing those with high interest, those with moderate interest, and those with little or no interest.
Table 5.2.

Sample size and proportion of responses for categories of recoded Likert-scale items.

<table>
<thead>
<tr>
<th>Item</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designed to be Educational</td>
<td>60 (21%)</td>
<td>68 (23%)</td>
<td>116 (40%)</td>
<td>49 (17%)</td>
</tr>
<tr>
<td>Educational Value</td>
<td>58 (20%)</td>
<td>110 (37%)</td>
<td>99 (34%)</td>
<td>28 (10%)</td>
</tr>
<tr>
<td>Interest</td>
<td>86 (29%)</td>
<td>134 (45%)</td>
<td>77 (26%)</td>
<td>---(^a)</td>
</tr>
<tr>
<td>Portrayal of Science</td>
<td>44 (15%)</td>
<td>72 (25%)</td>
<td>94 (32%)</td>
<td>83 (28%)</td>
</tr>
<tr>
<td>Portrayal of Nature</td>
<td>73 (25%)</td>
<td>91 (31%)</td>
<td>101 (35%)</td>
<td>28 (10%)</td>
</tr>
</tbody>
</table>

\(^a\) Recoded scale only included three categories.

One additional Likert-scale item was recoded; Rank Knowledge was recoded from a 6-item scale to three categories. These categories represented those individuals that felt they know significantly more about wildlife than nature film producers, those that felt they know slightly more, and those that felt they know the same or less.

Variables were coded and analyzed using SPSS (v16.0). Generally, non-parametric tests (Chi-square, Mann-Whitney U-test, Kruskal-Wallis H-test) were used to analyze relationships because of the non-numerical nature of most variables and violation of normality assumptions for other variables, whether they be independent or dependent. Where variables did not appear to violate assumptions of normality, analogous parametric tests were used.
Results

Characteristics of the Sample Population

Of the 480 surveys sent out by mail, 207 were returned for a 43% return rate. In addition, 94 responses were obtained via the on-campus survey. The average age of the 289 participants that provided their age was 47.1 years old (SE = 1.20). Proportions in 10-year age categories were fairly consistent with proportions from the 2006 American Community census, however ages from 25 to 45 were slightly underrepresented and ages 55 to 64 were slightly overrepresented in this sample. In addition, more males (53%, n = 157) than females (47%, n = 139) completed surveys. Nearly half (49.0%) of all respondents had completed at least a bachelor’s degree, although, as would be expected, this sample was highly dependent upon the survey sub-sample; campus respondents were generally still completing their first degree and mail respondents had completed degrees (Table 5.3). Nevertheless, campus respondents had not taken more biology courses than mail respondents (Table 5.4).

Respondents were not all avid nature film viewers, as might be expected from a self-selected sample. In fact, responses were distributed fairly evenly across the options for frequency of viewing except those that rarely or never watched (> 1-2 times per month = 26%, 1-2 times per month = 23%, 1-2 times every few months = 26%, 1-2 times per year = 19%, and never = 5%; n=300). In addition, mail survey respondents were not more likely to represent avid nature film viewers than campus survey respondents (Figure 5.2). Interest in biology, ecology, or the natural sciences was highly skewed, however, with more than 70% of respondents ranking their interest as high (1-3 of a possible 7;
Table 5.3.

*The proportion of respondents in the mail and campus samples and the highest level of education they had attained.*

<table>
<thead>
<tr>
<th>Highest Level of Education</th>
<th>Mail</th>
<th>Campus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Some high school</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>High school diploma or equivalent</td>
<td>27</td>
<td>9</td>
</tr>
<tr>
<td>Some technical school</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Technical degree or equivalent</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Some college</td>
<td>35</td>
<td>45</td>
</tr>
<tr>
<td>2-year college degree</td>
<td>14</td>
<td>8</td>
</tr>
<tr>
<td>Bachelor’s degree</td>
<td>60</td>
<td>18</td>
</tr>
<tr>
<td>Master’s degree</td>
<td>37</td>
<td>9</td>
</tr>
<tr>
<td>Higher degree</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>204</strong></td>
<td><strong>94</strong></td>
</tr>
</tbody>
</table>

*Note.* The difference between samples was significant ($\chi^2 = 20.78$, 3 df, $p < 0.001$).
Table 5.4.

The proportion of respondents in the mail and campus samples and the number of courses they had taken that included biology, ecology, or the natural sciences.

<table>
<thead>
<tr>
<th>Number of Biology Courses</th>
<th>Mail</th>
<th></th>
<th>Campus</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>none</td>
<td>28</td>
<td>14%</td>
<td>7</td>
<td>7%</td>
</tr>
<tr>
<td>1-2</td>
<td>59</td>
<td>29%</td>
<td>33</td>
<td>35%</td>
</tr>
<tr>
<td>3-4</td>
<td>54</td>
<td>27%</td>
<td>23</td>
<td>24%</td>
</tr>
<tr>
<td>5-6</td>
<td>23</td>
<td>11%</td>
<td>10</td>
<td>11%</td>
</tr>
<tr>
<td>more than 6</td>
<td>39</td>
<td>19%</td>
<td>21</td>
<td>22%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>203</strong></td>
<td><strong>94</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* The samples were not significantly different ($\chi^2 = 3.405$, 4 df, $p = 0.49$).

Chapter Appendix 1). The campus survey respondents tended to be more interested in these subjects than the mail survey respondents, but the difference was not significant.

**Scale Construction**

Because the overall purpose of the survey was not to develop scales describing audience beliefs but to predict relationships between beliefs about knowledge and beliefs about the educational value of nature programs, items were generally treated as separate variables. Two scales were identified *a priori*, however: personal epistemology and audiences’ defining characteristics of nature programs. Different approaches were
Figure 5.2. Proportion of respondents from each sub-sample (mail survey n = 207, campus survey n = 93) watching nature films regularly (more than 1-2 times per month), frequently (1-2 times per month), often (1-2 times every few months), and rarely (1-2 times per year to never).

necessary in the development of these scales because the original items did not all yield the same kind of data (e.g., nominal or interval).

Personal Epistemology Dimensions: A limited and varying number of items addressed three axes of personal epistemology, so the items addressing the (1) tentative nature of knowledge, (2) source of knowledge, and (3) complexity of knowledge were collapsed to reflect the boundaries of their respective dimensions (Table 5.5). First, to address what respondents believed about the tentative nature of knowledge (from stable
Figure 5.3. Proportion of respondents ranking the educational value of nature programs from not educational to educational (n = 295). Original = non-recoded data. Recoded = data were adjusted for respondents likely misreading the ranking scale.

and unchanging to uncertain and evidentiary), a single Likert-type item that asked about agreement or disagreement with the idea that our basic understanding of a topic would not change in five years was collapsed to reflect the sample population. Fifty-nine percent of respondents strongly disagreed indicating some understanding of the tentative nature of knowledge, but 25% only mildly disagreed, and 16% believed otherwise. As a result, a high score of “3” was assigned to respondents that strongly disagreed, a moderate score of “2” to those that only mildly disagreed, and a low score of “1” to those that agreed or strongly agreed (Table 5.5).

Second, two items were posed that were directed at the source of knowledge from omniscient authority to evidence and reason. Respondents were asked about the
educational value of a nature film using a trustworthy narrator, and 39.0% indicated that yes, the narrator’s credibility was associated with an educational experience. Likewise, when asked whether respondents agreed or disagreed with the statement that if two different nature films present two different arguments about the same topic, at least one of them must be wrong, the majority of respondents disagreed (yes = 12.9%, no = 87.1%, n = 294). Using a cross-tabulation of the two yes/no items, individuals were assigned a score of “2” (use of evidence and reason) if they responded “no” to both, and a score of “1” (respond to omniscient authority) if they responded “yes” to either (Table 5.5).

Third, the last epistemological characteristic explored respondents’ beliefs about the structure of knowledge by focusing on the importance of isolated bits of information versus integrated concepts. When asked if scientific theories are unimportant because they are “just theories” (a vernacular misconception about the nature of scientific theories), a significant majority disagreed (yes = 13.4%, no = 86.6%). Similarly, when asked whether only facts not theories should be presented in nature films, 20.4% said “yes” and 79.6% said “no.” Two additional items addressed respondents’ beliefs about this complexity of knowledge using Likert-type scales. In general, respondents agreed that nature films were easy to understand because they contained so many facts, and that most things worth knowing in nature films are simple to understand (Figure 5.4). These four items employed different scales and collapsing required a series of cross-tabulations that divided respondents based on some ability to recognize the complexity of knowledge or their reliance on facts (Table 5.5). Consequently, I used cross-tabulations in three steps. First, I combined the two yes/no items into a single variable with three categories (“yes” to both, “no” to both, and combination of “yes” and “no”). Second, I combined
Table 5.5.

*Items used to measure and construct three nominal scales describing personal epistemology: understanding of the tentative nature of knowledge, the role of the source of knowledge, and understanding the complexity of knowledge.*

<table>
<thead>
<tr>
<th>Scale</th>
<th>Item</th>
<th>Mean</th>
<th>Mode</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tentative Nature of Knowledge</td>
<td>Stable Knowledge (Likert-type)</td>
<td>1.6</td>
<td>1</td>
<td>0-4</td>
</tr>
<tr>
<td></td>
<td>recoded</td>
<td>2.4</td>
<td>3</td>
<td>1-3</td>
</tr>
<tr>
<td></td>
<td>(low, medium, high)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Source of Knowledge</td>
<td>Trustworthy Narrator (yes/no)</td>
<td>1.6</td>
<td>2</td>
<td>1-2</td>
</tr>
<tr>
<td></td>
<td>Omniscient Authority (yes/no)</td>
<td>1.9</td>
<td>2</td>
<td>1-2</td>
</tr>
<tr>
<td></td>
<td>recoded</td>
<td>1.5</td>
<td>2</td>
<td>1-2</td>
</tr>
<tr>
<td></td>
<td>(low, high)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complexity of Knowledge</td>
<td>Nature of Theories (yes/no)</td>
<td>1.9</td>
<td>2</td>
<td>1-2</td>
</tr>
<tr>
<td></td>
<td>Fact-based Knowledge (yes/no)</td>
<td>1.8</td>
<td>2</td>
<td>1-2</td>
</tr>
<tr>
<td></td>
<td>Easy Knowledge (Likert type)</td>
<td>2.9</td>
<td>2</td>
<td>1-3</td>
</tr>
<tr>
<td></td>
<td>Simple Knowledge (Likert-type)</td>
<td>2.8</td>
<td>2</td>
<td>1-3</td>
</tr>
<tr>
<td></td>
<td>recoded</td>
<td>1.6</td>
<td>2</td>
<td>1-2</td>
</tr>
<tr>
<td></td>
<td>(low, high)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* See Chapter Appendix 1 for survey.

* Items within each sub-category were collapsed using cross-tabulation and grouping to produce the recoded variables.
Figure 5.4. The proportion of respondents that agreed or disagreed with the survey Likert-scale items addressing the epistemological characteristic Complexity of Knowledge (n = 296). Easy = “wildlife and nature films are easy to understand because they contain so many facts”. Simple = “most things worth knowing in nature films are simple to understand”.

Easy Knowledge with Simple Knowledge into another variable, the highest values (5-6) were recoded to “3”, the intermediate values (4) to “2”, and the lowest values (2-3) to “1”. Third, I combined the values from these two variables to produce the final collapsed item, with low values (2-3) representing low understanding (“1”) and high values (4-5) representing high understanding (“2”). These new collapsed variables (Tentative Knowledge, Source of Knowledge, Complex Knowledge) were used to test for effects of personal epistemology on respondents’ beliefs about the educational value of nature films.
The Defining Characteristics of Educational Nature Programs: One of the approaches used to determine what respondents believed about the educational value of nature programs involved a series of statements describing potential characteristics of educational nature films; respondents were asked to agree or disagree with each in a Likert-scale format. Not surprisingly, the responses to this series of items were highly correlated. In fact, only 11 relationships were not correlated at the $p < 0.001$ level, and those primarily involved respondents’ beliefs about giving human motivations to wildlife, whether nature films should fake situations, and whether review and approval by filmmakers was an important component of defining an educational film. Factor analysis indicated that the items could be reduced to two components that together explained 52% of the variation in the original items (Table 5.6). These two components represented the concept of accurate portrayal (Portrayal = scientist approval, accurate, real stories, current science, no sensationalism, and learn from watching), and the concept of representative production aspects (Production = fake scenes, anthropomorphism, and filmmaker approval; Table 5.7). As a result, the two new variables Portrayal and Production were used as dependent variables to examine audience beliefs about the educational value of nature programs.

Personal Epistemology

As theory would predict, the descriptive characteristics of respondents were indeed related to the epistemological characteristics (Table 5.9). For example, respondents with more education, especially in the natural sciences, generally had higher scores for both Tentative Knowledge and Complex Knowledge than those with less
Table 5.6.

*Factor structure of the initial and rotated factor analysis of items describing the characteristics of an educational nature program.*

<table>
<thead>
<tr>
<th>Component</th>
<th>Initial</th>
<th></th>
<th>Rotated</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Eigenvalue</td>
<td>% variance</td>
<td>Eigenvalue</td>
<td>% variance</td>
</tr>
<tr>
<td>1</td>
<td>3.135</td>
<td>34.831</td>
<td>3.128</td>
<td>34.752</td>
</tr>
<tr>
<td>2</td>
<td>1.601</td>
<td>17.794</td>
<td>1.609</td>
<td>17.873</td>
</tr>
</tbody>
</table>

*Note.* n = 262. Eigenvalues < 1.0 have been omitted.

education. Age also appeared to affect how respondents thought about the Source of Knowledge, but in an unexpected direction. Apparently, younger individuals were more wary of authority in nature programs than older individuals.

**Audience Beliefs about the Educational Value of Nature Films**

An overwhelming majority of respondents believed that nature films are educational (yes = 95.9%, no = 4.1%), and ranked the educational value high (mode =6, 65% ranking 5 out of 7 or above). This unwavering homogeneity of responses did not lend itself to meaningful analyses with the independent variables, however. Only level of interest and the epistemological characteristic Complex Knowledge were related to the educational value respondents assigned to nature films (Table 5.10). Those that tended to rank their level of interest as low also ranked the educational value of nature films as low.
Table 5.7.

*Factor loadings for components identified with factor analysis using the items describing the characteristics of an educational nature program.*

<table>
<thead>
<tr>
<th>Item</th>
<th>Component 1</th>
<th>Component 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accurate</td>
<td>0.767</td>
<td></td>
</tr>
<tr>
<td>Scientist Approval</td>
<td>0.742</td>
<td></td>
</tr>
<tr>
<td>Real Stories</td>
<td>0.741</td>
<td></td>
</tr>
<tr>
<td>Current Science</td>
<td>0.731</td>
<td></td>
</tr>
<tr>
<td>Sensation</td>
<td>0.633</td>
<td></td>
</tr>
<tr>
<td>Learn from Watching</td>
<td>0.517</td>
<td></td>
</tr>
<tr>
<td>Anthropomorphism&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td>0.824</td>
</tr>
<tr>
<td>Filmmaker Approval</td>
<td></td>
<td>-0.697</td>
</tr>
<tr>
<td>Fake&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td>0.606</td>
</tr>
</tbody>
</table>

*Note.* n = 262. All loadings smaller than 0.4 have been omitted.

<sup>a</sup> Reverse keyed.
Table 5.8.

The proportion of respondents in the mail and campus samples and their interest in biology, ecology, or the natural sciences.

<table>
<thead>
<tr>
<th>Level of Interest</th>
<th>Mail</th>
<th>Campus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (low interest)</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>28</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>52</td>
<td>14</td>
</tr>
<tr>
<td>6</td>
<td>49</td>
<td>19</td>
</tr>
<tr>
<td>7 (high interest)</td>
<td>45</td>
<td>32</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>203</strong></td>
<td><strong>94</strong></td>
</tr>
</tbody>
</table>

*Note.* The samples were not significantly different ($\chi^2 = 11.790$, 6 df, $p = 0.07$).
Table 5.9.

*Statistical relationships between descriptive and epistemological characteristics of the sample population.*

<table>
<thead>
<tr>
<th>Descriptive characteristic</th>
<th>Epistemological characteristic</th>
<th>Tentative Knowledge</th>
<th>Source of Knowledge</th>
<th>Complex Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>χ²</td>
<td>df</td>
<td>p</td>
</tr>
<tr>
<td>Highest level of education</td>
<td></td>
<td>13.310</td>
<td>6</td>
<td>0.038</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.888</td>
<td>0.004</td>
</tr>
<tr>
<td>Biology courses</td>
<td></td>
<td>23.183</td>
<td>8</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.045</td>
<td>4</td>
<td>0.090</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13.239</td>
<td>4</td>
<td>0.010</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td>2.834</td>
<td>2</td>
<td>0.242</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.616</td>
<td>1</td>
<td>0.057</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.423</td>
<td>1</td>
<td>0.515</td>
</tr>
<tr>
<td>Numerical age of respondent</td>
<td></td>
<td>2.485</td>
<td>2, 282</td>
<td>0.208</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.282</td>
<td>1, 273</td>
<td>0.022</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.153</td>
<td>1, 265</td>
<td>0.284</td>
</tr>
</tbody>
</table>
Table 5.10.  

*Statistical relationships between items that addressed whether respondents believed nature programs were educational and respondent characteristics.*

<table>
<thead>
<tr>
<th>Respondent characteristics</th>
<th>Educational</th>
<th>Educational Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Descriptive characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Highest level of education</td>
<td>$\chi^2$</td>
<td>2.660</td>
</tr>
<tr>
<td></td>
<td>df</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.447</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.746</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Biology courses</td>
<td>$\chi^2$</td>
<td>6.457</td>
</tr>
<tr>
<td></td>
<td>df</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.168</td>
</tr>
<tr>
<td></td>
<td></td>
<td>17.084</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Interest</td>
<td>$\chi^2$</td>
<td>0.632</td>
</tr>
<tr>
<td></td>
<td>df</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.729</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16.713</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Gender</td>
<td>$\chi^2$</td>
<td>0.137</td>
</tr>
<tr>
<td></td>
<td>df</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.711</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.854</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Numerical age of respondent</td>
<td>$F$</td>
<td>1.871</td>
</tr>
<tr>
<td></td>
<td>df</td>
<td>1, 280</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.172</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.196</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3, 278</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.089</td>
</tr>
<tr>
<td><strong>Epistemological characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tentative Nature of Knowledge</td>
<td>$\chi^2$</td>
<td>3.602</td>
</tr>
<tr>
<td></td>
<td>df</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.165</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.899</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Source of Knowledge</td>
<td>$\chi^2$</td>
<td>0.344</td>
</tr>
<tr>
<td></td>
<td>df</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.558</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.703</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Complexity of Knowledge</td>
<td>$\chi^2$</td>
<td>0.402</td>
</tr>
<tr>
<td></td>
<td>df</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.526</td>
</tr>
<tr>
<td></td>
<td></td>
<td>17.548</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.001</td>
</tr>
</tbody>
</table>

*Note.* Educational was operationalized as a nominal variable (yes/no) and a Likert-scale variable (range 1-7) whose values were collapsed to four nominal categories (see above).
Similarly, those less likely to think of knowledge as isolated bits (Complexity of Knowledge) were more critical and likely to rank the educational value as low.

Another measure of what audiences believed about how educational nature programs are involved agreeing or disagreeing with a series of statements describing the characteristics of educational nature programs. Respondents clearly believed that to be educational nature films should be accurate, the stories should have really happened, nature films should present the most current findings, and people should learn from watching (Figure 5.5). The majority of respondents at least mildly agreed (mildly agree = 53.4%, strongly agree = 30.0%) that to be educational, scientists should have approved the content of the nature film. Although respondents agreed that nature films should not sensationalize how nature works (Figure 5.5), respondents did not feel strongly about anthropomorphizing wildlife or faking situations to add to the story (Figure 5.6). Feelings were mixed about whether other filmmakers should have approved the content; about half agreed and the other half disagreed.

As with the straightforward items about educational value, little evidence indicated that respondents waivered from their beliefs when defining characteristics of nature programs. Portrayal (the new scale developed from the data) was related only to the personal epistemology characteristic Complex Knowledge (Table 5.11). Those with higher Complex Knowledge scores had lower scores on the Portrayal scale than those with lower Complex Knowledge scores. The highest level of education and all three epistemological characteristics were related to the new scale, Production, that described respondents’ beliefs about production aspects of nature films. Higher levels of education and higher epistemological scores were related to higher Production scores.
Figure 5.5. Proportion of respondents that agreed or disagreed with items comprising the Portrayal scale characterizing educational nature films (n = 262).

Figure 5.6. Proportion of respondents that agreed or disagreed with items comprising the Production scale characterizing educational nature films (n = 262).
When examined separately, epistemological characteristics were related to the use of anthropomorphism in nature films, and the role of film-maker approval, but not whether producers fake scenes to add to the story (Table 5.12). Individuals that tended to believe in unchanging knowledge passed from authority in isolated bits were more likely to accept anthropomorphism as a characteristic of nature programs than those that accepted knowledge as tentative (Tentative Nature of Knowledge), arising from reason and evidence (Source of Knowledge), and complex (Complexity of Knowledge). Similarly, individuals that accepted knowledge as tentative, arising from reason and evidence, and complex were less likely to believe that film-maker approval was an important characteristic in defining educational nature programs than those that believe in unchanging knowledge passed from authority in isolated bits.

Audience Beliefs about the Design of Nature Programs

As discussed previously, respondents believed nature films were designed to be educational; over half scored them in one of the top two positions. Similarly, respondents believed that the primary goal of most nature films is to teach about nature (yes = 87.4%, no = 12.6%), and the narration for nature films is written to explain and clarify what we know about nature (yes = 87.2%, no = 12.8%). When asked to rank their knowledge versus nature program producers, respondents consistently believed they knew less about wildlife and the natural sciences than producers. In fact, nearly half (47.2%) believed producers knew “significantly more” than they did. In contrast, however, only 20.9% of respondents believed producers for nature films were experts in the natural sciences.
Table 5.11.

*Statistical relationships between items that addressed the defining characteristics of nature programs and respondent characteristics.*

<table>
<thead>
<tr>
<th>Respondent Characteristics</th>
<th>Portrayal</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Descriptive characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Highest level of education</td>
<td>0.911</td>
<td>6.529</td>
</tr>
<tr>
<td>df</td>
<td>3, 255</td>
<td>3, 255</td>
</tr>
<tr>
<td>p</td>
<td>0.436</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Biology courses</td>
<td>0.638</td>
<td>2.129</td>
</tr>
<tr>
<td>df</td>
<td>4, 255</td>
<td>4, 255</td>
</tr>
<tr>
<td>p</td>
<td>0.636</td>
<td>0.078</td>
</tr>
<tr>
<td>Interest</td>
<td>1.982</td>
<td>1.401</td>
</tr>
<tr>
<td>df</td>
<td>2, 259</td>
<td>2, 259</td>
</tr>
<tr>
<td>p</td>
<td>0.140</td>
<td>0.248</td>
</tr>
<tr>
<td>Gender</td>
<td>0.083</td>
<td>3.766</td>
</tr>
<tr>
<td>df</td>
<td>1, 258</td>
<td>1, 258</td>
</tr>
<tr>
<td>p</td>
<td>0.774</td>
<td>0.053</td>
</tr>
<tr>
<td>Numerical age of respondent</td>
<td>&lt;0.001</td>
<td>0.006</td>
</tr>
<tr>
<td>df</td>
<td>1, 253</td>
<td>1, 253</td>
</tr>
<tr>
<td>p</td>
<td>0.927</td>
<td>0.220</td>
</tr>
<tr>
<td><strong>Epistemological characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tentative Nature of Knowledge</td>
<td>0.039</td>
<td>8.057</td>
</tr>
<tr>
<td>df</td>
<td>2, 258</td>
<td>1, 258</td>
</tr>
<tr>
<td>p</td>
<td>0.962</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Source of Knowledge</td>
<td>0.371</td>
<td>10.273</td>
</tr>
<tr>
<td>df</td>
<td>1, 255</td>
<td>1, 255</td>
</tr>
<tr>
<td>p</td>
<td>0.543</td>
<td>0.002</td>
</tr>
<tr>
<td>Complexity of Knowledge</td>
<td>13.997</td>
<td>8.357</td>
</tr>
<tr>
<td>df</td>
<td>1, 251</td>
<td>1, 252</td>
</tr>
<tr>
<td>p</td>
<td>&lt;0.001</td>
<td>0.004</td>
</tr>
</tbody>
</table>
### Table 5.12.

**Statistical relationships between the three items comprising the Production variable and epistemological characteristics.**

<table>
<thead>
<tr>
<th>Epistemological characteristics</th>
<th>Anthropomorphize</th>
<th>Fake Scenes</th>
<th>Film-Maker Approval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tentative Nature of Knowledge</td>
<td>$\chi^2$</td>
<td>15.023</td>
<td>6.892</td>
</tr>
<tr>
<td></td>
<td>df</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.020</td>
<td>0.331</td>
</tr>
<tr>
<td>Source of Knowledge</td>
<td>$\chi^2$</td>
<td>9.980</td>
<td>3.176</td>
</tr>
<tr>
<td></td>
<td>df</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.019</td>
<td>0.365</td>
</tr>
<tr>
<td>Complexity of Knowledge</td>
<td>$\chi^2$</td>
<td>17.873</td>
<td>0.519</td>
</tr>
<tr>
<td></td>
<td>df</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>&lt;0.001</td>
<td>0.915</td>
</tr>
</tbody>
</table>

The variables addressing the design of nature films were only somewhat related to descriptive characteristics. Individuals with some post-high school education were most likely to agree that the primary goal of nature films was to teach about nature than individuals with more or less education (Table 5.13); the number of biology courses respondents had taken was not related to their beliefs. Although age was not related to agreeing with this goal, gender was. Females were more likely than males to agree that the primary goal was to teach about nature. Females also were more likely than males to agree that the narration is written to clarify what we know about nature. Although a surprising proportion of respondents believed that producers know more about wildlife and the natural sciences than they did (Figure 5.7), biology education, interest, gender, and age influenced respondents’ ranking. Those with more biology education and/or interest tended to rate producers’ knowledge relative to their own as being lower than
those that had fewer biology courses or less interest. Females underrated their knowledge more than males. Older individuals also were more likely to believe nature program producers know significantly more about the natural world than they do. In addition, gender and interest were related to how strongly respondents believe nature programs were designed to be. Females ranked this variable the highest more often than males. Respondents with high interest tended to believe nature programs were designed to be educational more strongly that those with low interest (Table 5.13).

Personal epistemology was related to design variables with most effects resulting from how people thought about the complexity of knowledge. The variables describing respondents’ understanding of knowledge complexity were related to whether respondents believed the primary goal of nature films was to teach about nature, whether the narration was written to clarify what we know about nature, and how educational respondents believed nature films were designed to be (Table 5.13). In all three relationships, individuals with more developed personal epistemologies were more likely to identify the production of nature films as media goals rather than educational goals.

Indeed, defining experts may be an important media literacy issue in nature films. The personal epistemology variables that described the source and complexity of knowledge explained how respondents ranked their knowledge relative to producers was affected by both how they viewed the Source of Knowledge and the Complexity of Knowledge variables (Table 5.13). Similarly, responses to whether or not respondents believed producers were experts. In fact, respondents who believed in stable knowledge (Tentative Nature of Knowledge) passed from authority (Source of Knowledge) in
Table 5.13.

Statistical relationships between items related to how educational nature programs are designed to be and respondent characteristics.

<table>
<thead>
<tr>
<th>Respondent Characteristics</th>
<th>Primary Goal</th>
<th>Narration</th>
<th>Rank Knowledge</th>
<th>Designed to be Educational</th>
<th>Experts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Descriptive characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Highest level of education</td>
<td>χ²</td>
<td>7.780</td>
<td>0.879</td>
<td>3.712</td>
<td>10.172</td>
</tr>
<tr>
<td></td>
<td>df</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>.051</td>
<td>0.830</td>
<td>0.716</td>
<td>0.337</td>
</tr>
<tr>
<td>Biology courses</td>
<td>χ²</td>
<td>3.501</td>
<td>2.043</td>
<td>37.776</td>
<td>6.904</td>
</tr>
<tr>
<td></td>
<td>df</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.478</td>
<td>0.728</td>
<td>&lt;0.001</td>
<td>0.864</td>
</tr>
<tr>
<td>Interest</td>
<td>χ²</td>
<td>0.533</td>
<td>0.255</td>
<td>22.591</td>
<td>33.781</td>
</tr>
<tr>
<td></td>
<td>df</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.766</td>
<td>0.880</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Gender</td>
<td>χ²</td>
<td>4.236</td>
<td>4.215</td>
<td>7.178</td>
<td>8.971</td>
</tr>
<tr>
<td></td>
<td>df</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.040</td>
<td>0.040</td>
<td>0.028</td>
<td>0.030</td>
</tr>
<tr>
<td>Numerical age of respondent</td>
<td>F</td>
<td>0.017</td>
<td>0.237</td>
<td>5.820</td>
<td>1.175</td>
</tr>
<tr>
<td></td>
<td>df</td>
<td>1, 271</td>
<td>1, 281</td>
<td>1, 286</td>
<td>3, 276</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.897</td>
<td>0.627</td>
<td>0.003</td>
<td>0.319</td>
</tr>
<tr>
<td><strong>Epistemological characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tentative Nature of Knowledge</td>
<td>χ²</td>
<td>2.596</td>
<td>0.692</td>
<td>2.302</td>
<td>9.047</td>
</tr>
<tr>
<td></td>
<td>df</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.273</td>
<td>0.708</td>
<td>0.680</td>
<td>0.171</td>
</tr>
<tr>
<td>Source of Knowledge</td>
<td>χ²</td>
<td>0.853</td>
<td>0.825</td>
<td>11.600</td>
<td>1.712</td>
</tr>
<tr>
<td></td>
<td>df</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.356</td>
<td>0.364</td>
<td>0.003</td>
<td>0.634</td>
</tr>
<tr>
<td>Complexity of Knowledge</td>
<td>χ²</td>
<td>10.891</td>
<td>5.058</td>
<td>7.436</td>
<td>13.509</td>
</tr>
<tr>
<td></td>
<td>df</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.001</td>
<td>0.025</td>
<td>0.024</td>
<td>0.004</td>
</tr>
</tbody>
</table>
Figure 5.7. The proportion of respondents ranking producers’ knowledge about wildlife and the natural sciences as higher or not higher than their own given the number of courses they’d taken that included biology, ecology, or the natural sciences (n = 297).

Isolated bits (Complexity of Knowledge) were more likely to agree that producers were experts than those who did not.

Two items were included in the survey specifically to test the effects of beliefs about the *design* of nature programs on respondents’ beliefs about the credibility of the resource. In every case, respondents’ beliefs about the credibility of the information in nature programs were related to their beliefs about the design of the programming. For example, if respondents believed that the primary goal of nature programs was to teach and the narration was written to clarify what we know about nature, they often believed that both the science was portrayed accurately and nature was portrayed accurately (Table 5.14). Similarly, the relationships between both the accurate portrayal of science and of
Table 5.14.

Statistical relationships between items related to how educational nature programs are designed to be and how accurately respondents believe the science and nature are portrayed.

<table>
<thead>
<tr>
<th>Educational Value</th>
<th>Primary Goal</th>
<th>Narration</th>
<th>Rank Knowledge</th>
<th>Designed to be Educational</th>
<th>Experts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portrayal of Science</td>
<td>$\chi^2$ 23.037</td>
<td>27.250</td>
<td>26.502</td>
<td>99.564</td>
<td>15.849</td>
</tr>
<tr>
<td></td>
<td>df 3</td>
<td>3</td>
<td>6</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>p &lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Portrayal of Nature</td>
<td>$\chi^2$ 18.641</td>
<td>12.162</td>
<td>28.882</td>
<td>144.4821</td>
<td>20.042</td>
</tr>
<tr>
<td></td>
<td>df 3</td>
<td>3</td>
<td>6</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>p &lt;0.001</td>
<td>0.007</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

nature were related to respondents’ beliefs about producers’ expertise. Moreover, the degree to which respondents believed nature films were designed to be educational was related to the accuracy of the science and nature portrayed. Likewise, the degree to which respondents believed producers knew more about the natural sciences than they did was related to respondents’ beliefs about the accuracy of the science and nature portrayed.

Discussion

Only recently have science educators attempted to define “educational” in free-choice environments. Typically, these types of explorations are based on deficit models – models that set a standard and then determine how well the public rises to meet that standard with their knowledge (Sturgis & Allum, 2004). Researchers exploring the free-
choice environment, however, have stressed that people are very competent in specific areas of their own choosing and related to their own interests (Falk, 2002). This survey took a different approach, allowing the public to identify whether they viewed nature programs as educational resources.

The overwhelming majority of respondents believed nature programs were educational. More importantly, respondents believed that nature films were designed to be educational and people should learn from watching them. Consequently, the role these programs play in the public understanding of science and evolution in the marketplace of ideas may be significantly related to these two variables alone. Nearly half of the respondents indicated that they watched nature programs at least once or twice a month. As an audience, therefore, they are not only motivated to learn, they are thinking of the experience as “educational.”

How did consumers define educational nature films? Respondents were asked to rank their agreement or disagreement with a series of statements about potential characteristics of nature programs. Expectations were clearly related to accurate explanations of current scientific understanding. Nevertheless, audiences were more open than expected to anthropomorphizing and faking scenes (apparently only as long as the stories were not overly sensationalized). Although the item was designed to address how we might define “educational” in terms of a nature show, respondents may have interpreted the question to mean that if a show had been identified as educational, how well did it meet the criteria listed. Either way, these diverging concepts might have been related to audiences’ perceptions of these programs as a form of entertainment; over 90% agreed that nature films are designed to be entertaining. Because this inconsistency was
not related to personal epistemology, perhaps respondents believed they were savvy enough about the medium to see production value in the visual and story aspects at the expense of realism.

Items about where one might go to watch educational and entertaining programs on the survey instrument indicated similar conflict with the definition of “educational” in free-choice situations. Most respondents indicated that they would turn to the Discovery Channel (versus PBS) to watch “entertaining” shows. To watch “educational” shows, however, they would turn to PBS and Discovery. Individuals may consider PBS a credible source that airs programs of high educational value. Alternatively, if respondents have conceptually defined “educational” as “not entertaining,” it may be from experiences that led them to believe PBS shows one kind of nature program (dry, boring, “educational”) and the Discovery Channel shows another (entertaining and, perhaps, even “educational”). In addition, some of the difficulties in defining educational in this context may be due to a “nature film tautology”: nature films are educational, by definition, and the two concepts cannot be disconnected.

If the marketplace of ideas holds similar dilemmas for consumers approaching other free-choice science resources, understanding personal epistemology may provide valuable insight to how these dilemmas play out. Public understanding of science research wrestles with questions of expertise and authority related to socioscientific issues (e.g., Collins & Evans, 2002; Jasanoff, 2003; Kolstø, 2001; Rip, 2003; Wynne, 2003), and many authors suggest examining how individuals negotiate through the knowledge offered in the marketplace (e.g., Felt, 2000). This work highlights some important points easily transferrable to other free-choice opportunities.
For example, personal epistemology research suggests that individuals who believe knowledge is certain and passed down from “expert” filmmakers serving as authority figures were not likely to question the information presented. As predicted, several relatively basic measures of personal epistemology were related to what respondents believed about the role of expertise. In fact, those respondents relying on authority as a source of knowledge were most likely to believe in the importance of filmmaker approval ($\chi^2 = 9.611$, 1 df, $p = 0.022$), as well as the expertise of film-makers. Respondents who believed in complex knowledge were more critical of the importance of film-maker approval in defining an educational experience, as well as anthropomorphism as a device, and the educational value of nature films in general.

Surprising were the significant relationships between the respondents’ ranking of their own knowledge relative to filmmakers and how respondents viewed authority and knowledge complexity. Even though many respondents had significant experience with biology, ecology, and the natural sciences, nearly 46% of respondents believed filmmakers knew significantly more about science and nature than they did. This relationship was apparent during the testing of the instrument, too. In fact, the pre-test individuals were upper-level university students majoring in ecological sciences. Most had significant experience with these disciplines, yet over half believed filmmakers had more expertise than they did. Few nature film producers, in fact, have advanced degrees in science, however; their expertise comes in the form of telling stories through television. Even the Natural History Filmmaking Master of Fine Arts Program at Montana State University, a program designed specifically to enhance nature film production, does not require advanced coursework in the sciences (students are
encouraged to develop working relationships with scientists and assist in field projects; http://naturefilm.montana.edu/index.php). Therefore, respondents may have presumed some context-specific expertise associated with the filmmaker’s personal research and ability to tell a story. Apparently, the relationship is affected by advanced familiarity with the biological sciences, however. The small sample of ecologists and science educators used in the pre-testing was less likely to believe filmmakers knew significantly more than they did; over half ranked them as slightly or significantly less. Nevertheless, the fact that the accuracy of the portrayal of both the science and nature were strongly related to how respondents ranked their personal knowledge speaks volumes about how consumers may approach expertise and authority in the marketplace.

Of greater concern is the level of personal epistemology at which most individuals operate according to the Reflective Judgment Model (King & Kitchener, 1994). Years of research indicate that after four years of college, individuals are thinking at only a quasi-reflective level (understanding that knowledge is constructed – not simply accepted from others, recognizing that uncertainty is part of the process of knowing and different types and rules of evidence, but subject to idiosyncratic views of knowledge claims). In this view, the variability in how diverse publics interface with science in the marketplace may be the result of personal epistemologies that predominately represents pre-reflective and quasi-reflective thinking. The idiosyncratic beliefs about credibility and authority associated with these levels of reflective judgment result because of the tenuous relationship between gathering evidence and drawing conclusions in the marketplace of ideas (King & Kitchener, 1994).
Television may be especially important to consider from a personal epistemology perspective. Because of its broad reach and celebrity-making power, television may have particularly strong appeal in terms of credibility and authority. de Cheveigné and Véron (1996) classified television viewers according to their attitudes toward television and attitudes toward acquiring knowledge from television (Table 5.15). They found that even viewers who believed the acquisition of knowledge from television was problematic (“beneficiaries” and “intellectuals”) relied strongly on credibility and authority in their judgments. Indeed, Livingstone (1998) suggested that when it is a trusted and solemn source of information, television likely affects viewers in a strong sense. Paradoxically, nature films classified as “blue-chip” (‘mega-fauna’ in an environment of visual splendor, a dramatic story line, and marked by the absences of politics, people or historical reference points) and “presenter-led” (expanded human presence, more human/animal interaction, dynamic editorial approaches) generally contained the most egregious narratives with respect to evolution (Dingwall & Aldridge, 2006). Although D. R. Anderson (1998) argued that “educational television is not an oxymoron,” not all “educational” television is created equal. The influence of apparently credible sources combined with narratives that introduce misconceptions to broad and diverse audiences may make “educational” television the antithesis of “educational.”

The results from this survey indicate at least three issues that need to be addressed more thoroughly within the theoretical framework of personal epistemology: issues of gender, issues surrounding knowledge gaps, and issues surrounding evolution understanding. Females underrated their knowledge relative to producers more than males and more strongly believed nature films were designed to be educational. Gender
Table 5.15.

Classification of science television viewers according to their attitudes toward television and acquiring knowledge from television (from de Cheveigné & Véron, 1996).

<table>
<thead>
<tr>
<th>Attitude toward television</th>
<th>Acquisition of knowledge from television</th>
</tr>
</thead>
<tbody>
<tr>
<td>Favorsable</td>
<td>“beneficiaries”</td>
</tr>
<tr>
<td></td>
<td>TV is a legitimate source of knowledge, and science is accessible</td>
</tr>
<tr>
<td></td>
<td>a credible authority is essential</td>
</tr>
<tr>
<td>Not favorable</td>
<td>“intellectual”</td>
</tr>
<tr>
<td></td>
<td>TV is not a legitimate source of knowledge</td>
</tr>
<tr>
<td></td>
<td>prefer documentaries with unmediated viewpoint</td>
</tr>
<tr>
<td>“intimistic”</td>
<td>positive attitudes toward TV, but more critical and less curious about learning</td>
</tr>
<tr>
<td>“excluded”</td>
<td>“can’t” understand science and what they do understand can’t be science</td>
</tr>
</tbody>
</table>

is apparently related to disparities in attitudes toward science that materialize from socio-demographic backgrounds (education and religious belief; Hayes & Tariq, 2000).

Personal relevance is obviously important to discussions about science and evolution (Sadler, Chambers, & Zeidler, 2004). In addition, women tend to use media that fosters informal learning less than men and may hold comparatively lower levels of scientific knowledge (Nisbet et al., 2002).

Likewise, the knowledge-gap hypothesis predicts that increasing the flow of news on topics, such as climate change and evolution, results in greater acquisition of knowledge about that topic among the more highly educated segments of society than
less educated segments (Tichenor, Donohue, & Olien, 1970). Indeed, knowledge gaps may result specifically because individuals with more education tend to have more developed personal epistemologies and may be able to navigate the competing ideas of the marketplace better than those less well educated. The results from this survey indicate that nature programs may fall into that gap.

Other research has shown gender to be an important predictor of attitudes about human evolution (Haider-Markel & Joslyn, 2008; Schibeci, 1984). These results suggest that females should have poorer understanding of evolution, especially if they are using nature films to construct knowledge. Clearly, future research needs to examine the role of personal epistemology in gender-specific understanding of evolution.

Ultimately, these findings may have particular importance in terms of how evolution is portrayed in nature films. Evolution educators have a distinctly different view of the educational value of nature films (see also Smith & Resier, 1997). Content-analyses indicate serious issues regarding the presentation of this important biological process (Aldridge & Dingwall 2003; Dingwall & Aldridge, 2006). Although the approach and experiences audiences bring to a learning opportunity in the free-choice marketplace may be more important to learning outcomes than the content (D. Anderson, Lucas, & Ginns, 2003; Falk & Adelman, 2003; Gijlers & de Jong, 2005; Lawson & Worsnop, 1992; Livingstone, 1998; Rubin, 2004; Stocklmayer & Gilbert, 2002), the combination of audience approach and poor science content has the potential to significantly affect conceptions about evolution.

Evolution is a complex concept, and the path of least resistance is often the wrong one. Personal experiences comprise a powerful source of perceived evidence that can be
incorporated into “lay theories” about how the world works. Where these lay theories relate to ecology, and evolution in particular, they can lead to misconceptions that can be very difficult to alter (Wandersee et al., 1994). If a nature program resonates on some level with individuals’ “lay theories” about evolution, it may have long-lasting effects on learning. For example, people identify with individuals, not populations, and the concepts of “improvement” and “adaptation” frequently are applied to individuals overcoming adversity – everyone loves the triumph of the underdog. If this application stems from an experience they perceive watching television (such as the orphaned cheetahs that survive in the harsh and cruel savannah), it may end up as an unconscious embodiment of the process of evolution (R. W. Busselle & Greenberg, 2000). Of course these events are relevant to biological evolution; who survives and who does not underlies a major component of fitness and the process of natural selection.

Conclusions

From a consumer’s perspective, scientific “truth” in the free-choice marketplace might be defined through some connotation of “educational,” and this definition may be much broader than how a producer (science educator) might define it. Understanding epistemological worldviews may help audiences bridge this gap. Epistemological worldviews that ultimately help consumers navigate through science learning opportunities in the marketplace of ideas may be developed and nurtured in formal education environments with “mile-deep” philosophies that incorporate the nature of knowledge in general, and the nature of scientific knowledge in particular (see Alters & Nelson, 2002; Bell & Lederman, 2003; Cobern, 2000). Teachers also need to be aware of
the flaws in nature film narratives. Beautifully crafted nature programs that highlight the splendor of the natural world may be valuable tools to generate interest in ecology and science in students. However, constructivist frameworks clearly caution about the difficulties with which alternative conceptions are overcome (Mintzes & Wandersee, 1998). Nature film narratives that use concepts of “design” indiscriminately may be promoting misconceptions unintentionally (Dingwall & Aldridge, 2006). A broadly defined “educational” experience used in the science classroom may be even more harmful to science conceptions than a similar experience in the free-choice world.

Nevertheless, as Ziman (1992) noted, in the marketplace of ideas “the public receives and uses scientific knowledge that is incoherent, practically inadequate, incredible, and inconsistent.” If nature films are an important source of free-choice science learning, the issue is clear: audiences inevitably will incorporate misconceptions about science and nature if no effort is made to teach some level of media literacy. Nature films cannot be considered “educational” by default. Especially if teachers are using nature programs in the science classroom, “educational” has to be defined and standards have to be developed that programs must meet before taking on the “educational” moniker. In the free-choice environment, clearly a need to inform the public of the misnomer emerges.

Recently, Falk et al. (2007) suggested that rather than framing efforts in communicating science, educators should approach this from the perspective of offering the public opportunities for engaging with, appreciating, and better understanding the science that interests them. Giving the public the tools to navigate those opportunities in an open marketplace is difficult, however. Several authors have called for developing a
learning infrastructure that includes both free-choice and formal learning opportunities (Bybee, 2001; Muscat, 2001) with a goal to create an agenda centered on lifelong learning (Muscat, 2001). Although such an extensive network within a diverse and ever-changing marketplace of ideas seems overwhelmingly difficult to achieve, the possibility of a system that casts a wide net and helps consumers navigate through the myriad of resources, no matter their level of interest or prior knowledge, is intriguing.

References


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of Knowledge (pp. 423-452). Peru, IL: Open Court Publishing.


Appendix 1. The Survey Instrument

AUDIENCES’ BELIEFS ABOUT
THE EDUCATIONAL VALUE OF NATURE FILMS

This short survey addresses how audiences feel about films that portray wildlife and nature. The survey is part of a graduate student project, and the information will be used to assist educators at the University of Montana using these types of films. Participation is completely voluntary and no record of participants will be kept. All information is strictly confidential. If you have any questions, contact Alison Perkins (alison.perkins@mso.umt.edu). Please, only one adult per household need respond. Thank you for taking the time to share your thoughts.

Start Here

1. How often do you watch nature films?
   - □ More than 1-2 times per month
   - □ 1-2 times per month
   - □ 1-2 times every few months
   - □ 1-2 times every year
   - □ Never

2. Where have you watched most nature films?
   - □ Film festival
   - □ Television
   - □ Video rental
   - □ Online

3. Why would you watch a nature film? (Select all that may apply.)
   - □ To learn about nature
   - □ To be entertained
   - □ To see wildlife in its natural environment
   - □ Other ______________________________.
4. Wildlife and nature films are easy to understand because they contain so many facts. (Easy Knowledge)

☐ strongly agree  
☐ mildly agree  
☐ mildly disagree  
☐ strongly disagree  
☐ no opinion

5. What are the characteristics of an educational nature film? Please indicate whether you would agree or disagree with the following statements:

If a nature film is educational, then you believe:

- **a.** it is accurate.  
  - strongly agree  
  - mildly agree  
  - mildly disagree  
  - strongly disagree

- **b.** the content has been reviewed/approved by scientists.  
  - strongly agree  
  - mildly agree  
  - mildly disagree  
  - strongly disagree

- **c.** the story it tells really happened.  
  - strongly agree  
  - mildly agree  
  - mildly disagree  
  - strongly disagree

- **d.** it presents the most current scientific understanding.  
  - strongly agree  
  - mildly agree  
  - mildly disagree  
  - strongly disagree

- **e.** it may fake situations or scenes to add to the story.  
  - strongly agree  
  - mildly agree  
  - mildly disagree  
  - strongly disagree

- **f.** people should learn from watching it.  
  - strongly agree  
  - mildly agree  
  - mildly disagree  
  - strongly disagree

- **g.** it gives wildlife human motivations we can relate to.  
  - strongly agree  
  - mildly agree  
  - mildly disagree  
  - strongly disagree

- **h.** the content has been reviewed/approved by other filmmakers.  
  - strongly agree  
  - mildly agree  
  - mildly disagree  
  - strongly disagree

- **i.** it does not sensationalize / over-dramatize how nature works.  
  - strongly agree  
  - mildly agree  
  - mildly disagree  
  - strongly disagree
6. Do you believe the primary goal of most nature films is to teach about nature?

☐ Yes
☐ No

7. Do you believe the narration for nature films is written to explain and clarify what we know about nature?

☐ Yes
☐ No

8. Do you believe that nature films are educational?

☐ Yes
☐ No

9. How educational do you believe nature films are designed to be? (Please circle the number that represents your belief on a scale from 1 = designed to be educational to 7 = not designed to be educational.)

<table>
<thead>
<tr>
<th>Designed to be educational</th>
<th>Not designed to be educational</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  2  3  4  5  6  7</td>
<td>1  2  3  4  5  6  7</td>
</tr>
</tbody>
</table>

10. How educational do you believe nature films actually are? (Please circle the number that represents your belief on a scale from 1 = not educational to 7 = very educational.)

<table>
<thead>
<tr>
<th>Not educational</th>
<th>Very educational</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  2  3  4  5  6  7</td>
<td>1  2  3  4  5  6  7</td>
</tr>
</tbody>
</table>

11. Scientific theories are not important in nature films because they are just theories. (Nature of Theories)

☐ Yes
☐ No
12. If you wanted to watch an *entertaining* nature film, what channel would you go to?

- [ ] Discovery Channel
- [ ] Animal Planet
- [ ] National Geographic Channel
- [ ] Public Broadcasting System (PBS)
- [ ] Other __________________________

13. How would you rate your interest in biology, ecology, or the natural sciences? 
(Please circle the number that represents your belief on a scale from 1 = high interest to 7 = low interest.)

<table>
<thead>
<tr>
<th>High interest</th>
<th>Low interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
</tbody>
</table>

14. If you wanted to watch an *educational* nature film, what channel would you go to?

- [ ] Discovery Channel
- [ ] Animal Planet
- [ ] National Geographic Channel
- [ ] Public Broadcasting System (PBS)
- [ ] Other __________________________

15. Most things worth knowing in nature films are simple to understand. (Simple Knowledge)

- [ ] strongly agree
- [ ] mildly agree
- [ ] mildly disagree
- [ ] strongly disagree
- [ ] no opinion

16. How accurately do you believe wildlife and nature films portray *science*? (Please circle the number that represents your belief on a scale from 1 = very accurately to 7 = not very accurately.)

<table>
<thead>
<tr>
<th>Very accurately</th>
<th>Not very accurately</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
</tbody>
</table>
17. How accurately do you believe wildlife and nature films portray nature? (Please circle the number that represents your belief on a scale from 1= very accurately to 7= not very accurately.)

<table>
<thead>
<tr>
<th>Very accurately</th>
<th>Not very accurately</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
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<tr>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

18. Do you believe the producers for nature films know more about wildlife and natural sciences than you do?

- [ ] Significantly more
- [ ] Slightly more
- [ ] About the same
- [ ] Slightly less
- [ ] Significantly less
- [ ] No opinion

19. If two different nature films are presenting two different arguments about the same topic, at least one of them must be wrong. (Omniscient Authority)

- [ ] Yes
- [ ] No

20. Do you believe the producers for nature films are experts in the natural sciences?

- [ ] Yes
- [ ] No

21. Nature films are more educational when they use a trustworthy narrator in the program than when the narration is just added in later by an unknown voice. (Trustworthy Narrator)

- [ ] Yes
- [ ] No
22. Five years from now, producers don’t need to make a new nature film about a topic because, even though they might get some new footage, there probably will not be much that is new to add to our basic understanding of the topic. (Stable Knowledge)

[ ] strongly agree
[ ] mildly agree
[ ] mildly disagree
[ ] strongly disagree
[ ] no opinion

23. Do you believe nature films are designed to be entertaining?

[ ] Yes
[ ] No

24. Nature films should only include facts about nature not theories. (Fact-based Knowledge)

[ ] Yes
[ ] No

25. What is the highest level of education you have received?

[ ] Some high school
[ ] High school diploma or equivalent
[ ] Some technical school
[ ] Technical degree or equivalent
[ ] Some college
[ ] 2-year college degree
[ ] Bachelor’s degree
[ ] Master’s degree
[ ] Higher degree

26. How many courses have you taken that included biology, ecology, or the natural sciences?

[ ] none
[ ] 1-2
[ ] 3-4
[ ] 5-6
[ ] More than 6
27. What is your gender?

☐ Male
☐ Female

28. What is your age? __________ years

Do you have any comments?

Thank you so much for taking the time to fill out this survey!
CHAPTER 6.

SOURCES AND SENTIMENT: HOW NATURE PROGRAMS MAY BE LEADING SCIENCE LITERACY ASTRAY

Abstract:
Television is a powerful source of mass communication, but the “educational” content is rarely critically examined. Nature and wildlife programs are generally considered educational; audiences clearly believe them to be accurate sources for the portrayal of science and nature. These programs use the same devices as fictional television, however, and the narratives often include serious misconceptions about science and important ecological processes, such as evolution. I used the Science and Nature Program Assessment Tool (SNaP) to examine the science content of programs appearing during a sweeps month on four channels: Animal Planet, Discovery Channel, National Geographic Channel, and PBS. Overall, programs did not score well (range 33-78%); the presentation of science was particularly poor (8-57%). Misconceptions were common in the Presentation of Facts and Interpretation category; Animal Planet and Discovery Channel programs were the most egregious and National Geographic programs the least. In fact, Animal Planet and National Geographic Channel differed significantly in all categories describing the presentation of science, as well as Total Score. These differences may translate to science literacy issues on a socio-economic scale. Nevertheless, because nature programs are such beautiful spectacles, they have the potential to be credible educational resources. Science educators need to be aware of the issues associated with these programs, however, and design instruction materials and
approaches that specifically address the poor science. SNaP can be a valuable tool for students to learn more than just science content, they also can use this too to develop the critical evaluation skills necessary to make scientific sense of the content.

Keywords: nature programs, evolution understanding, nature program assessment tool

In spite of on-going efforts by science educators, research indicates that many people still hold serious misconceptions about evolution and other key scientific concepts (Nelson, 2000; Rudolph & Stewart, 1998; Southerland, Abrams, Cummins, & Anzelmo, 2001). These misconceptions can have far-reaching effects when they influence policy at the public interface with science. Whether it be adding “intelligent design” as part of the science curriculum in schools (see, for example, Evolution shares a desk with ‘Intelligent Design’ [Washington Post 12/26/04]) or dismissing compelling and peer-reviewed evidence of global climate change, misconceptions commonly held by the general public diminish opportunities to engage thoughtfully in civic discourse that has important policy implications.

But where do these misconceptions come from? Misconceptions are constructed from a variety of sources, whose influences surely overlap. The Committee on Undergraduate Science Education (1997) outlines several sources of misconceptions about science, including vernacular issues, experience, and formal and informal sources. Misconceptions can arise because common words have different meanings in scientific versus common language contexts. For example, “fitness” may refer to physical strength (Bishop & Anderson, 1990), and “theory” is often used in everyday language to mean a
“guess”. Everyday experiences also may lead to misconceptions; for example, personal experiences with streams and rivers may lead to misconceptions about how water flows underground (Committee on Undergraduate Science Education, 1997). The inheritance of a genetic disease or family characteristic may affect how individuals think about heritability, variation, and time. Another important source of misconceptions arises from formal educational environments that do not adequately address prior misconceptions that students hold. If students are taught new information without being encouraged to confront their own preconceived notions and nonscientific beliefs, they may simply accommodate the new knowledge in the framework of an old misconception (Alters & Nelson, 2002; Committee on Undergraduate Science Education, 1997). For example, teaching genetics does not necessarily help students incorporate the role of changes in gene frequencies into how populations actually change over time (Clough & Wood-Robinson, 1985). Indeed, without finding a way to learn something about the more abstract statistical components of genetics, misconceptions may arise about beneficial mutations and the directed transformation of species over time. In addition, informal sources, including parents, television, the Internet, fiction, and religious and myth-based sources may influence misconceptions. Clearly, wives tales about lightning strikes can be transmitted and learned in informal environments (Committee on Undergraduate Science Education, 1997). Similarly, fictionalized accounts in movies and on television of a young earth and humans living with dinosaurs conflict with scientific evidence.

Nature programs can provide a powerful tool for science education and lifelong science learning, especially if they address science and nature content thoughtfully. In fact, viewing television programs, such as Jacques Cousteau’s The Cousteau Odyssey,
can positively influence public attitudes and behaviors toward the environment (Eagles & Demare, 1999; Fortner, 1985; Holbert, Kwak, & Shah, 2003). Attitudes and understanding are not the same, however. Nature programs may be enticing emotional sentinels for the natural world, but without balance, positive environmental attitudes may conflict with science understanding. This conflict may have unintended consequences such as pitting endangered shorebirds against introduced red foxes in ecosystem management.

Science-related programming can just as easily promote or create misconceptions about scientific concepts and theories. Misconceptions about science can be especially problematic if the way the concepts are presented encourages, rather than challenges, prior naïve conceptions (see Linn 1983; Posner, Strike, Hewson, & Gertzog, 1982; Strike and Posner 1992; Watson and Kopnicek 1990). Science educators need to be aware of the range of influences these free-choice opportunities can have on public understanding, especially in relation to important ecological processes such as evolution.

Audiences, and many educators, view nature films as environmental documentaries, but most are fictionalized accounts whose narratives are driven by the cinematic themes and thrills of mainstream entertainment that ensure commercial success (Bousé, 2000; Cottle, 2004; Mitman, 1999). Some educators have cautioned that the use of language in these programs may reinforce misconceptions about evolution (e.g., Bishop & Anderson, 1990; Dingwall & Aldridge, 2006). Indeed, the very production values of awe-inspiring nature programs (expert photography, underexplored locations, respected presenters, cutting-edge science) not only promote teleological (purpose-
driven) and design-based explanations of evolution but also misconceptions about the nature of the scientific endeavor (Dingwall & Aldridge, 2006).

Similarly, video images designed to enhance the narratives of nature programs may serve as powerful “virtual witnessing” events for viewers (Kirby, 2003, see also Graber, 1990), resulting in an epistemological impact that is difficult to overcome, especially with socially controversial topics such as evolution and global change. Even scientists fall prey to the power of the moving image. For example, Padian (1987) suggests that scientific reconstructions of bat-winged pterosaurs were influenced by “plausibility” of pictorial images. He notes, “a picture is not only worth a thousand words; however inaccurate, it may be worth a wealth of well-documented evidence to the contrary” (p. 76). Visual representations (such as graphs) are essential for communicating ideas in the science classroom; however, the design of such representations is not always beneficial for learners (Cook 2006). Viewers make factual assessments using the experiences gained watching crime dramas, for example (Shrum, 1999), and judgments about evolution and science likely are correspondingly affected based on experiences with nature programs. Indeed, research into the effects on learning from one beautifully crafted nature film suggests that the misconceptions presented in the narration affect undergraduate students’ understanding of evolution (Bright et al., abstract; Dissertation Appendix 1). Consequently, individuals may approach democratic issues related to science with prior knowledge and naïve conceptions about the natural world that may stem directly from experience, or virtual experience, with nature programs.
Understanding what individuals learn outside of school is a difficult task because the free-choice marketplace for science education content is consumer oriented. Individuals have different identity-related motivations for their free-choice learning opportunities, and these motivations can predict learning outcomes (Falk, Heimlich, & Bronnenkant, 2008). If viewers distinguish between educational and entertainment value, they may approach the content presented in a film or program differently, being more open to learning from programs that are considered “educational.” More importantly, the understanding of individuals motivated to learn about nature from programs they deem “educational” may be affected more than those that are watching purely for entertainment, or not watching at all.

In a recent survey concerning audiences and the educational value of nature programs, respondents were asked about their beliefs regarding the educational value of nature programs (see Chapter 5). Respondents indicated that the National Geographic Channel and PBS were the primary sources they would turn to to watch educational nature programs. Discovery Channel also was listed as a source of educational programs but most frequently listed as a source of entertaining programs. Animal Planet largely was considered a source of entertaining programs. (National Geographic and PBS were less frequently listed as a source of entertaining nature programs.) The criteria for how individuals make that value judgment were not clear because the vast majority of respondents (>95%) believed that nature programs were indeed educational and that they portrayed science and nature accurately.

Clearly, people are looking to specific channels for their science content, but what are they actually getting? I predicted that the nature programs appearing on channels
with a mission geared toward educational programs would represent the science related to nature better than those whose mission was geared towards entertainment. My assumptions were that commercial channels were driven by different factors than those funded with public money, and that comparisons would be valid from a human constructivist perspective, where ultimately, the viewer was the important variable.

Methods

To determine the quality of science education resources available to viewers, I examined a selection of nature programs offered during a “sweeps” month for their accuracy and presentation of the science. Sweeps is the period where commercial stations are rated for their commercial value. As a result, channels actively solicit audiences with new programming and scheduling to enhance viewership. Stations funded with public money, such as PBS, are not subject to the same commercial ratings, but they may schedule programs to encourage viewership to determine their audience share. Programs on each of four channels (Animal Planet, Discovery Channel, National Geographic Channel, and PBS) during November, 2008, were identified using schedules found on their websites. Only programs identified as broadly including nature and/or wild animals were included. Animal Planet and National Geographic Channel both offered significant programming, and 10 hours of programming were selected randomly from among an alphabetized list of potential programs. Recording equipment availability affected access to National Geographic Channel programming, however, and several shows had to be replaced based on their scheduling. Nature programming was far less common on PBS and Discovery Channel during November, 2008. Because they rely on
public funding, PBS was not affected by sweeps. On the other hand, Discovery promoted a series titled *Whale Wars* about the tactics of protesters to foil whale hunting expeditions for that month’s sweeps. As a result, few nature programs were included in the November, 2008, schedule for Discovery. Discovery Channel did produce the highly acclaimed *Planet Earth* series, however, and two episodes that appeared in January, 2009, were included in this assessment to add to the limited sample size.

The accuracy and quality of the science presented in the nature programs viewed were assessed using the Science and Nature Program Assessment Tool (SNaP; Dissertation Appendix 1). The review criteria used in the tool were based on important elements of the National Science Education Standards (National Research Council, 1996) and the *Guidelines for Excellence* (North American Association for Environmental Education (NAAEE), 2000). The SNaP tool grouped review criteria into categories representing the presentation and interpretation of facts, scientific context, presentation of nature of science “issues,” and the human dimensions of the science profession. All criteria, except for two categories describing misconceptions, were scored on a scale from one (poorly met or addressed) to four (highly met or addressed). Each scale was converted to quarter points so that each criterion contributed a maximum of 1.0 point to the overall score. As a penalty within the presentation of facts and interpretation category, the two categories assessing the inclusion of misconceptions were scored from zero (no misconceptions) to three (serious misconceptions) and converted to a negative third-point scale. Each of these criteria contributed a maximum of -1.0 to the overall score (see Table 6.1 for an example calculation). Because not all programs address all the elements that could be reviewed using SNaP (e.g., not all programs include graphics),
scores for each category were standardized by summing all scores for relevant criteria and dividing by the number of criteria evaluated. The final score was weighted by the total score of a separate category describing the overall impression of the program.

In a previous study, the SNaP tool proved applicable to a broad range of nature programs, the scores were consistent among science educators, and the criteria functioned to identify nature programs with serious flaws in the presentation of ecological science (Dissertation Appendix 1). In addition, the evaluation of characteristics of nature programs using SNaP was flexible enough to assess programs in out-of-school settings. For the present study, I was interested specifically in the factual presentation and interpretation of the science, the context of the science presented, and the presentation of the nature of the scientific process. Programs were recorded and reviewed individually, and the scores entered into a spreadsheet for tallying. I calculated the mean score for each category and the total weighted score for each program. I used parametric statistics (SPSS v. 16.0) to compare programs scores among channels.

Results

Program diversity varied among the four stations. All offered some high production nature programs – programs that included extensive high quality footage and scripting (“blue-chip” programs of Aldridge & Dingwall, 2003), in addition to a number of “one-off” programs (“one-off” programs are usually produced independently, and they may or may not be incorporated into a series). Animal Planet offered the greatest diversity of programs, including several under-produced series that simply recited bits of information about the organism or incorporated amateur footage, such as Untamed and
Table 6.1

*Example calculation of criteria used in the SNaP tool.* Within the Facts & Interpretation category, the first five criteria were scored from one (poorly met or addressed) to four (highly met or addressed), converted to a quarter-point scale, and averaged as the category sub-total. The last two criteria were scored from zero (no misconceptions) to three (serious misconceptions), converted to a third-point scale, averaged, and then subtracted from the category sub-total as a penalty.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Score</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authorities are credible</td>
<td>4</td>
<td>1.0</td>
</tr>
<tr>
<td>Factually correct</td>
<td>3</td>
<td>0.75</td>
</tr>
<tr>
<td>Correctly presents current theory</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>Presents a range of perspectives from different scientists and/or different research groups</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>Actively investigates alternative interpretations of scientific theory/fact as part of the story</td>
<td>1</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>sub-total</strong></td>
<td><strong>0.75</strong></td>
<td></td>
</tr>
<tr>
<td>Inadvertently promotes misconceptions of scientific theory or facts (penalty)</td>
<td>2</td>
<td>-0.66</td>
</tr>
<tr>
<td>Intentionally promotes misconceptions of scientific theory or facts (penalty)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>sub-total</strong></td>
<td><strong>-0.33</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Total Presentation of Facts &amp; Interpretation score</strong></td>
<td><strong>0.42</strong></td>
<td></td>
</tr>
</tbody>
</table>
Uncut, Unexplained/Unexplored, and Weird, True, & Freaky. Orangutan Island was the only ongoing series reviewed during this assessment; in its second season, the program included 13 episodes that explored the orangutan rescue operation in Borneo. The only two nature programs that appeared on the Discovery Channel during November, 2008, were pseudo-experimental examinations of feeding in bears and crocodiles. The program host demonstrated the awesome power of these ferocious predators and then climbed into a sturdy, clear predator-safe box to react to them as they approached. In contrast, Planet Earth was the highly acclaimed “blue-chip” series produced for Discovery and originally aired on British Broadcasting Company in 2006 and in the US in 2007. Planet Earth represented high production values and investment. National Geographic highlighted nature with several series featuring diverse content, including Wild, America’s Wild Spaces, Living Wild, and Reptile Rulers. The nature programming on PBS was essentially limited to Nature, a weekly one-hour series and the occasional one-off programs offered by local program directors.

Nature programs were not the dominant type of program on any channel during the review period. Programs that included nature were most common on Animal Planet; approximately 40% of the weekly schedule was devoted to nature programs. Both Discovery Channel and National Geographic Channel focused on a diversity of program content. Discovery’s content was extremely limited in November, 2008, but the Planet Earth series was featured in January, 2009. Nature programs accounted for approximately 15% of weekly programs on National Geographic (pet shows accounted for over 20%). As mentioned previously, PBS’s nature programming was almost
completely restricted to *Nature*, although *NOVA* has explored ecological science in the past (just not in November).

Several themes emerged in the content presented in the programs reviewed. Sensationalizing fear of nature was a common programming trend, at least on the commercial stations. The *Maneaters* series, on Animal Planet, featured individual programs titled “Killers in the Water” and “Big Cats.” *Untamed and Uncut* was a series of short segments (approximately 5 minutes) that almost exclusively featured animals attacking humans or each other. Discovery programs highlighted the “feeding frenzy”, including “Bear Feeding Frenzy” and “Crocodile Feeding Frenzy.” Similarly, *Wild*, on National Geographic Channel included shows titled “Man-eating Prides” and “Whales: The Dark Side.” (Surprisingly, the “dark side” of killer whales included interesting research on their mating behavior and cultural transmission of some behaviors.) *Living Wild*: “Nature’s War Zone,” also on National Geographic, depicted the nesting behavior of sea turtles, and although sea turtles and their young faced different predators, the “war zone” metaphor was without merit (or support in the script). Despite its name, however, “America’s Deadly Dozen” (*America’s Wild Spaces* series) was less about being afraid of the animals that prey on humans and more about human intrusion into their habitat.

Shark stories also were popular on both Animal Planet and National Geographic Channel in November (Discovery hosts “Shark Week” annually in late summer).

Titles notwithstanding, the nature programs that appeared during the November sweeps did not represent the science well. Using SNaP, science scores were universally very low with Animal Planet, Discovery, and PBS averaging about 25% of the total possible (Table 6.2). National Geographic averaged somewhat higher with an average
score of 42%. Even the adjusted scores weighted by overall impression and recommendation were 60% and below (Table 6.2).

The overall impression of programs was generally high whereas NOS and context tended to be relatively low across all four channels (Figure 6.1). Differences were apparent in the Facts and Interpretation category, however. Misconceptions were accounted for in the Facts and Interpretation category and were subtracted from the overall category score. When examined separately, National Geographic programs included the fewest misconceptions, and programs airing on Discovery and Animal Planet included the most (Figure 6.2). The context of the science and the nature of the scientific endeavor were rarely explored in any program on any channel. National Geographic and PBS tended to include more context in their programs than Animal

<table>
<thead>
<tr>
<th>Channel</th>
<th>n</th>
<th>Total science score</th>
<th>Adjusted score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal Planet</td>
<td>12</td>
<td>27%</td>
<td>48%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(9%-51%)^a</td>
<td>(30%-64%)</td>
</tr>
<tr>
<td>Discovery</td>
<td>3</td>
<td>23 %</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(17%-30%)</td>
<td>(33%-65%)</td>
</tr>
<tr>
<td>National Geographic</td>
<td>13</td>
<td>42%</td>
<td>60%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(26%-57%)</td>
<td>(48%-69%)</td>
</tr>
<tr>
<td>PBS</td>
<td>4</td>
<td>31%</td>
<td>56%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(9%-45%)</td>
<td>(46%-78%)</td>
</tr>
</tbody>
</table>

^a Range of scores.
Figure 6.1. Mean percentage scores obtained using the SNaP Assessment Tool for the Facts & Interpretation (Facts), Scientific Context (Context), Nature of Science Issues (NOS), and Overall Impression (Impression) categories for programs viewed on Animal Planet, Discovery, National Geographic, and PBS.

Planet and Discovery, and National Geographic was the only channel that regularly included at least some discussion of evidence, uncertainty, explanation, and prediction. When programming on Animal Planet and National Geographic Channel was compared, the two channels differed significantly in quality of science presented. All three SNaP content scores, as well as the adjusted scores, were significantly higher in programs on National Geographic Channel than on Animal Planet (Table 6.3).
Figure 6.2. Mean scores for the Presentation of Facts and Interpretation category of the SNaP Assessment Tool for programs viewed on each channel. Misconception scores are separated out of the total category score for comparison.

Discussion

The results clearly illustrate that nature programs do not represent science or the scientific process well, despite the fact they are consistently labeled as “educational.” Not only is the science misrepresented, evolutionary theory is often presented as teleological, need-based, or caused by the environment (see also Aldridge & Dingwall, 2003; Dingwall & Aldridge, 2006). Nature and science television shows may be the only contact a significant portion of the population has with the natural world, and programs often are used in classrooms as teaching tools. Science educators should be concerned about the content of the programs being produced and promoted because these programs
Table 6.3.

Mean scores and standard errors of the Facts & Interpretation, Scientific Context, Nature of Science Issues, and Overall Impression categories from the SNaP Assessment Tool for programs viewed Animal Planet and National Geographic Channel.

<table>
<thead>
<tr>
<th>Channel</th>
<th>n</th>
<th>Facts &amp; Interpretation$^a$</th>
<th>Scientific Context$^b$</th>
<th>Nature of Science Issues$^c$</th>
<th>Overall Impression$^d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal Planet</td>
<td>12</td>
<td>0.23 ± 0.11</td>
<td>0.33 ± 0.02</td>
<td>0.26 ± 0.01</td>
<td>0.60 ± 0.03</td>
</tr>
<tr>
<td>National Geographic</td>
<td>13</td>
<td>0.49 ± 0.06</td>
<td>0.40 ± 0.02</td>
<td>0.36 ± 0.03</td>
<td>0.74 ± 0.02</td>
</tr>
</tbody>
</table>

$^a F = 4.570, 1, 23 \text{ df}, p = 0.043.$

$^b F = 7.149, 1, 23 \text{ df}, p = 0.014.$

$^c F = 7.050, 1, 23 \text{ df}, p = 0.014.$

$^d F = 12.303, 1, 23 \text{ df}, p = 0.002.$

may have profound effects on the knowledge students bring to the classroom, as well as on the conceptual knowledge they will have once they leave the formal education system.

Ausubel (1968) emphasizes that the most important aspect for teaching is to find out what a learner already knows. Students indeed bring the experiences they have had with television into the science classroom (Dhingra, 2003, Aikenhead, 1988), not just textual readings, but visual representations as well (Cook, 2006). In a constructivist context, individuals watching nature shows are “experiencing” science, and unfortunately the lesson they may take home is that nature is purposeful and responds to need. Moreover, they may learn that scientific knowledge is idiosyncratic and certain, and that evidence is not separated from explanation and consensus. Consequently, for educators,
understanding prior knowledge is critical in designing instruction that adequately addresses potential areas of misunderstanding (National Research Council, 2007). Familiarity with the merits and faults of nature programming may give educators a foundation from which to draw in the conceptual change process. Indeed, the challenge to science educators is to use this media effectively to address naïve views about science (Aikenhead, 1988, see Chapter 3 for an example of how to do this).

Knowledge Gaps

The disparity between channel availability and programming quality also is alarming. Neither Animal Planet nor National Geographic Channel is a broadcast channel; typically both are available only through cable or satellite services. National Geographic Channel is offered most often in high-end packages. The difference in price between packages that include Animal Planet and National Geographic, at least for satellite service, currently runs about $35 per month nationally. The cost of cable services is highly variable. Special promotions may alter those price points, especially with cable services, but because promotions typically extend only 3-6 months, they may not overcome financial deterrents. What does this mean in terms of educational content for consumers? Nature programs featured on National Geographic Channel were consistently better quality, in terms of the science presentation, than programs on Animal Planet. Most importantly, Animal Planet programs included a host of misconceptions about evolution and science in general. On this station, science often was portrayed as derived from single observations, and it was fact-based and certain. If access to different
channels depends on socio-economic status, this could be an implication with consequences for knowledge gaps among segments of a democratic society.

The Knowledge Gap Hypothesis (Tichenor, Donohue, & Olien, 1970) suggests that mass media tends to increase, rather than decrease, the gap in knowledge between segments of the population with higher and lower socioeconomic status (SES) because higher SES individuals are able to acquire this information at a faster rate. Higher education and, thus, higher SES, is associated with better reading and comprehension skills, and greater prior knowledge (Tichenor et al., 1970). Moreover, people with more education may be both qualitatively and quantitatively better at encoding information from audio-visual media, in particular, than those with less education (Grabe, Lang, Zhou, & Bolls, 2000). Of course, like learning in informal environments, the motivation of individuals is an important variable that can alter this relationship (Garramone, 1983; Kwak, 1999).

What is the consequence of different access to high quality science-related programming? Ecological science messages may move through segments of society at different rates. As a result, assessment of messages related to socio-scientific issues, such as evolution or global climate change (Sadler, 2004), may be differentially affected by SES. In fact, individuals that have attained higher education levels may be more likely to believe in the promise of science in those messages and less likely to hold reservations than those that have not advanced in their formal schooling (Nisbet et al., 2002). For example, because those with more education already have comparatively higher levels of factual and procedural knowledge of science (Nisbet et al., 2002), exposure to different media of different quality may affect a knowledge gap related to accepting evolution.
Nature programs are one source of media that individuals can choose to learn about evolution in nature. Sadly, the sources of information available to individuals motivated to learn about nature may be limited based on socio-economic circumstances. The combined effect of poor prior knowledge about ecological processes and economically limited ability to access quality sources of information may enhance knowledge gap effects in the general public when it comes to understanding nature and wildlife.

Nature Programs and Science Literacy

Why are nature programs afforded a level of “educational” integrity when the science content related to the natural world is so poorly presented and potentially harmful to public understanding? Does the credibility relate more to sentiment than science? This concern is especially important for those individuals motivated to learn (Falk et al., 2008) or with a positive environmental attitude (Holbert et al., 2003). There is no question that nature programs can be beautifully crafted, enchanting and instilling viewers with a love for the natural world that, ultimately, may affect their behavior as a citizen. Furthermore, Papson (1992) argues that nature films are legitimized by emphasizing claims to educational and scientific “truth” when in fact they use the same production devices as fictional programs. Most viewers would be expected to realize that CSI: Crime Scene Investigation is fictional and not an educational program. Yet, the science it portrays, although highly sensationalized, is often at least as accurate as that found in nature programs based on my reviews. Interestingly, the program has had a significant effect on the number of college students choosing science-related career paths (see Johnston, 2003). The “CSI Effect” is currently a popularly debated media effect; the
science, it seems may or may not influence jurors in terms of the expectations and beliefs of real forensic evidence (see Schweitzer & Saks, 2007; Shelton, Kim, & Barak, 2006).

Using emotional relationships with nature to garner public interest is not a recent phenomenon, nor is this science-versus-sentiment controversy unique to nature programs. As naturalism was becoming popular at the turn of the 19th century, nature writers began overdramatizing and anthropomorphizing nature to such an extent that John Burroughs felt compelled to call the issue to the attention of the general public (Lutts, 2001). These fantastic stories, however, were extremely popular with readers and opened a world seen by few at that time. The problem lies with the use of the term “educational” as a descriptor. According to Lutts, the problem with the “nature fakers” was less about fraud, and more about sentimentalism, philosophical bias, and an inability or unwillingness to use the tools of science to learn about nature and wildlife. Although most would assume the educational value of nature books has been resolved since the highly public debate initiated by Burroughs, the conflict in communication strategies and expectations continues (Lutts, 2001). The approach to factual representation, accuracy, and misrepresentation, as well as how well facts can be differentiated from fiction, are still common issues with nature books (Mayer, 1995). Critical assessment is key (Eggerton, 1996). Just as teachers need to consider the content of the trade books they bring to classrooms because science learning in children can be obstructed by fanciful stories (Mayer, 1995), so too should they consider nature and wildlife programs.

Nature programs on television are not critically examined. This may be a result of the visual experience audiences have as they witness wildlife and the natural world. Indeed, from a production perspective, emphasis on photography in nature films (like
pornography) can supersede emphasis on the actual story. Moreover, models that have some success are replicated. Audiences are rarely concerned with the appearance of “truth” in television; their interest is more focused on the coherence and logic of stories (Shapiro & Fox, 2002). In fact, unless an inconsistency is easily observed, individual viewers have no reason to assess the realism at all (Busselle & Bilandzic, 2008).

The SNaP tool allows viewers to focus and reflect on the science realism in nature programs and helps them navigate the murky waters of science and sentiment related to the popularization of ecological science. Ford (2008) argues that students need to learn the importance of knowing how to assess the efficacy of scientific claims, stating “the ideal vision of students making their own sense of content is superseded by a more defensible ideal vision of students learning how to make scientific sense of content.” Students working individually or in groups can use the SNaP tool to critically evaluate the science they observed while watching these extraordinary programs. In conjunction with curricula designed to address the language we use to describe evolution (Chapter 3), this kind of critical examination also may be able to help students overcome common misconceptions about evolution. Indeed, with the proper tools, nature programs can be an amazing source for sharing information about the wonders of wildlife and the natural world, and to initiate valuable lessons about important ecological processes, such as evolution.

References


CHAPTER 7.

**CLIO THE SCIENTIST: USING NARRATIVES TO BROADEN THE IMPACTS OF INQUIRY**

Abstract:

Inquiry is a vital component of science teaching, and incorporating science texts may broaden its pedagogical value. We developed an inquiry and take-home story to engage families in their children’s science learning. We designed the inquiry, “What in the world do insects see?”, for 1st and 2nd grade students as an exploration of how insects see their world. Our goal was to illustrate how our understanding of ecological relationships is affected by our perceptions. By examining the structure of insect eyes, students learned that insects may see the world very differently than they themselves do. Students were introduced to insects as pollinators using ultraviolet photographs of flowers, and they observed flowers and pollinators outdoors. To complement this investigation, the inquiry was re-written as a story for families to read with their children. The story included activities from the classroom inquiry and encouraged families to explore their own backyards. Pre- and post-assessments indicated that the inquiry significantly increased student understanding that insect pollinators may see flowers quite differently than humans, but students experiencing both the story and the inquiry gained a better appreciation of the nature of science than those experiencing either the inquiry or story alone.

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1 All graduate students who received NSF GK-12 funding from the ECOS grant were required to present one investigation they developed as a chapter in their dissertation and for publication. This chapter was developed specifically for the journal *Science & Children*, a journal whose audience is elementary school teachers.
Once upon a time there was a little scientist named Clio.

She loved insects!

She loved creepy crawly insects.

She loved beautiful flying insects.

She loved ancient insects.

And she loved insects that pretended to be something other than insects.

She loved looking at them so much, it got her to thinking…

Do insects like looking at her as much as she likes looking at them?

“I wonder what they see when they look at me?” she asked.

Clio’s questions begin a journey with her grandmother and her father, a story that builds on concepts learned during a school inquiry on insect vision. Inquiry is a way of teaching science that exemplifies scientific questioning. Asking questions and proposing explanations based on evidence reflects the ways in which scientists examine the natural world, so an emphasis on the scientific process in school may more accurately reveal science as a world of curiosity rather than a world of facts (National Research Council 1996). Because learning is a cumulative process, creating rich experiences for learning outside of school in informal (or free-choice) environments can connect and reinforce understanding (Dierking et al. 2003). In fact, students with enriched informal learning environments may develop higher reasoning abilities than students who do not have such opportunities (Gerber et al. 2001). Sharing these experiences with peers, siblings, or adults is essential to maximize their effectiveness (Gerber et al. 2001), so one way to
foster the development of scientific reasoning in children is to engage families to participate in these informal learning experiences (Crowley et al. 2001). Family members can help students build on “islands of expertise” the children have developed (Crowley and Jacobs 2002), expertise that was perhaps initiated and nurtured in their classrooms at school.

How can parents, siblings, and the extended family make the connections between science at school and at home? By reading together! Science-related reading is a great source of learning that can transcend these environments. Parents often read about science and nature to their children, and children are fond of science-related books (Korpan et al. 1997). Reading, like inquiry, draws on experience and knowledge, and readers actively construct understanding (Butzow and Butzow 2000; Casteel and Isom 1994). Purposefully designing lessons that connect school with home environments using science-related stories not only creates positive attitudes in children toward science, it provides positive experiences for parents and leads to new avenues of communication for parents and teachers (Shymansky et al. 2000).

Children love learning about insects, providing amazing opportunities for classroom and schoolyard exploration and inquiry. These engaging creatures provide diverse opportunities for addressing many science standards, even for the youngest students. By capitalizing on children’s innate fascination with insects, we can extend inquiry not just from the classroom to the home, but from the indoors to the outdoors, and from cities to rural locations – insects are everywhere! “Clio the Scientist” is one such means to engage the family in the exploration.
Setting the Stage: What in the World Do Insects See?

Many insects rely on vision to find nectar and pollen, but what do insects see when they look at a flower? Insect vision is an area of active research in science – an area that allows fruitful exploration into the nature of the scientific endeavor because of the bias our own vision brings. As scientists, we use our senses to make observations, but we can’t assume that what we see is what insects see; we are forced to think outside of our own senses when we ask questions about insect vision. Our inquiry uses insect pollinators to help students think about what scientists currently know about insect eyesight, what they can know, and how students, as scientists, can begin to investigate eyesight (see http://www.bioed.org/ecos/inquiries/Inquiries/InsectEyes.pdf and Chapter Appendix 1).

To connect school and home, we developed a narrative take-home story about “Clio the Scientist” (available at http://www.bioed.org/ECOS/clio). In the story, a young girl, Clio, who is already interested in insects, turns to her family for help to explore how insects see the world around them. Her family discusses the same optical illusions used in the classroom inquiry and provides some new insight into what scientists know about how birds see (some birds may see ultraviolet colors, too). The story encourages Clio and the readers to use a scientific approach to answering questions about what insects see. The readers are prompted to make observations of insect pollinators in their own backyards, and to draw and record their observations directly in their “book.” Clio’s story also includes an exercise using cardboard tubes and a discussion of ultraviolet colors in flowers, similar to the classroom inquiry. The story concludes by encouraging more questions.
Assessing the Impacts

Can linking classroom-based inquiry with an engaging story that puts students to work as scientists when they go home enhance learning? To test the impact of the inquiry and the take-home story, we collaborated with three enthusiastic teachers. One teacher used just the class-based inquiry, another used only the “Clio the Scientist” story, and the third used both the class-based inquiry and the take-home story. Each teacher gave her students a simple assessment both before and after the unit that included drawing and responding to several statements.

In the first part of the assessment, students were shown a potted flowering plant and asked to draw the flower the way an insect might see it. In the pre-assessment, students in the Inquiry Only class most often drew multiple images of flowers or the faceted insect eye to represent the multiple images, however one student believed that insects could only see in black and white, another that insects can’t see the flowers, and another believed the image would be “fuzzy.” Only one student indicated that insects were small relative to flowers. Other students drew simple flowers or did not guess what insects might see. During the post-assessment, this teacher encouraged students to think about the pictures they had seen during the inquiry. Sixty percent of her students drew flowers similar to the ultraviolet photos they had seen with dark centers and light outer edges. Three students drew multiple images of the flower in the post-assessment (all three had drawn multiple images in the pre-assessment), but one incorporated the ultraviolet colors of flowers into the multiple images.

Drawings made by students in the Story Only classroom were diverse. Although the majority of students drew simple flowers during the pre-assessment, four incorporated
some kind of multiple images of the flower or insect’s eye. Other students believed insects could see through flowers, two argued that insects could only see black and white, and two suggested that insects had only smell as a way of finding flowers. Two students drew the insects as tiny compared with flowers. For the post-assessment, students drew wonderful portrayals of pairs of flowers illustrating the way humans see them and the way they may appear in ultraviolet light; nine students drew flowers with large areas of dark and light contrast. Drawings of three students did not differ between assessments: one drew the flower as black and white, another drew a simple flower, and the third drew the flower as multiple images.

In the Inquiry+Story classroom, only one of the students drew multiple images representing faceted eyes in the pre-assessment, three students suggested insects could only see in black and white, two students offered a different range of colors, and one suggested that insects could only see flowers (not the stems). After completing the inquiry and reading the story at home, almost all the students drew flowers reflecting the ultraviolet photographs in the post-assessment. The single student who had indicated multiple images in the pre-assessment also drew the flower as a contrasting dark center with light petals, but he added the insect would “see millions of the same picher [sp].” One student drew the flowers as colorful for humans and gray for insects.

Regardless of how the information was presented, all the children improved their understanding of how insects sense the world through vision. Responses to statements in the second part of the assessment indicated that before
instruction, most students believed that insect eyes are not the same as human eyes, that we may not see things the same way, and that our eyes are not the same (Table 7.1). Especially for students who did not have a view point initially, the inquiry effectively improved their understanding. In both classrooms that used the inquiry, the differences were significant: students no longer believed that “Insects see flowers the same way I see flowers” and “Insect eyes are just like human eyes”. In the Inquiry+Story classroom students had a better understanding of the nature of the scientific endeavor – that our brains process the information we see, and that science is active. The classrooms differed in their effects on learning outcomes, however (Table 7.2). Based on the differences in pre- and post-assessment scores, students experiencing the inquiry changed their answers more often or to a greater degree than those who only read the story. The largest effect on learning was related to the nature of the scientific endeavor. The proportion of students who realized that scientists don’t know everything about how insect eyes work jumped from 9% to 93% in the Inquiry+Story classroom.

Clearly, both the inquiry and the story were effective in improving student understanding about insect eyesight. Through informal conversations with students in the Inquiry Only classroom at the end of the school year, we discovered that one of their favorite science learning experiences was to pretend they were insects. Students from the Inquiry+Story classroom made thank-you posters showing dragonfly eyes as multi-faceted and noted they were really good predators capable of catching mosquitoes because of their keen eyesight. For a local newspaper story, several students mentioned learning what insects see as their favorite outdoor experience, and one student adeptly
Table 7.1.

Proportion of students disagreeing with statements made during assessment (only students completing both the pre- and post-assessments were included in the statistical analyses).

<table>
<thead>
<tr>
<th>Statement</th>
<th>Inquiry Only</th>
<th>n</th>
<th>Inquiry + Story</th>
<th>n</th>
<th>Story Only</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Insects see flowers the same way I see flowers</strong> (combined: $Z = -3.65$, $p &lt; 0.001$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-test</td>
<td>50%</td>
<td>14</td>
<td>25%</td>
<td>12</td>
<td>63%</td>
<td>19</td>
</tr>
<tr>
<td>Post-test</td>
<td>88%&lt;sup&gt;a&lt;/sup&gt;</td>
<td>17</td>
<td>100%&lt;sup&gt;b&lt;/sup&gt;</td>
<td>14</td>
<td>82%</td>
<td>11</td>
</tr>
<tr>
<td><strong>Insect eyes are just like human eyes</strong> (combined: $Z = -1.90$, $p = 0.06$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-test</td>
<td>77%</td>
<td>13</td>
<td>77%</td>
<td>13</td>
<td>79%</td>
<td>19</td>
</tr>
<tr>
<td>Post-test</td>
<td>94%&lt;sup&gt;c&lt;/sup&gt;</td>
<td>17</td>
<td>100%&lt;sup&gt;d&lt;/sup&gt;</td>
<td>15</td>
<td>91%</td>
<td>11</td>
</tr>
<tr>
<td><strong>The way I see the world is the way the world really is</strong> (combined: $Z = -2.42$, $p = 0.02$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-test</td>
<td>21%</td>
<td>14</td>
<td>36%</td>
<td>11</td>
<td>11%</td>
<td>19</td>
</tr>
<tr>
<td>Post-test</td>
<td>41%</td>
<td>17</td>
<td>80%&lt;sup&gt;e&lt;/sup&gt;</td>
<td>15</td>
<td>55%</td>
<td>11</td>
</tr>
<tr>
<td><strong>Scientists know how insect eyes work</strong> (combined: $Z = -1.71$, $p = 0.09$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-test</td>
<td>14%</td>
<td>14</td>
<td>9%</td>
<td>11</td>
<td>5%</td>
<td>19</td>
</tr>
<tr>
<td>Post-test</td>
<td>12%</td>
<td>17</td>
<td>93%&lt;sup&gt;f&lt;/sup&gt;</td>
<td>14</td>
<td>9%</td>
<td>11</td>
</tr>
</tbody>
</table>

<sup>a</sup> $Z = -2.46$, $p = 0.01$.

<sup>b</sup> $Z = -2.76$, $p = 0.01$.

<sup>c</sup> $Z = -1.73$, $p = 0.08$.

<sup>d</sup> $Z = -1.73$, $p = 0.08$.

<sup>e</sup> $Z = -2.27$, $p = 0.02$.

<sup>f</sup> $Z = -2.27$, $p = 0.02$. 
Table 7.2.

Tests for differences in the distribution of differences scores (the inverse of the post-assessment score minus pre-assessment score) for the three classrooms.

<table>
<thead>
<tr>
<th>Question</th>
<th>Likelihood ratio</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insects see flowers the same way I see flowers</td>
<td>10.917</td>
<td>6</td>
<td>0.09</td>
</tr>
<tr>
<td>Insect eyes are just like human eyes</td>
<td>12.983</td>
<td>6</td>
<td>0.04</td>
</tr>
<tr>
<td>The way I see the world is the way the world really is</td>
<td>8.025</td>
<td>8</td>
<td>0.43</td>
</tr>
<tr>
<td>Scientists know how insect eyes work</td>
<td>23.526</td>
<td>8</td>
<td>0.003</td>
</tr>
</tbody>
</table>

linked an insect investigation on mouthparts from later in the school year to the insect eye inquiry.

Conclusion

Literacy and inquiry learning are strongly connected (Yore 2004). From a constructivist learning perspective, reading can develop similar kinds of science skills as inquiry. Questioning and analyzing are processes taught by both reading and inquiry; they provide the framework to set goals, to develop predictions, to organize and explore, and for reviewing and reflection (Casteel and Isom 1994). Developing narratives from freely available inquiries is a fairly straightforward process, and it can really enhance learning. Teachers can use the background information provided in the inquiry to develop their own storylines and characters based on their personal understanding of both the topic and their students. Similarly, scientists visiting a classroom could use this
approach to enhance the impact of their visits. Moreover, take-home narratives can provide new opportunities to assess student understanding.

In addition to helping students develop skills that can be applied to both inquiry in science and reading for literacy (Casteel and Isom 1994), inquiry oriented narratives may serve a diversity of student needs. Reading inquiry oriented narratives may engage students that identify themselves more as readers than as scientists (e.g., girls; Ford et al. 2006). Development of these narrative texts may be even more valuable to low-socioeconomic status school districts where informational texts can be unavailable (Duke 2000). Best of all, using a simple narrative may help family members feel more comfortable with scientific inquiry and provide one way of bridging formal and informal environments to enhance science education in our communities (Resnick 1987; Rutherford and Billig 1995; Zuzovsky and Tamir 1989).

Acknowledgements

We are completely indebted to our teachers Kathy Dungan, Christy Meuer, and Elizabeth Sharkey, along with the amazing students at Lewis & Clark Elementary School in Missoula, without whom we could not have completed this project! We’d also like to thank Nathan Gordon and Diane Smith for their help and support. This project was funded by the NSF GK-12 Program at the University of Montana.

References


Appendix 1: Inquiry

In a nutshell: What in the world do insects see?
Understanding the limits of scientific knowledge using insect vision

Objectives:
- To explore the physical structures of insect eyes
- To recognize the assumptions scientists make to understand what insects see

Grade Level: 1-2

Materials:
- toilet paper tubes
- 3”x3” cutouts of magazine pictures
- handouts of optical illusions
- pictures of flowers in regular and ultraviolet light from the internet
- scanning electron microscope images of fly eyes
- magnifying jars (or magnifying glasses and containers)
- sweep nets/butterfly nets
- insect mounts

Engage:
First, students explore the limits of binocular vision. Using the cardboard tubes, they gaze through the tube with one eye and slowly move their hand away from their other eye until they see “through” their hand. Using two tubes at once, students try to see two different pictures at once. They also use the tubes to restrict their field of vision as they try to find their teammate (the cheese) as they pretend to be a fly.
Second, several different optical illusions help students explore how our brains make us see. Third, students start to think about what may be important for insects to see (food resources in flowers), and some of the interesting circumstantial evidence scientists have for their ideas about what insects actually do see (ultraviolet photographs of flowers and nectar guides).

Explore:
Students go outside and observe insects and flowers and think about what is important (color, location, flower shape) for insects to see. Using sweep nets, students capture several kinds of insects and put them into the magnifying jars to observe the different shapes and placement of eyes. Scanning electron microscope (SEM) images permit students to see extremely close views of insect eyes. They can develop hypotheses about insect eyes based on their observations in the outdoors, and have their own SEM images made.

For more detail, see What in the World Do Insects See at http://www.bioed.org/ecos/Inquiries/inquiries.aspx
CHAPTER 8.
EXECUTIVE SUMMARY

My research examined evolution understanding – what it is and where and when it develops. Because wildlife and nature programs so often deal with evolutionary theory, either directly or indirectly, I wanted to explore the role these programs played in the public understanding of evolution. Specifically, I was interested in determining how wildlife and nature programs that address ecology and evolution affected learning about evolution and the natural world.

I began by addressing the literature in a variety of disciplines, from philosophy to education, and history to communication. Without knowing the context of the problem, developing an experiment to address the issues or finding a solution is not possible. I began by chronicling the legal threats to evolution education, and the shift in creationist tactics to redefine the nature and scope of scientific knowledge. With the nature of knowledge in question, I examined the ontological and epistemological commitments related to science and evolutionary knowledge in our society and the historical development of this important theory. The theory of evolution is complex, however, and evolution educators have learned much about how people understand evolution, the nature of science, and knowledge in general in the last 25 years. Indeed, the literature review in Chapter 2 strongly supports a need for additional research that addresses science education, and evolution understanding specifically. The remaining chapters remedied some of that need.
Using data collected during two introductory biology courses, I asked exactly what students understood about evolution, and could nature films be used to affect that understanding (Chapter 3). A multi-step curriculum was designed to help students overcome misconceptions about evolution; the nature program *Fatal Flower* was used as a surrogate to reduce any personal affiliation with the common misconceptions students held. Initial assessments indicated students indeed held naïve views of evolutionary processes, and post-assessments indicated that a number of these misconceptions were overcome as a result of the curriculum. Students were asked to respond to four prepared alternative explanations about a natural phenomenon. These were similar in content but differed in their inclusion of common misconceptions about evolution. The results indicated that students’ conceptual ecologies varied, and as they began to grasp the complexity of evolutionary theory, their explanations included mostly proximate explanations and few misconceptions. Students who understood the more abstract concepts associated with the theory, however, included both misconceptions and proximate conceptions in their ecologies, indicating a struggle in their conceptual development. The data from my work and the literature strongly support an approach to teaching that embraces the diversity of concepts students may hold, recognizing that learning takes time, numerous contexts are required, and that conceptual change will be different for different students (diSessa, 2008).

Clearly, the results from the curriculum implemented provided indirect support for the influence of television programs on evolution understanding, but the data collected did not address the prior knowledge students brought with them to the classroom, let alone important covariates that may affect outcomes, such as attitudes
towards science and beliefs about knowledge. I addressed this gap by examining the influences that attitudes towards science, attitude toward evolution, beliefs about knowledge, and understanding the Nature of Science had on evolution understanding within a large-scale experiment (Chapter 4). I used a beautifully crafted nature program with poor presentation of evolution content and designed an experiment to tease apart effects of narration and imagery on understanding. I enlisted students in introductory biology courses from The University of Montana, Eastern Washington University, and Michigan State University to experience one of four versions of the nature program: the original version (re-voiced for consistency), a version with modified narrative but original imagery, a version with original narrative but modified imagery, and a version with both modified narrative and imagery. Results of the experiment indicated that the one-time viewing of a nature program may indeed have affected students’ evolution understanding. More importantly, this affect was apparent in students that had a moderate grasp of evolutionary theory – that is, students with the “best” understanding in this study. The relationships among understanding and individual characteristics, such as Attitudes toward Science, Attitudes toward Evolution, and Nature of Science Understanding (NOS) were complex, however. Individuals with a poor understanding of evolution (most students in the study) were likely influenced by a combination of poor presentation in the nature program and rhetoric proliferated by anti-evolutionists in the “marketplace of ideas” that questions the validity of theories in science. Indeed, NOS was an important covariate in most analyses. As a direct test of watching a single nature program on evolution understanding, the trends were apparent despite the complexity of
the experimental design, human research subjects, and the single event viewed at students’ leisure.

The poor quality of science presented in nature programs in the free-choice learning environment warranted examining learning from the perspective of the consumer of those programs. I explored audience beliefs about the educational value of wildlife and nature films because those beliefs may strongly impact learning outcomes (Chapter 5). Residents of Missoula, Montana were asked to respond to a survey addressing the characteristics they believed important to educational programs their beliefs about the presentation of the science in nature programs. As host to the International Wildlife Film Festival each spring, residents should have been more familiar with the genre relative to the general population. Over 95% of respondents believed nature films were “educational” and slightly fewer agreed that the primary goal for these programs was to teach about nature. In fact, the more they believed these programs were designed to be educational, the more they believed that the science and nature were portrayed accurately. Audiences clearly treated nature programs as credible and authoritative sources of science information, a significant issue given that they are expecting to learn from something that teaches evolution so poorly (Dingwall & Aldridge, 2006).

Chapter 5 prompted an important follow-up question: if audiences interested in the natural world were tuning to nature programming with an interest in learning, what exactly were they getting in terms of science and evolution education? I developed the Science and Nature Program Assessment Tool (SNaP) to analyze the content of nature programs quickly and reliably (Dissertation Appendix 1). Indeed, SNaP permitted evaluation of over 30 nature programs appearing on Animal Planet, Discovery Channel,
National Geographic Channel, and PBS during November, 2008, “sweeps” and in January, 2009. Programs did not score well, especially in the category describing the presentation of science. Misconceptions were common. The lowest scoring programs most often appeared on Animal Planet and Discovery Channel; National Geographic tended to air relatively high-scoring programs. The results indicated that, coupled with other variables related to socio-economic status, the difference in educational program quality among channels at different price-points may have repercussions for mass-media audiences and the public understanding of evolution.

My research with university students lends support to the role of understanding the nature of the scientific endeavor in understanding evolution and evaluating science in civil discourse. Teaching NOS is difficult, however, and we take very different approaches to teaching science to younger versus older students. Young students are often taught very simple views that do not reflect the power of the knowledge that is generated with a scientific approach. By the time students reach higher grades, they are expected to quickly grasp a new, complex approach to scientific inquiry. Teaching NOS to young children is clearly important; they may be quite capable of sophisticated thinking, especially within carefully sequenced learning experiences. Unfortunately, most curricula do not reflect what is now known about younger children’s cognitive capabilities (National Research Council, 2007).

Using an inquiry plus story approach, *Clio the Scientist* (Chapter 7) attempted to remedy the lack of available curricula for young students. I developed an inquiry around insect vision and what scientists can actually know about what insects see for first and second graders at Lewis and Clark Elementary School in Missoula, Montana. I wrote and
designed a take-home story to recapitulate some of the important points and investigative strategies accompanied the inquiry. Pre- and post-assessments of students’ experience with the inquiry alone, the story alone, or the inquiry+story indicated that the inquiry was quite successful at teaching NOS issues. Adding the story re-enforced concepts and engaged students in a way that the inquiry alone had not. This work showed that even with a minimum time investment, the effects were large; young students unequivocally grasped the tentative nature of science conclusion. “Scientists are still working on it!”

Significance

Science is but one way of knowing, and knowing about science requires sophisticated reasoning skills about the nature of knowledge and how that knowledge is generated. Advances in science engender their own issues in the public forum, issues that require understanding of science to address. It is within the public arena that the individuals need to weigh science with other ways of knowing as they make important civic decisions. Individuals may or may not have grasped important scientific concepts, like evolution, during formal schooling. My research suggests that if individuals are motivated to learn more about the science necessary to make these decisions, they may need new or different tools to assess the resources available in the free-choice marketplace. The video interface is increasing at a rapid pace, and free-choice science learning opportunities related to science in general, and evolution understanding in particular, will likely become more accessible. Future research needs to apply the wealth of recent literature related to cognition and learning to both public resources for evolution education and assessment of learning in those environments.
References


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Nature programs may be extremely engaging, but they often depict science and scientific processes poorly. We believe teachers need to be aware of the lack of scientific accuracy of these programs. We developed and tested a tool designed to help teachers assess the educational value of nature programs.

Nature programs are more than just entertainment, they also serve as a source of information and inspiration about the natural world. In fact, several studies indicate that viewing television can positively influence public attitudes and behaviors toward the environment (Holbert, Kwak, & Shah, 2003; Eagles & Demare, 1999). If we assume that nature and science programs actually address science and ecological issues thoughtfully, then this type of television programming could be a powerful tool for science education. Unfortunately, science-related programming can just as easily promote or create misconceptions about scientific concepts and theories, especially if the way the concepts are presented encourages (versus challenges) prior naïve conceptions. Nature programs are widely accepted as environmental documentaries, thereby giving them high standing with viewing audiences, but most nature films actually are fictionalized narratives driven by the cinematic themes and thrills of mainstream entertainment that ensure commercial success (Bousé, 2000; Mitman, 1999). Indeed, many educators have cautioned about the use of language in these programs that reinforces misconceptions (e.g., inheritance of acquired characteristics; Bishop & Anderson, 1990; Dingwall & Aldridge, 2006). We believe that teachers and science educators need to be aware of the concepts these programs promote, so they can take action to help students become literate in both media and science (see also Dhingra, 2006). To that end, we developed the Science and Nature...
Program (SNaP) Assessment Tool as an evaluation tool that teachers, and students, can use to critically examine the content of nature programs.

Nature programs present a host of questions for educational communities. For example, are the facts and scientific context accurately presented, and are theoretical constructs, such as natural selection or ecological relationships, adequately explained? Do films present science in ways that enrich the viewers’ understanding of the scientific enterprise, or do they make science appear to be nothing more than a set of absolute and unchanging facts? And when presenting difficult and controversial topics, such as global climate change or evolution, do the films represent the best science on what is known about a particular topic, or do they inadvertently (or purposefully) repeat commonly held misconceptions? These are the kinds of questions educators need to ask of all educational media, including nature films. Although several film festivals featuring wildlife and ecological themes offer awards to producers in the genre, these festivals do not use quantifiable criteria that can help reviewers identify programs with poor educational content or provide any criticism of inadequate, biased, and/or junk science. In fact, shows that illustrate science poorly receive awards for aspects unrelated to their educational or scientific content (e.g., cinematography). Worse yet, some may even receive recognition for their “educational value,” in spite of their inadequate or incorrect representations of nature or science. Several alternative sources for reviews of nature and science films exist (e.g., AAAS publication Science Books and Films), but these reviews are not quantifiable summaries. Therefore, we developed a review tool with quantifiable criteria to evaluate whether or not nature films represent science and the scientific process accurately and whether or not they use relevant metaphors to explain and
interpret key ecological concepts. Our goal was to develop a rubric that teachers could use to analyze the scientific content of a broad selection of wildlife and nature programs.

**Developing an Evaluation Tool**

To ensure SNaP was a credible tool for evaluating the scientific content and educational value of nature and science films, we based review criteria on important elements of the National Science Education Standards (National Research Council, 1996) and the *Guidelines for Excellence* (North American Association for Environmental Education (NAAEE), 2000). We also consulted with educators and scientists familiar with both the constraints of film and television production and with national science standards. We grouped review criteria into categories representing the scientific context, presentation of facts, presentation of nature of science “issues,” and the human dimensions of the science profession (Figure 1). We also included a category for reviewers to record their overall impression of the program, both quantitatively and qualitatively.

All criteria, except for two categories describing misconceptions, were scored on a scale from zero (poorly met or addressed) to four (highly met or addressed). The scale was converted to quarter points so that each criterion contributed a maximum of 1.0 points to the overall score. A penalty was assessed against the overall score for inclusion of misconceptions (deliberate or not) using a similar quarter-point scale. We calculated the mean score for each category for each film. We evaluated films across categories by compiling mean criteria scores and mean scores per category for all programs reviewed. We used non-parametric statistics (chi square) to test for differences among category
scores. Final “grades” were assigned by calculating the mean score of the science education categories and weighting this score using the Overall Impression Category. Based on the percentage score, we assigned a traditional letter grade. In general, shows receiving an “A” were outstanding in all aspects, including accuracy, context, and interpretation. Shows assigned a “B” may not have represented the science as well as they could have (e.g., better portrayal of the tentative nature of scientific conclusions), but were above average overall and visually engaging. A “C” grade indicated the show was captivating but did not represent scientists or the scientific process very well. Grades of “D” and “F” indicated both unacceptably poor representations of science and visual presentation. We developed a flower icon teachers can use to provide a visual depiction of the quality and highlight a film’s overall effectiveness (Figure 2). On the flower, each petal represents one of the major content categories plus the Teaching Value category. The leaves represent the appropriateness for Approach of the Story and coverage of Human Diversity. Problems in any particular category are clearly illustrated by fallen petals.

**Going to the Movies**

To test this tool, we took advantage of the International Wildlife Film Festival (IWFF), held annually in Missoula, Montana. The IWFF is one of the longest running film festivals, nearly 30 years, whose mission is “to foster and promote knowledge and understanding of wildlife and habitat through excellent and honest wildlife films.” Over 200 films are entered annually in this juried competition from a wide range of producers including corporate producers such as the British Broadcasting Company, Discovery, and
National Geographic, and independent producers whose work is often picked up by these companies. The films are judged on broad elements such as “excellence in scientific accuracy, technical achievement, aesthetic presentation, ethical wildlife practices, and educational value” (http://www.wildlifefilms.org/festivals/iwff/2009_IWFF_Packet_Entry.pdf, last accessed 15 February 2009). Consequently, the IWFF provides a unique opportunity to review a large sample of programs that typically enter the television market.

We had three objectives during the test phase of the evaluation tool. First, we tried to get as many reviewers as possible to review as large a selection of shows as possible to determine the range of programming for which the tool was best suited. Second, we assessed the consistency of the SNaP Tool in identifying problems and issues in the reviewed films; we used the film *Fatal Flower*, a previous award winner (Finalist, Merit Award for Soundmix, Merit Award for Narration, Merit Award for Editing, Merit Award for Scientific Content), in a case study to assess some of the basic functionality of the criteria. Third, we assessed variation across a large sample of reviewers with three specific award-winning programs to explore consistency of the ratings.

A Selection of Shows

We recruited faculty, graduate students, and volunteers interested in environmental issues to review films at the screenings they attended. We provided each reviewer with instructions on how to use the SNaP tool. The team of reviewers critiqued 27 films; the mean number of reviewers per film was 2.4 (range 1-5). Most films were natural history stories, typically presenting “a year in the life of an individual of species
x.” Indeed, 75% were rated as 3 or 4 (highly met or addressed) for “Describes the natural history of a species or place” in the program description category, indicating extensive agreement among the reviewers. The final distribution of grades was illuminating (Figure 3); few films scored a passing grade (mean=35%) even after the scores were weighted by overall impression (mean=52%). In fact, all but three films received failing grades for the science content (context, facts, and nature of science issues). The best overall grade was given to a film discussing whether the “culture” of the great apes was in any way similar to human culture. In contrast, an advocacy film about saving the planet received the lowest score; the film was full of serious, and seemingly deliberate, misconceptions about ecological concepts, such as the disconnect between personal actions and advocacy (e.g., drawing pictures of leaves to save a forest without recognizing that paper comes from trees).

The grades films received based on the SNaP Tool were not congruent with the awards presented at the IWFF. All of the films we reviewed received, at a minimum, a “Finalist Award,” suggesting they had met the festival’s criteria for educational value and science content. The SNaP Tool revealed a different story about the scientific and educational value of most of the films we reviewed. Using the SNaP Tool, our reviewers failed all of the films that had received awards, such as Best of Festival, Best Animal Behavior, and Best Children’s Show. Even the film awarded Best Science Content, one program in a series entitled The Shape of Life, scored a miserable 37% based on its science and educational values, and received a “D” once the overall score was weighted by the general impression of the film. In fact, the film awarded Best Educational Value only received a 46% from our reviewers.
One Fatally Flawed Film

Fatal Flower is a traditional natural history story that explores the evolution of orchids and their pollinators, as well as their relationships with humans. The program shows how different species of orchids have adaptations that enable them to be pollinated by specific pollinators (insects and birds). Thus, from an educational perspective, the film appears to document an excellent example of co-evolution and natural selection.

Six reviewers with science and education backgrounds concurrently viewed and critiqued the film using the SNaP Tool. The final weighted grade for Fatal Flower was only 45% (an “F”); worse yet, its science content rated only 13%. The low grade was a result, in large part, to the prevalence of misconceptions in the narration (Presentation of Facts and Interpretation score = 8%). Both seemingly deliberate (orchids “cheat”) and inadvertent (orchids changed specifically to cheat pollinators) misconceptions were apparent throughout the narrative. For example, one passage explains that:

“The crucifix orchid also tries to be something that it is not; it copies other plants nearby which have clusters of yellow and red flowers. The color guides the butterflies to the nectar, which is produced in the yellow parts of the flower heads. The crucifix orchid seems to know this, and its flower heads have the same color pattern, too. Some of the flowers are dark red, while the freshest are orange and yellow. But there, the similarity ends, as this orchid is a cheat. It may look like the others, but its flowers are empty. There is no nectar reward at all, so the butterflies are fooled into pollinating it for free. Orchids really are the femme fatale of the natural world. They’ve made cheating an art form, using it get
exactly what they need from the creatures that fall for their many and varied charms” (emphases added).

Although this dialog may seem engaging, it promotes misconceptions about evolution such as evolution as an individual-based phenomena, as a Lamarckian process, and as need-based. The program was quite visually impressive, however (score=0.96). We found no difference among reviewers in the overall scores ($\chi^2=0.822, 6$ df, $P=0.222$) nor in the science content categories alone ($\chi^2=0.639, 6$ df, $P=0.381$). The reviewers also were equally consistent about the Overall Impression of the program ($\bar{x}=0.61\pm0.081$). Consequently, Fatal Flower seems fatally flawed based on SNaP. Clearly, using this film in a classroom requires careful curriculum planning and intervention to address the misconceptions. Ironically, this program may be highly educational but only if teachers use SNaP to identify and dispel the misconceptions about evolution within its narrative.

**Reviewing the Reviewers**

To assess variation across reviewers, we recruited 15 students, faculty, and professionals from around Missoula to evaluate three films at the 2005 IWFF: Ants – Nature’s Super Power (festival awards: Best Educational Value, Best TV Program; merit awards: Macrophotography, Animal Behavior, and Science Presentation), Capuchins: The Monkey Puzzle (festival awards: Best Animal Behavior, Best Narration; merit awards: Scientific Content, Music, and Educational Value), and Tarantula – Australia’s King of Spiders (festival awards: Best Scientific Content, Best Script; merit awards: Educational Value, Graphics & Animation, and Editing & Photography). Not all reviewers were able to view all films. Using SNaP, all three films received scores that
were higher on average than scores for the first set of films we reviewed (64% vs. 35%). Nevertheless, the scores for science content categories were surprisingly low given the significance of the awards won by these shows. Misconceptions also were prevalent; reviewers identified seemingly accidental misconceptions in all three films, and deliberate misconceptions in both the program about capuchin monkeys (e.g., larger brain size necessarily leads to larger intelligence) and about ants (e.g., kin selection v. altruism). The Overall Impressions were only slightly greater than the science content scores; thus the weighting factor did not greatly affect the final scores. In these comparisons, we identified some differences in scores among reviewers (ants: \(X^2=36.84, 14\) df, \(P=0.001\); capuchins: \(X^2=27.30, 13\) df, \(P=0.011\); tarantulas: \(X^2=26.00, 11\) df, \(P=0.007\)). We also found differences when only the science content categories were considered (ants: \(X^2=32.18, 14\) df, \(P=0.004\); capuchins: \(X^2=30.80, 13\) df, \(P=0.004\); tarantulas: \(X^2=24.26, 11\) df, \(P=0.012\)). When the reviews were dissected, the differences were due in large part to the influence of a single reviewer whose background was not in the sciences specifically and whose scores were consistently higher than other reviewers’ scores. Finally, scores for Overall Impression of programs were similar (ants: \(\bar{X}=0.79\pm0.027\), capuchins: \(\bar{X}=0.80\pm0.031\), tarantulas: \(\bar{X}=0.77\pm0.030\)). Thus, the SNaP Tool was generally consistent from reviewer to reviewer, but as with any critical review, it may require some level of reviewer training for the reviews to be the most useful to people selecting films to use in an educational setting.
So Where is the Science in Nature Films?

The results of widespread testing of the criteria in our tool revealed that most nature films do not represent the underlying science adequately. Indeed, other disciplines take issue with the effect the narrative form may have. Vivanco (2002), in a review of environmental films, argues that “we have more to gain by scrutinizing the vehicles of representation, including the realisms they project and the dilemmas they omit, than by taking their messages and images as disinterested indications of ‘how nature works’ and how to resolve its problems.” As we struggle for scientific literacy in the 21st century, we need to be more concerned about scientific context and whether or not theoretical constructs are misrepresented, especially given popularity of nature films and the extent to which viewers believe the content to be factual and documentary. Papson (1992) argues that nature films are legitimized by emphasizing the educational and scientific “truth,” as distinguished from “fiction,” yet these films use devices common to fiction to add drama and to create meaning for humans. For example, CSI: Crime Scene Investigation, a fictional drama, uses science in very effective stories, yet few would promote the show as educational. “Docu-dramas” about nature (Bousé, 2000) that imply some level of scientific accuracy, especially when they have been conferred some level of credibility through awards ceremonies, are particularly problematic.

What are the key problems? Information in programs tends to be presented as “ready-made science” – the “final product” of scientific inquiry (i.e., characterized by a stable consensus that is no longer a fruitful avenue for challenge), as opposed to “science in the making” representing the forefront of scientific research where debatable claims are common (Latour, 1987). In a recent study exploring students understanding of the
nature of science from television genres, students watching episodes of *Wild Discovery* and *Bill Nye the Science Guy* (programs where the science was presented as a set of facts with a high degree of certainty) had few questions about the content (Dhingra, 2003). Without an understanding of the nature of the scientific endeavor, students can have difficulty assessing the merits of the information presented (see also Darley, 2003, Kirby, 2003). Moreover, as part of the narrative story, many wildlife films individualize the “struggle for existence”; they humanize the dramas (the orphan that struggles to survive and returns victorious to breed) that can mislead viewers to teleological and Lamarckian misconceptions about evolution (for excellent reviews of the history of film leading to this style see Bousé 2000, Mitman 1999). Indeed, Aldridge and Dingwall (2003) and Dingall and Aldridge (2006) show that references to evolution in nature programs indeed tend to be teleological – the narratives imply evolution is driven by some purpose. In fact, these authors conclude that the narrative in this genre actually increases the differences in understanding of evolution between the general public and biological scientists (Dingwall and Aldridge 2006). They note “it is highly questionable whether wildlife and nature programming is making an appropriate contribution to the preparedness of civil society to deal with key issues in biological and environmental sciences.”

Misconceptions are difficult enough to deal with in a classroom, but when they are promoted in informal and free-choice educational environments, especially with complex and controversial topics such as evolution and global climate change, they can be particularly insidious. We believe that programs students may perceive as educational should be reviewed with intense scrutiny to avoid errors that lead to misunderstandings of
wild animals and the natural world. To this end, the SNaP criteria may be effective in identifying programs particularly prone to misinforming students’ understanding of science.

And the Emmy Goes to…

But what is the intent of nature programs? Champ (2002) argues that wildlife films, for example, encourage wildlife protection, and environmental educators tout their positive influence on environmental attitudes (Holbert et al., 2003). Indeed, many ecologists point to wildlife and nature films as inspirational in choosing their profession (Ecological Society of America, 1993). To be sure, watching educational television is a choice made by viewers over other options, so captivating audiences is important. In a study of the effects of different genres, Dhingra (2003) suggests that students are engaged in television science programs, especially when they include characters and experiences relevant to the students (The X-Files was included to begin to address this point). Stories are the heart of the entertainment media, but they may have unintended consequences. March of the Penguins is a phenomenal visual glimpse into the world of Emperor Penguins (Aptenodytes forsteri), but without the scientific context, the narrative focuses public attention on “good parenting” and “intelligent design” (Penguin Family Values [New York Times 9/18/05]; Penguin Paradox [Boston Globe 10/14/05]). Nature films often have spectacular footage that can captivate students and draw them in, but they also can send messages that may have a profound impact on science literacy.

We designed SNaP to assess the quality of the representation of science in nature programs because so many of these films are used to enrich science instruction in
schools. Teachers could use the evaluation form to explore the presentation of the science in nature programs with their students. Indeed, SNaP may be an ideal tool to begin addressing misconceptions about evolution as students can be critical of the narrative, indirectly confronting their own misconceptions. In advanced grades, SNaP could be used as a teaching tool that allows students to explore the science content more deeply and to investigate misconceptions and inaccuracies. We believe nature programs offer exciting and emotional gateways to awareness of the environment and ecology. Our intent is to promote scientific literacy by providing teachers and other viewers with the tools they need to assess the information quality presented to them through the powerful medium of television.

Acknowledgements

We thank all the film review volunteers for their time and interest in helping develop this evaluation tool, especially Kim Notin. Thanks also to Diane Smith and reviewers of an earlier draft of this manuscript; their comments elucidated the need for quantifiable evaluation of these types of films. This work was supported in part with grants to the University of Montana from the Howard Hughes Medical Institute and the NSF GK-12 Program.
References


Ecological Society of America. (1993). Profiles of ecologists: Results of a survey of the membership of the ecological Society of America. Part II. Education and


Promoting the best SCIENCE in Nature Films

Reviewer Name: ________________________________

Title of Film: ________________________________

Rate each criterion from 1 (poorly met) to 4 (highly met). If the criterion is not applicable to film being evaluated, choose N/A. If you do not know, choose D/K (don't know).

### PRESENTATION OF FACTS & INTERPRETATION

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Poor</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>D/K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authorities are credible</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>D/K</td>
</tr>
<tr>
<td>Factually correct</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>D/K</td>
</tr>
<tr>
<td>Correctly presents current theory</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>D/K</td>
</tr>
<tr>
<td>Uses relevant metaphors to explain concepts</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>D/K</td>
</tr>
<tr>
<td>Presents a range of perspectives from different scientists and/or different research groups</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>D/K</td>
</tr>
<tr>
<td>Actively investigates alternative interpretations of scientific theory/ fact as part of the story</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>D/K</td>
</tr>
</tbody>
</table>

**Treatment of alternative conceptions**

- Inadvertently promotes misconceptions of scientific theory or facts
- Intentionally promotes misconceptions of scientific theory or facts

### SCIENTIFIC CONTEXT

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Poor</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>D/K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presents unifying themes and important concepts related to topic of program</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>D/K</td>
</tr>
<tr>
<td>In your opinion, what was the unifying theme?</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>D/K</td>
</tr>
<tr>
<td>Film acknowledges that feelings, experiences, and attitudes shape perspectives presented</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>D/K</td>
</tr>
<tr>
<td>Presents historical perspective of the development of the idea</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>D/K</td>
</tr>
<tr>
<td>Clearly presents the current state of the scientific debate</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>D/K</td>
</tr>
<tr>
<td>Context includes social and economic aspects</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>D/K</td>
</tr>
</tbody>
</table>

### "NATURE OF SCIENCE" ISSUES

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Poor</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>D/K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distinguishes scientific approaches from non-scientific and pseudo-scientific approaches</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>D/K</td>
</tr>
<tr>
<td>Discusses lines of evidence</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>D/K</td>
</tr>
<tr>
<td>Emphasizes the tentative nature of scientific conclusions</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>D/K</td>
</tr>
<tr>
<td>Discusses explanations and predictions</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>D/K</td>
</tr>
<tr>
<td>Addresses science as a process of consensus</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>D/K</td>
</tr>
<tr>
<td>Uses “hypothesis,” “theory,” and “fact” correctly</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>D/K</td>
</tr>
</tbody>
</table>
Figure 1. The SNaP criteria.
Figure 2. Icon used to depict the final grade assigned with the Science in Nature Program (SNaP) Assessment Tool. In the center of the Echinacea flower’s cone is the overall grade assigned to the program. Each petal symbolizes one of the categories scored in the rubric. The leaves represent the two descriptive categories. As an example of the icon’s function, a C-quality program may look like the inset.
Figure 3. Distribution of percentage scores of programs rated in the first broad test of the Science in Nature Program (SNaP) Assessment Tool. Figure 3a shows the distribution of the final grade; Figure 3b shows the percentage scores based only on the science content (gray bars=scores weighted by impression, maroon bars=science/education scores). Letter grades associated with each bar are shown. The position of Fatal Flower’s score is indicated by the arrow.