

A MATTER OF LIFE AND DEATH:
RETHINKING EVOLUTION AND THE NATURE
OF SCIENCE ON TELEVISION

by

Susanne Clara Bard

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Fine Arts

in

Science and Natural History Filmmaking

MONTANA STATE UNIVERSITY
Bozeman, Montana

July 2006

© COPYRIGHT

by

Susanne Clara Bard

2006

All Rights Reserved

APPROVAL

of a thesis submitted by

Susanne Clara Bard

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the Division of Graduate Education.

Chair of Committee

David Scheerer

Approved for the Department of Media and Theatre Arts

Department Head

Dr. Walter Metz

Approved for the Division of Graduate Education

Graduate Dean

Dr. Joseph J. Fedock

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Susanne Clara Bard
July 10, 2006

ACKNOWLEDGEMENTS

I would like to thank the USGS Pacific Islands Ecosystems Research Center and Kilauea Field Station, the University of Hawai'i, Hawai'i Volcanoes National Park, and the Bishop Museum for generously donating their time, expertise, facilities and resources for the making of my films. Without the assistance of USGS scientists and the Biocomplexity of Introduced Avian Diseases research project, they would not have been possible. The scientists, technicians and volunteer field crew that provided the backbone of the films included, among others, Dr. Carter T. Atkinson, Dr. Dennis LaPointe, Dr. Sue Jarvi, Dr. Bethany Woodworth, Dr. Patrick Hart, Bob Peck, Erik Tweed, Allison Klein, Peggy Farias, Carlie Henneman, Chrissy Rich, Mindi Hertzog, Brent Vickers and Jennie Walcek. Appreciation also goes out to my intrepid field crew, made up of Michael Baird and Sara Shier, who braved the lava and rain "on the Hilo side" every day to make these films.

Finally, without the funding support of the National Science Foundation and EPSCOR, this project would have remained merely a dream.

TABLE OF CONTENTS

1. INTRODUCTION.....	1
2. THE IMPORTANCE OF EVOLUTION IN OUR DAILY LIVES	3
3. HOW WE LEARN (AND MISUNDERSTAND) EVOLUTION	5
4. EVOLUTION ON THE SMALL SCREEN: DOES TELEVISION PARALLEL EDUCATION?.....	15
5. REFLECTIONS ON THE THESIS FILM.....	46
6. CONCLUSION.....	50
REFERENCES CITED.....	52

ABSTRACT

In a world where antibiotic resistance can make bacterial infections deadly and the HIV virus constantly mutates inside the human body, an understanding of evolution and its mechanisms is increasingly important. Yet much of the public is still either hostile to or misunderstands evolution and its mechanisms.

Television provides the bulk of the general public's exposure to science once formal education has ended. The rhetorical strategies employed by much of science and evolution programming, along with an emphasis on content over process, delivers the message that science is a search for absolute truths rather than a dynamic process relying on falsification and tentative knowledge. The way in which science and evolution is presented parallels failures in the educational system to teach science as more than just a collection of absolute truths and unassailable facts. In both science teaching and science television, critical thinking often loses out. Science television, especially that dealing with evolutionary themes from the distant past, tends to reinforce an authoritarian view of science by using visual images that are difficult to argue with, and an omniscient narrator.

Evolution, and much of science, is counterintuitive and difficult to learn. Presenting subject matter in the absence of context is inadequate for building epistemological structures. Producers, like teachers, must first gain a mastery of the true nature of science in addition to the subject matter they cover, in order to encourage critical thinking in their audiences. Several television programs do an excellent job of this, even though they are far removed from the beautiful and expensive "blue chip" films normally considered to be high-quality offerings in science and natural history programming.

INTRODUCTION

Evolution is a theory that has not been falsified. Despite increasing evidence that it occurs all around us, sometimes with deadly consequences (Quammen, 2004; Yang, et al., 2003; Wooding, 2004), a substantial percentage of the public still remains resistant to the idea (Brooks, 2001; Pigliucci, 2002), impeding their understanding of how it might affect their daily lives. In addition, evolution is often misunderstood inside the classroom by students who have incomplete epistemological tools to question the nature of science. Science education tends to be authoritative, and students treat evidence as incontrovertible facts that prove ideas. Additionally, as evolutionary knowledge grows, students associate a belief in its mechanisms with negative social and personal consequences (Brem et al. 2003). And once people leave formal schooling behind, television may become the main source of science for the general public. I suggest that science television (and evolution-themed programs especially) often parallel the dominant form of science education by discouraging the questioning of authority. Some of this has to do with the visual persuasiveness of the media. It can be hard to question what one sees, even when it is full of artifice. For instance, the seamless interaction of Computer-Generated Imagery (CGI) dinosaurs with real-life filmed environments lulls viewers into believing what they see to be true. Reenactments allow for compelling manipulation – the way in which programs about UFOs foster credulity is one example.

I propose a new litmus test for science television – one that does not divorce the content and results from the epistemological process that led to them. Such films will

query not just *what* science has discovered, but “how we know what we know” (Sandoval and Morrison, 2003). By encouraging critical thinking in adult viewers, and balancing content with scientific process, they might be able to refine their epistemological knowledge as well as expand their understanding of evolution.

In this paper I will examine 1) why there is a need to depict evolution on television, 2) how evolution is learned, as well as misunderstood, and why this might influence its effective presentation on television, 3) how science tends to be taught as the search for right answers and incontrovertible truths as opposed to a dynamic process of ideas subject to falsification, 4) why this is detrimental to critical thinking, and how encouraging the development of more sophisticated epistemological beliefs in both the classroom and small screen could improve science literacy and evolutionary knowledge, 5) evolutionary films that succeed and fail in addressing how we know what we know, and why we know it, and finally, 6) I will reflect on my own thesis film and how it fares in the light of my new litmus test, and what I would do differently next time.

THE IMPORTANCE OF EVOLUTION IN OUR DAILY LIVES

According to a recent Gallup poll, 39% of Americans believe that the theory of evolution is unsupported by evidence, and 41% do not believe in human evolution at all. Though 81% of respondents reported that they were at least reasonably informed about the theory of evolution, there is still widespread misunderstanding among the general public about its mechanisms, most specifically, natural selection (Brooks). Theodosius Dhobzhansky, an important figure in modern evolutionary synthesis, famously remarked that without evolution as a framework, “nothing in biology makes sense” (Dhobzhansky, 1973). And the signs of evolution are many and growing (Quammen; Wooding; Yang, et al.; Zimmer, 2005). Yet, according to polls, the public does not consider the teaching of evolution (or creationism) in school to be an educational necessity. “Only 28% of Americans say evolution should be a required subject and 49% say it should be an elective” (Moore, 2004). What are some of the real-world consequences of widespread misunderstanding and/or ignorance of evolution and natural selection? It is well-accepted by the scientific community that antibiotic use in humans is selecting for increasingly resistant strains, including the harmful Staphylococcus bacterium, making common infections more difficult to treat and sometimes even deadly. This problem will likely continue to grow and stump epidemiologists for years to come (Nesse and Williams, 1994). One solution was a campaign that encouraged patients not to ask for antibiotics for viral infections (for which they are useless). But unless the public understands the background of the problem (evolution by natural selection) as a

framework, this information carries little explanatory power. Pigliucci contends that HIV “makes the point that evolutionary theory is not just an academic matter, but is of vital importance for the survival and welfare of human beings.” Divergent strains of HIV complicate treatment and may require different epidemiological strategies. Furthermore, the rapidly evolving virus makes it a moving target that foils attempts to find a cure (Yang et al.; Pigliucci).

Clearly, an understanding of evolution is an important form of science literacy, having a tangible impact on human lives. But public opinion about evolution is deeply entrenched and has not changed dramatically for at least several decades (Brooks). And why is evolution so often misunderstood? Why is science education, and evolution especially, not just a matter of enlightening the public? To answer this question, we must first look at how evolution is learned and taught and at the cognitive constraints on its comprehension from the early years through adulthood. If school systems fail students in evolution, is there hope for the general public to learn it elsewhere, later in life?

HOW WE LEARN (AND MISUNDERSTAND) EVOLUTION

“When formal education in science ends, media become the most available and sometimes the only source for the public to gain information about scientific discoveries, controversies, events, and the work of scientists. Science and scientists are portrayed in the mass media on a daily basis. It is through television and other mass media that individuals receive much of their knowledge about science and scientists.” (Nisbet, et al., 2002)

If most people get their science education through television once formal schooling is over, the potential effectiveness of television as a teaching tool is not an insignificant topic. An awareness of how we learn and often misunderstand evolution may have an impact on how it can be effectively presented on television. To do so, we need to return to elementary school. Teaching a third grader evolution is like using a plastic knife to cut a diamond; it may verge on the impossible. This is not simply a matter of the complexity of the material. Cognitive constraints on how children conceptualize their world before age ten may influence their ontological belief systems. Studies of children attending public, non-fundamentalist and fundamentalist schools suggest that regardless of the child’s background or school environment, children (in the U.S. at least) between the ages of five and seven, create either “spontaneous generationist” beliefs of species origins from direct but naïve observation (ie. life spontaneously emerges during the spring) or essentialistic creationist views, which emphasize the immutability of life and “bridgeless gaps” between forms (Evans, 2001), with different species created by god, conceived of as an omnipotent parent or other adult. According to Evan’s studies, by the time children reach eight years of age, they start asking existential and teleological questions, such as the purpose of a particular

being or entity. At this point, creationist-essentialist explanations of origins begin to hold more explanatory coherence than spontaneous generation can provide. Children switch to an exclusively creationist viewpoint around this time, up until the age of ten, regardless of the community they come from. Children between the ages of five and ten resist all attempts to sway them toward evolutionary perspectives. Not until age ten and older do they start adopting evolutionary explanations. In a public school study, where parental beliefs were unknown, students embraced almost exclusively evolutionary beliefs at this age. In the study of fundamentalist and non-fundamentalist school communities, pre-adolescents from non-fundamentalist backgrounds adopted their parents' evolutionary beliefs and those from fundamentalist families kept their essentialistic beliefs, which continued to align with their community's creationist beliefs. Evans argues that "children generate intuitive beliefs about origins...while communities privilege certain beliefs and inhibit others, thus engendering diverse belief systems."

Why isn't evolution more intuitive? And why is it so misunderstood even by older students and adults? Is it because so much of modern science is counterintuitive and defies common sense? While evolution "is simply a change of gene frequencies over time," and well-supported by population genetics and modern molecular biology (Pigliucci), its mechanism, natural selection, is not easy to comprehend at first glance. A large body of literature suggests that to many people it remains opaque (Brumby, 1984; Anderson et al., 2002; Jimenez Alexandre, 1996; Greene, 1990; Sandoval and Morrison; Brooks), and even sinister (Brem et al.), while creationism as an explanation of origins, though not a science, remains easy to grasp. "Natural selection as a mechanism of

evolution is a central concept in biology; yet, most non-biology majors do not thoroughly understand the theory even after instruction” (Anderson et al.). Ironically, it may be natural selection itself that short-circuits our ability to maximize critical thinking and consider complex views. Our brains have been selected for quick decision-making abilities, which would come in handy when a predator stalked us nearby. Trial and error informs much of this common sense and intuition. But in the modern world, such thinking can keep us from deferring judgment, and even feed superstition, belief in supernatural explanations for extraordinary phenomena, and general gullibility. In other words, we may be our own worst enemies when it comes to critical thinking (Pigliucci: 272).

Lamarckism is an older and more intuitive mechanism to explain evolution than natural selection. According to the Lamarckian view, characteristics acquired during an individual’s lifetime are passed down to its offspring, in contrast to the selection of random mutations for their survival benefit as in natural selection. Lamarck’s mechanism has been tested and routinely falsified (Maynard Smith, 1997). But he laid down the framework for evolution, which Darwin would later revise. Darwin (and Alfred Russel Wallace) used Lamarck’s ideas as a springboard, providing a new, less intuitive, but more accurate mechanism, natural selection, to explain how evolutionary change actually takes place in the real world. Many students today continue to repeat Lamarck’s mistake. They regularly intuit evolution in Lamarckian terms (Jimenez Aleixandre), including medical students (Brumby). These conceptions could have very real and detrimental consequences for patients when these future physicians are

confronted with genetic diseases in their practices. Rote learning, “in which technical jargon and bits of information are learned, but do not find an appropriate structure to fit into,” may be a primary culprit for the persistence of such beliefs, even at higher levels of education (Jimenez Aleixandre). Rote learning may be a consequence of how science is presented to students. “Science to them may be seen as a body of absolute knowledge, most of which is recorded in books, or yet to be discovered by books” (Brumby). This paper will return to return to the idea of absolutism, as it is a key concept that connects the failings of science learning and literacy in schools to the problems of presenting science (especially evolution) on television.

The challenges of teaching evolution reflects a greater problem in science education. At an age when children begin to be exposed to serious biology classes, they are in their most essentialistic ontological phase. It’s little wonder, then, that younger children view science as a set of unchanging facts (Sandoval and Reiser, 2004). But science is most emphatically *not* “a body of knowledge” (Pigliucci: 127). After the age of ten, there is an opportunity for educators to present a much more dynamic concept of science. According to Sandoval and Reiser, a goal of national standards in science education should be to develop in students a “sophisticated understanding of the nature of science,” but we fall short. Instead, “the way that teachers and students talk science in school communicates a set of values suggesting scientific knowledge is authoritarian, objective, and incontrovertibly factual” (Sandoval and Morrison). A large body of literature on science learning over the last 50 years suggests that students view scientific theories not as “creative ideas that are developed to explain observed data,” but instead

they see data as “definitively able to determine if an idea is right or wrong, or sometimes say the data *is* the answer to the question” (Sandoval and Reiser). This type of education has been deemed “final form science” (Duschl, 1990), with theories disassociated from the long process that developed them. Instead of developing deep epistemological frameworks, students typically conceive of science as simply an unquestioned accumulation of discoveries about the world” (Sandoval and Reiser).

Without an epistemology to build upon, a coherent understanding of the nature of science or “how we know what we know” is inhibited. After a biological inquiry unit that turned middle school students into investigators who had to explain the causes for certain natural phenomena (implicitly but not explicitly a hands-on lesson in natural selection processes), students continued to see their work as the “search for right answers” (Sandoval and Morrison). In the course of the study, the students’ misconceptions about the nature of science were recorded in detail. They saw experimental data as the answer to questions, not evidence for or against ideas, they believed that experiments proved ideas, and that scientists want to prove their ideas, and that theories are proven ideas. In the same vein, they thought scientists would be lenient on data that was “borderline” if it confirmed their hypothesis. Most telling of all was that the concept of falsification was entirely counter-intuitive. If the goal of science is “to be right”, then progress can only come from right answers. Being wrong moves science backwards, not forwards (Sandoval and Morrison). Students had no concept of science as probabilistic. But probability and statistics are why falsification works and proof does not (Pigliucci: 128). Science embraces the opposite viewpoint from that of the students:

“Is any other profession so generous toward its admitted mistakes?...Science progresses by correcting its mistakes, and makes no secret of what it still does not understand. Yet the opposite is widely perceived.” (Dawkins, 2000: 31)

But who goes to school to learn about epistemology? Or falsification? Or the process of science? Or the history of science? The philosophy of science? Very few. Even science majors get very little exposure to the nature of science in their college coursework. Most courses are content-based, and do not engage in questions of critical thinking. The scientific method is discussed over and over again, but rarely its historical or philosophical underpinnings (Pigliucci). Students are ill-equipped to explain why someone should trust astronomy more than astrology, and why one thing is called science and another pseudoscience. In a study of his own science students, evolutionary biology professor Massimo Pigliucci found that 8% more science majors were likely to believe in paranormal phenomena than non-majors, and this was a statistically significant result (though admittedly based on a small sample size at one university). “The most revealing thing was that most of the non-science students were philosophy or psychology majors, who actually take courses on the scientific method and critical thinking. In contrast, science majors are *never* exposed to that sort of course and spend most of their initial science education in a large classroom where somebody who calls himself a professor, and whom they can barely see from a distance, inundates them with a flood of disconnected facts that they are supposed to remember in order to pass the test” (Pigliucci: 266).

This is just the sort of situation that Carl Sagan warns against when advising his readers how to avoid the perils of being taken in by pseudoscience: beware of arguments from authority. Just because someone is a professor, one cannot trust what he or she says

without question. He tells us: “in science, there are no authorities; at most, there are experts (Sagan, 1995: 210). The parallel in science television is the medium itself: the visual presentation of “facts” can be seen as incontrovertible, as when CGI dinosaurs seamlessly inhabit real landscapes. This will be discussed further in the next section.

When the nature of science is misunderstood - not only epistemology, but what science is and what science is not - the public can fall prey to the naturalistic fallacy, and nowhere is this more evident, or destructive to discourse, than in evolution. The naturalistic fallacy, defined by George Edward Moore (but going back to the “is-ought” problem originated by David Hume), conflates the natural with the moral. Because something is, this means it ought to be (Low, 2000: 29). When it comes to evolution, this suggests a predetermined course for human behavior that can’t be changed. For instance, if competition between kinship groups is a basis for selfishness, xenophobia, racism or violence, the naturalistic fallacy states that those behaviors are justified. More genetic differences are found between racial groups than within them. By the logic of the naturalistic fallacy, this means we should not be racist. Modern culture and free will allow us to decide xenophobia, racism or violence is acceptable, surely we don’t need biology or genetics to tell us what is right or moral!

Brem, et al. found that in a large sample of college students from diverse ethnic and religious backgrounds and fields of study, greater exposure to evolutionary theory was associated with “greater negativity regarding the consequences of believing in evolution,” whether one was pro- or anti-evolution in his or her worldview. They also felt that their sense of life purpose was reduced, and that evolution was incompatible with

spiritual beliefs. If these students had received the authoritative, final form science education typical of the United States at large, it is not surprising, then, that the naturalistic fallacy influenced their attitudes. This is speculative, but if one's view of science is static, and dominated by incontrovertible facts and truths, a genetically predetermined view of behavior is a more probable outcome than one that allows for an appreciation of variability, and the interaction of environment with culture in forming behavior. If these students had been equipped with more open-minded epistemological beliefs, they might have had the scientific framework to think their way critically past the naturalistic fallacy.

Epistemic beliefs can be measured empirically. Some people tend to seek single answers to questions, do not criticize authority, and accept knowledge as certainty, while others engage in actively open-minded thinking and routinely process ambiguous information. The latter considered more sophisticated epistemological beliefs. There is limited preliminary support for the idea that some epistemological beliefs, such as open-minded thinking, are correlated with an understanding of evolution (Sinatra, et al., 2003). The authors of this study advocate for the integration of the nature of science into science curricula. Evolution can be a daunting subject even when one's "personal beliefs do not conflict with the content," but showing that science is tentative, that there are limits to scientific knowledge, and "portraying science as a bounded human enterprise," may help decrease resistance to learning evolutionary concepts (Sinatra, et al.).

If one's epistemological beliefs are still not fully formed after school is over, and one's evolutionary understanding is incomplete or inaccurate, is it too late to learn

evolution? If television programming is our main source of science education after leaving school, can it teach us evolution?

Pigliucci suggests that the rationalistic fallacy lies behind most well-intentioned science documentaries, that is: producers often believe that science is a matter of common sense, and people just need to have it explained to them. As previously discussed, science (especially evolution) is not intuitive, so appealing to rationality will result in failure if the goal is to educate mass audiences. In a similar vein, in Representing Reality, Bill Nichols suggests that “realism in documentary supports a commonsensical view of the world, one where a reasoned perspective appears to subordinate and mobilize passion for its own purposes rather than orchestrate feelings to address or resolve contradictions that remain intractable to reason” (Nichols, 1991: 166). Reason competes with all sorts of conflicting worldviews, and common sense does not necessarily support rationality. Non-scientific and pseudoscientific explanations for the world vie for attention all the time (Pigliucci: 234), inside and outside the television screen.

Perhaps there is another way. Does the rhetorical strategy of the typical science show parallel science education by presenting information authoritatively? in its authoritarian presentation of information? Perhaps there is little room for alternative explanations, or a view of science that is tentative, probabilistic and ever-changing. Could science television become more effective at teaching evolution if it infused the nature of science into its content? Can television encourage critical thinking or does it accomplish the opposite?

“The details of the subcellular structures or of the classification systems of plants will soon be forgotten after the course, and at any rate, they are available in books and articles if one knows what one is looking for and where to find it. The ability to approach problems in terms of rational thinking and empirical evidence, however – once developed – stays with students for life and can be applied to everything, from buying a car to making a career decision.” (Pigliucci: 278)

To foster this kind of critical thinking, however, “teachers themselves must have a sophisticated epistemological understanding and many do not” (Sandoval and Morrison). The same goes for television, where the link between “instruction” (viewing) and “learning” is even more tenuous and unknown than in the classroom. To be successful, science television hosts and voice-over writers must not only fully grasp the content they are presenting, but must also develop strong epistemologies regarding the nature of science themselves, and the same goes for producers who choose the way in which the material will be delivered. For the average viewer, factual scientific knowledge (*what?*) is strongly correlated with procedural scientific knowledge (*how?*), and they could have an impact on each other. The new litmus test for a good science film should go far beyond “does it convey accurate information?” to explore innovative ways of challenging the audience to ask themselves “how do we know what we know?” without discrediting science. The next section will examine a variety of films that explicitly and implicitly explore evolutionary concepts. How well do they pass this litmus test? What are some time-tested traditions that promote or discourage critical thinking? What are some emerging models in science television that effectively illustrate the dynamic process of science, encouraging a scientific mode of thinking, and the importance of falsification? Is evolution television compatible with these approaches?

EVOLUTION ON THE SMALL SCREEN:
DOES TELEVISION PARALLEL EDUCATION?

Carl Sagan believed that television is “by far the most effective means of raising interest in science.” (1995: 76) But does science television encourage scientific thinking? Or, like science education, does it present scientific knowledge as authoritative, monolithic, and unassailable? Are the complexities of science too much for television to follow in a linear, time-limited format? And what is the role of producers, writers and hosts in shaping effective learning experiences from television? The effects of television on public perceptions of science have only started to be addressed empirically. Nisbet, et al. (2002) found that scientists are often depicted in a negative light: as evil or violent, mixed up in magic or the occult, or the powerless pawns of government – in many cases their science getting the better of them to the detriment of society. Scientists are also treated as the “other,” an elite and privileged group with all the answers, a priesthood of sorts, separated from the common man, often isolated, eccentric, or mad. Not surprisingly, the Nisbet study found procedural scientific knowledge to be correlated with content knowledge. But while science television viewing showed a weak positive relationship with content knowledge, it lacked a significant correlation with procedural knowledge. This suggests that producers are either not doing a very good job of depicting the scientific process on television, or that viewers simply lacked an understanding of the nature of science to begin with. In contrast, Nisbet, et al. found a positive relationship between reading science magazines and general newspapers with

several measures of *both* content and procedural knowledge. General television viewing was negatively correlated with both kinds of scientific knowledge, as well as with a negative attitude toward science. This study was conducted in 1999, before the advent of the highly rated procedural forensics drama, CSI. Emphasizing evidence-based scientific detective work on the cutting edge of technology, on the surface, CSI depicts science in a positive light. But when millions of viewers lack an understanding of science as conditional knowledge, and of its practical limitations, procedural knowledge may actually suffer from the success of such shows. The popularity of CSI has led to “unrealistic expectations” and the perception by jurors and the general public that forensic evidence is irrefutable and can answer any question in real-life court cases. But forensics labs that exist outside the television screen tend to suffer from under-funding and a backlog of samples, and as demand for such evidence grows, CSI remains more science fiction than reality (BBC).

And how is evolution depicted on television? Several studies have addressed this. Aldridge and Dingwall (2003), analyzed a large sample of science programs on British broadcast television that are concerned with evolution, and noted that most broadcasters’ approach to evolution is “purposive and goal-oriented” – at odds with most scientists’ views of a “random and contingent nature of the process.” The voice-over narrative of more expensive “blue-chip” films tends to mislead, by implying that evolution works toward perfection and purpose.

In contrast to most “blue-chip” films, producers and broadcasters have the opportunity with presenter-led programs to explain evolution in a less teleological

manner, and convey increased complexity. But Aldridge and Dingwall note that few recognize the occasion to do so.

In another study of evolution on television, “Unnatural history? Deconstructing the Walking with Dinosaurs phenomenon,” the authors note that in 1999, with its huge CGI budgets, this BBC series became the most-watched science program in British television history. Amid all of the hoopla, viewers failed to notice that they were not witnessing the real world of dinosaurs, but someone’s elaborate conception of it. Criticized for being dumbed-down and peppered with “pretty beasts,” it had the potential to convey much more scientific information. Its visual world, beautifully integrating CGI dinosaurs into their environment, creates the illusion of veracity, without drawing attention to the source. The series was “officially labeled as a natural history documentary” but actually mixed “fictional and factual genres,” especially given the Hollywood tradition of recreating dinosaurs in fictional motion pictures. The dinosaurs had to pass rigorous audience standards – not with regard to scientific plausibility since no one had actually ever observed a living dinosaur, but they had to adhere to the visual benchmark of the day, i.e. Jurassic Park’s dinosaurs. The natural history elements were contrived as well – following the cycle of the seasons, individual births, growth, maturity, and deaths as told through and omniscient narrator (Scott and White, 2003).

Bousé (2002) critiques the depiction of evolution on television as privileging the struggle of the individual, while suggesting that it would be more useful to speak of natural selection in terms of the survival of the group or the species. But this is inaccurate. If anything, television tends to erroneously promote group selection theory

and “for the good of the species” while simultaneously promoting the catchphrase “survival of the fittest.” Perhaps group selection makes more sense to the untrained writer or producer than individual selection, but as discussed earlier, much of science is counterintuitive. Survival of the species is almost a teleological phrase, as if someone or something is watching out for the whole herd, population or species as if it matters to nature that it continue to flourish. But nature has no morals.

Producers must guard against faulty assumptions similar to Bousé’s critique, and avoid barreling blindly into uncharted territory with evolution. “Scientists do not believe in evolutionary theory; they do not employ it based on a leap of faith” (Sinatra et al., 512). Neither should television producers; they should question their assumptions and cut their epistemological teeth before diving into production.

Representing what happened in the distant past is by definition problematical. Do we treat paleontologists and evolutionists as expert witnesses to the past, or simply interpreters of it (Nichols)? How should producers deal with conflicting hypotheses? What is unique about paleontology and documentaries on the origins of humankind is that the data is very thin, and pet theories are continuously being overturned by new evidence. To remain dogmatic in these fields is to miss the point of science. Here are perfect opportunities for documentaries to treat conflicting data, constant change and emerging tools as the basis for a scientific mystery story. But when approached as a “blue-chip” natural history re-creation, this kind of scientific inquiry and contingency would disrupt the flow of the narrative. Imagine a story about Tyranasaurus rex. CGI is used to show the species both as a scavenger and as a predator. As a “blue-chip” film,

the animations would have to be created twice, and the divergent behaviors would have to be explained. Because of this, the narrative cohesiveness and believability would be lost. Because the CGI world is a tenuous one in the first place, it must be vigorously defended by avoiding such inconsistencies and interruptions. British sociologists Aldridge and Dingwall point out that a “presumptive need for an orderly and satisfying ‘story’ does not easily accommodate alternative explanations, admissions that knowledge is incomplete, or a sustained emphasis on contingency.”

At the 2001 Jackson Hole Wildlife Film Festival, the audience of a nearly full theatre was told that it was about to become, in the words of the promoters, “an eyewitness to the past”: that is, to watch CGI dinosaurs fight, love, and romp through a filmed world in a two-hour special for the Discovery Channel called When Dinosaurs Roamed America. The film was narrated by John Goodman, whose matter-of-fact voice of authority described one behavior after another in the *present* tense. “The youngster has strayed from the center of the herd,” susceptible to the onslaught of an Allosaur. Elsewhere, a group of dinosaurs are seen hunting in packs, oddly reminiscent of wolves. A raptor comes upon another dinosaur but is confused about whether it represents predator or prey because to the raptor, it “looks like a half-plucked turkey” but “walks like a pot-bellied bear.” The producers did not divulge how they read the raptor’s mind. It’s not all death and destruction, however. The dinosaurs also find love. In one scene, sweet and romantic music signals the head-bobbing mating rituals of the Stegosaurus. As the two dinosaurs presumably copulate, the camera pans up to the sky. Unlike most “blue-chip” films where the filmed action is live rather than fabricated, the filmmakers

here seem too self-conscious to create dino-porn for mixed audiences. But the presumed copulatory cries of the stegosaurus are still heard. Later in the film, Goodman tells the audience that that the mating season for Zuniceratops has arrived, once again signaled by romantic music. “Once a year, come spring, some dinosaurs have more on their mind than food.” We are told that horns and frills have evolved not only to ward off rivals, “but to a female, they’re sexy.” When it comes to offspring, Triceratops are seen defending their young as a group – safety in numbers – and young Tyrannosaurus rex are shown still reliant on their parents for support. The film was a veritable clearinghouse for hypotheses of dinosaur behavior, but these hypotheses were presented as *fact*, in the form of lifelike CGI dinosaurs that conveniently behaved just as described. The script, however, had to be written before a single creature was conceived in a computer.

During the question and answer period at the end of the film, the producers were asked what their basis was for choosing and ascribing the behaviors they included in the film, since these animals lived millions of years ago. They answered that the behaviors were based on that observed in species living today, combined with clues paleontologists had gathered over the years. If this was the case, why wasn’t the behavior described or presented as conjecture or speculation even once during the entire film? Perhaps natural history film audiences expect a certain authority from “blue-chip” films. If an omniscient narrator starts presenting alternative ideas, can he or she be trusted? Given that paleontological data tends to come in small sets, most likely they are not very reliable or reproducible. Many behavioral hypotheses are extreme extrapolations at best, and most certainly highly speculative under any circumstances. Even if all of the behaviors

depicted in the film were based on well-reasoned studies of nest sites, tracks, and a variety of other clues to behavior, this is not the point. The audience is never privy to the basis for the behavioral reconstructions. They are simply expected to suspend their disbelief and become lost, swallowed up in this arbitrary world of fact. The problem with presenting dinosaurs in a “non-fiction” “blue-chip” film with an omniscient narrator is that to an uncritical eye, the compelling images become uncontested. The phrase popularized by Carl Sagan “extraordinary claims require extraordinary evidence” applies here. Whether or not the behaviors depicted are based on good science, they require extraordinary evidence to back up, and the film does not provide this evidence. The CGI artists were extremely careful to get the morphological and locomotory details of the dinosaurs correct (short of coloration and ornament, which is completely speculative), and the DVD special features make a point of this. But nowhere on the DVD is there any discussion of how the behaviors were arrived at. Whether or not extraordinary evidence exists, there’s little room for questioning the authority of the film. Bill Nichols suggests in Representing Reality that “(i)n documentary, realism serves to make an argument about the historical world plausible” (165). Films that attempt to re-create the distant past through the use of CGI provide a realistic-appearing world to support their argument. But the important question of on what basis one world (or set of behaviors) was chosen to be featured over another possibility is often ignored.

The expository mode of When Dinosaurs Roamed America leaves almost no opportunity for the audience to consider how the evidence was gathered or to consider alternative explanations. Like much of science education, it is authoritarian and filled

with irrefutable facts. The tightness of the story line would be ruptured by presenting explanations that diverge from the narrative argument (Aldridge and Dingwall).

Paleontology is a popular subject, one that excites and inspires generations of young people about science. The tentative nature of the discipline also spawned a documentary that provides the perfect counterpoint to the authoritativeness of When Dinosaurs Roamed America, and illustrates how the process of science and critical thinking can come to life onscreen, in an engaging format.

The History Channel might not be the first place one turns to for documentaries about paleontology that question cherished assumptions and examine how researchers update past “mistakes” with new data, but Dinosaur Secrets Revealed does just that. Such is the nature of a field in which “all witnesses are dead; all evidence has been left out in the rain for 65 million years.” While not primarily about behavior, a great deal of behavior is discussed in the film, and new discoveries and re-interpretations of evidence in dinosaur nests and track imprints turn previous assumptions about parental care and social behaviors on their head. This is exactly how a careful and responsible producer would approach each and every behavioral “hypothesis” presented without explanation or evidence in When Dinosaurs Roamed America. Dinosaur Secrets Revealed encourages open-mindedness and critical thinking through a combination of interviews with paleontologists, artists and special effects experts, integrated with dinosaur film clips, field work, and lab work, none of which seem to compete for center stage or throw off the central theme. The film succeeds where When Dinosaurs Roamed America fails. It shows healthy skepticism and avoids dogma while providing an entertaining portrait of

dinosaur research, at a fraction of the cost of CGI. In fact, dinosaur research here becomes a model for any kind of good science: dynamic, falsifiable and self-conscious. One could argue that When Dinosaurs Roamed America simply fills a different niche or even fits in a different genre. That may be the case, but unlike the former, Dinosaur Secrets Revealed can be *trusted*. It is curious that some of the same scientists turn up in both films.

Along the same lines as Dinosaur Secrets Revealed, is the History Channels' Ape to Man. From the start, the show takes issue with the fact that “the greatest question in the history of science” - that of human origins - had gone unaddressed until the mid-19th century. This alone indicts the ignorance of pre-evolution times, when supernatural origin theories held sway. The film uses reenactments of Neanderthals and modern humans, as well as a variety of other hominids, and researcher trying to make sense of them, together with interviews. Like When Dinosaurs Roamed America, the voice is in the present tense, which commands authority, but as in Dinosaur Secrets Revealed, the reenactments primarily serve to illustrate the scientific confusions and conflicts along the way, not reinforce incontrovertible facts. The discussion of Piltdown Man was rather pedestrian, but the writer did a good job of identifying the mistakes and delusions of scientists, subtly pointing out the need for critical thinking without making science itself look bad. Because the British scientists dearly wanted to believe that the missing link between ape and man was on British soil, they discounted much better evidence supporting an alternative hypothesis, to the ruination of at least one career. The film suggests that it was the personal investments of the scientists, rather than the scientific

process itself that caused the breakdown in rationality that led several decades of misinformation to dominate the field. Fields such as paleontology and anthropology become excellent subjects for films that delve into the nature of science, because they inhabit the edges of science, where the paucity of data can compromise interpretations, and scientists have to be doubly careful. When science is more sure of itself, when there is plenty of data, when the methods are airtight, it is harder for filmmakers to show potential flaws, and help the audience to question what they see as fact.

The film When Dinosaurs Roamed America was a work of fiction cloaked as a natural history film. It may or may not have told it like it was, but it never established on what basis it made these claims. There is something to be said for a hands-off, omniscient narrator, or a beautiful and poetic “blue-chip” nature film, but there is often a trade-off: due to their expository narratives, natural history films often fall short of allowing viewers to question the material presented, or show viewers the process that led to their claims. Any good natural history film bases its explanations of viewed phenomena on scientific observation, experiment, and often, well-supported hypotheses, even if it does not say where the information came from. But why should we believe what is said? Anyone can be a filmmaker.

Not just anyone can be Sir David Attenborough, but we trust him in our deference to authority (Sagan: 210). His BBC series, The Trials of Life, is a highly descriptive natural history of animal behavior. Evolution by natural selection is implied but typically not addressed directly. The VHS Jacket for the series reads: “Each episode shows a different stage in life, and the problems every animal must face in the course of passing

on their genes to the next generation.” (Ambrose Video Publishing, 1987). During the program, Attenborough sometimes references behavioral studies to make a point, but everything he presents and backs up with matching behavioral sequences is a presentation of Duschl’s “final form” science. If run without narration, there could be many explanations, hypotheses, if you will, for the behavioral sequences shown. Attenborough presents just one of them, and the audience is expected to believe it as truth because he is a respected authority, his explanation fits the video, and we have no reason to question what he says. Again, his science may be perfectly valid, and the content superior, but when audiences repeatedly see such documents presented as fact and reinforced by visual “evidence”, one may legitimately question what effect this has on the critical thinking skills of viewers.

In contrast the implicit evolutionary theme of The Trials of Life, Nick Upton’s “blue-chip” series, Triumph of Life, is a film dealing explicitly with themes of natural selection: “survival odds are not random,” the unseen narrator tells us, “each individual is the product of its parents, and some have an edge on others.” The narrative convention of using the present tense when showing scenes from the distant past (the episode entitled “The Four Billion Year War” intermixes CGI dinosaurs with real life baby turtles) is, as in When Dinosaurs Roamed America, a device that could influence the viewer’s ability to distinguish between fact and speculation. “Life is a war-filled with predation, rivalry and brutality,” Present tense lends support to truth claims because it leaves the mental, if not literal impression that something is happening in real time, and is therefore believable. Viewers are less likely to trust the past tense, because history is less reliable than

eyewitness testimony. The producers of Walking With Dinosaurs claimed to provide an eyewitness account of life during the Jurassic Period (Scott and White). When Dinosaurs Roamed America does the same thing, and Triumph of Life is not much different.

“Those fittest for the rigors ahead may one day return to breed themselves.”

Where most nature films go much too lightly on evolutionary mechanisms, or get it totally wrong, Triumph of Life spares few natural selection metaphors, and nearly hits the viewer over the head with them: “Some individuals fail. Others triumph. Only winners emerging from the battleground of life carry their family line forward,” and “only good hunters live to breed.” While natural selection is more than just a battle, the series uses its metaphors to effectively convey how this mechanism works without using jargon.

The problem with Triumph of Life, is that, like The Trials of Life and When Dinosaurs Roamed America, the language is too authoritative, and again the expository mode constrains it. How do we know only the best hunters survive? What if half the population has evolved scavenging what the hunters bring in as an alternate strategy? What if forming strategic social bonds is just as important as winning battles in order to gain reproductive success in a particular species? What is the evidence that natural selection in the form of the fitness metaphor is the best explanation as a mechanism of evolution? Again, all these things may be well-supported claims, but this mode of filmmaking demands that the audience not ask too many questions.

Some evolution and animal behavior films include life-and-death human drama, mirroring the supposed intensity of the species they feature. Perhaps this is a tongue-in-cheek (albeit dangerous) homage to natural selection, but more likely it boosts ratings.

SuperCroc is one such show, and like many others, also attempts to recreate the distant past. Produced by National Geographic, it was marketed with a sensationalistic and violent crocodile sequence. The tagline reads: “It didn’t walk with dinosaurs, it *ate* them.” SuperCroc teams up extant crocodile expert, Dr. Brady Barr, with paleontologist Paul Sereno, two men who complement each other in talent and personality, and also match the crocodile’s hypothesized behavior with their own high level of intensity and sense of reckless adventure in the swamps. But the film itself is much less sensationalistic than all the hype. The team searches for clues to the behavior of SuperCroc, Sarcosuchus imperator, by gathering clues from living crocodiles. By measuring the G-force of bites and the length of different crocodiles, the scientists hope to calculate whether SuperCroc was capable of attacking and actually killing dinosaurs. In order to do so, the men risk life and limb in crocodile swamps all over the world. The idea that anything could eat a dinosaur other than another dinosaur is intended to be the hook that draws an audience in, and the antics of the researchers keep them on the edge of their seats. But the way SuperCroc treats science is generally sound. “Speculation” is a word used often during SuperCroc, the scientists treat their knowledge as provisional, and by approaching the study of crocodiles with tools (such as biomechanics) that viewers might not normally think about, it encourages them not to believe everything that they are told, as well as creative thinking.

The Future is Wild: Hothouse World also attempts to re-create a distant time period – but this one far in the future. Few would disagree with any predictions about what the earth will look like in 100 million years, and any film project that treats this kind

of evolutionary extrapolation can be nothing but speculative. Yet the producers move seamlessly forward into uncharted territory. After all, where evolution will head is a fascinating and compelling question, worthy of discussion. So the filmmakers appealed to the authority of a variety of scientists who used predictions about climate change to dream up future evolutionary forms, descended from common ancestors alive today, and then they used clever CGI to back up their claims. The creatures that the scientists dream up are spoken of in the present tense using the language of certainty (“the X *is*...”), instead of the more tentative “we think X might evolve into this, or look like that”. There is no sense from the scientists that this is how it *might have been*, they are speaking of how it *will* be. The scientists hypothesize elaborate functional, symbiotic and parasitic relationships between the specialized creatures of this fantasy world, but describe them as if they are destined to come into being. These relationships are simplistic, which makes them easier to illustrate. During the one single instance of self-consciousness in the film, a scientist makes the logical argument that even though viewers may think this is science fiction, these are no made-up monsters, but, rather, descendents of those extant today. As in When Dinosaurs Roamed America, the behavioral adaptations and relationships between species are simply modifications of what scientists already observe in extant species. The Future is Wild makes that explicit in the narration and interviews, while When Dinosaurs Roamed America does not. In its digressions into the modern world, what the series does more than anything is provide the viewer with a plethora of reliable information about animals living today.

The scientists have even named their creations, further lending credence to their conception of the future world. For instance, the “Toraton” is a descendent of the modern tortoise with a case of gigantism, adapted to forage in high branches. And the “Blue Windrunner,” a specialized descendent of modern birds with four wings instead of two (so it can fly at high altitudes) and UV-reflective feathers for protection from the sun, that also serve as invisible (to humans) patterns for intraspecific recognition.

As in When Dinosaurs Roamed America, graphics illustrating the anatomy of proposed species are used to make the animals seem functionally and adaptively plausible. (and, say, not fall over from their own weight). But behavior is much more than a product of anatomy. The scientists and filmmakers are always careful to give adaptive explanations for the behaviors, but in the world of the future, populated by only a few creatures, each influencing the other’s evolution, explanations are kept simplistic and easy to understand.

The take home message of The Future is Wild: Hothouse World, is that the future may look different, but it’s not really. Making the alien world simply a modification of our own serves a normalizing function, it helps us relate to and identify with the future.

At the opposite end of the spectrum from films that present an authoritarian view of the world, Jacob Bronowski sets out to explicitly illustrate the provisional and probabilistic nature of science in the Ascent of Man: Knowledge or Uncertainty. His thesis? Through the metaphor of differing representations of a face depending on the perspective of the observer, he argues that twentieth century physics has shown that an exact picture of the physical world is unattainable. There is no absolute knowledge,

because the perspective of the observer is related to the precision of measurement, the underpinnings of the Heisenberg Uncertainty Principle, a cornerstone of quantum mechanics. He asks the viewer quite directly: how exactly can we see detail, “even using the finest, most perfect instruments”, since perspective changes?

Bronowski uses as an example the hubris of Hegel and other philosophers who professed to offer a path to knowledge “more perfect than observation”. According to Bronowski, Hegel’s tautological argument that there could be no more than seven planets because of the definition of planets, was revealed as an arbitrary claim when an eighth planet was discovered soon after Hegel published the statement.

Bronowski suggests that knowledge is confined within a certain tolerance, in other words, knowledge is probabilistic, and can only be based on observation. Thus, the *content* of his film warns viewers to avoid believing everything they are told at first pass. Instead of imparting “final form” science to an unquestioning audience, he asks them to think for themselves.

In a similar vein, Scientific American Frontiers: Life’s Biggest Questions, Alan Alda approaches his subject with an infectious enthusiasm and inquisitiveness balanced with skepticism. He joins scientists as they turn their computers into vehicles of natural selection: the computer starts with the basic instructions for swimming or ambulatory “creatures”, and generates random changes to the swimmers. The best swimmers or walkers are selected to “reproduce” through the next cycle, and some of their strategies are surprising: one “creature” is too tall and falls over, but adopts somersaults as its method of locomotion. Then Alda moves on to another lab to discover how well

evolutionary computer simulations hold up in the real world when they are constructed and let loose in the lab. In this episode, Alda witnesses instances of computer generated evolution along with the viewer. In this episode and others, he gets up close and personal with the scientists, often subjecting himself to experimental procedures. His approach is to play devil's advocate and put ideas to the test, not just accept them at face value. In Beyond Science? he investigates pseudoscience by testing paranormal claims alongside researchers. becomes simultaneously the science researcher and the guinea pig, the intimacy of which may appeal to viewers and draw them into the science.

The race to sequence the DNA of the entire humane genome is the subject of NOVA: Cracking the Code of Life, produced by Clear Blue Sky Productions. The human genome is described as the "four-billion-year-old storybook" of our lives, an implicit reference to evolution. Here, the process of genomic science is played in front of a backdrop of the intense competition between Craig Venter's privately-funded Celera Genomics laboratory and the publicly-funded National Institute for Health's Human Genome Project. Host/correspondent Robert Krulwich is on hand to guide viewers through the process of science and the human drama throughout the two-hour special. Like Alda, Krulwich becomes a guide who is discovering the science firsthand for himself, right alongside the viewer. Krulwich does not adopt Alda's skeptical affect for the most part, but the resulting product in both cases is far from the authoritarian "final form" science presented in many films.

"We will be raising a variety of issues," Krulwich informs us, and encourages viewers to participate by going online to take a survey which consists of questions about

the ethics of patenting genes and whether genetic information should be available to insurance companies (PBS). This is one way programs can attempt to help viewers identify with the content of the programming in a meaningful way. Those that take the time to complete the survey may reflect on how sequencing the human genome could affect their lives directly. The importance of genetics in our daily lives is further highlighted in the film by interweaving stories of families with children facing rare genetic diseases such as Tay Sachs. The promise of testing for a wide variety of genetic diseases before couples have children is presented as one of the many positive aspects of the Human Genome Project. By questioning the ethical implications and arguments over who owns genes and whether they can be patented, Cracking the Code of Life does not avoid or attempt to sugar-coat genomic science as politically or socially neutral. But overall, Krulwich's appeal to the personal benefits of genetic science in our lives is positive and provides a counterpoint to negative images of science in the media (especially the dangers of biology, or "science-gone-awry" in fiction movies and television) that often lead to public reservations about science (Nisbet, et al.). "It is, first and foremost, an early warning system for a host of diseases which will give, hopefully, parents, doctors and scientists an advantage that we have never had before," he tells us, "because when you can see trouble coming way, way before it starts, you have a chance to stop it, or treat it. Eventually you might cure it."

Krulwich uses that technology to illustrate in a simple, understandable way, how DNA is sequenced. "Human DNA is chopped by robots into tiny pieces," he tells us, "these pieces are copied over and over again in bacteria and then tagged with colored

dyes. A laser bounces light off each snip of DNA and the colors that it sees, represent individual letters in the genetic code. And these computers can do this 24 hours a day, every day.” This kind of clear language helps de-mystify the process of science, a counterpoint to the image of science as mysterious in the public consciousness (Long and Steinke, 1996).

To normalize DNA even further, Krulwich wonders what this molecule of molecules actually looks like in real life, not just as a list of As, Cs, Ts, and Gs: “that message contained in this stunning little constellation of chemicals we call DNA.” Stepping up to a lab bench, one of the principal government researchers, Eric Lander, pulls some extracted DNA out of a vial: “DNA has a reputation for being such a mystical high-falutin' sort of molecule, all this information, your future, your heredity, ” Lander tells Krulwich, “it's actually goop. So this here's DNA.”

Cracking the Code of Life does address the question of “how we know what we know”, but in an uncomplicated way. The human genome is purely descriptive. The scientists speculated and hypothesized about how many genes they would find, but a list of As, Cs, Ts, and Gs is simply a database. Of course, as such, it is a bottomless goldmine that will be referenced far into the future. We are simply shown the technology behind describing the biology, with little emphasis on the epistemological processes of science itself. We are also drawn into the human drama of “how we know what we know”. The human element does not change the result, other than the interesting but scientifically inconsequential revelation after the fact by Craig Venter that his DNA was used for most of Celera Genomics' sequence, the ultimate act of hubris (Herberman,

2002). Instead, the human drama unfolds over who will have access to the data, whether genes can be patented, and whether individuals can profit off of its outcome.

The Evolution series, another Clear Blue Sky production, narrated by Liam Neeson, attempts to cover the major content areas of evolution – from natural and sexual selection to extinction, in seven episodes. This includes a two-hour special called Darwin's Dangerous Idea, which basically plays out like a high production value period film on Darwin's travels, discoveries, and struggles, intercut with interviews, and a one-hour episode entitled What About God? which addresses the evolutionism-creationism debate as it plays out in an Indiana public school as well as a conservative Christian college. Auxiliary teaching materials are an important part of the larger educational mission of the series, which is used in many classrooms as an instructional tool. The PBS website for the series includes an "Evolution Library" containing clickable multimedia materials that draw directly from the series and other sources. One of the library categories is called "What Is Science?" and informs us that science is more than "a mountain of facts" and "does not prove anything absolutely - all scientific ideas are open to revision in the light of new evidence" (PBS). On this page, one can view clips about the nature and process of science, including the "scientific meaning of the word 'theory'", watch the process of testing sexual selection in peacocks in a clip from the episode Why Sex? with biologist Marion Petrie, and external links for teachers on the scientific method, and teaching the process of science to elementary school students, for instance. The auxiliary materials provide a rich environment for deeper learning of "how

we know what we know” for those who wish to go there and make the time. For those that don’t, much of this material can be found in the episodes themselves.

From the outset, the episode Why Sex?, makes certain basic assumptions. Neeson opens with the statement that “most of us will risk death to protect our children.” Why? Because they are the carriers of our genes and ensure “our immortality.” However, this essentialist view may be overly simplistic. Anthropologist Sarah Blaffer Hrdy, who served as an advisor on the Evolution series (Wikipedia), apparently was not consulted on this point, as she contends that maternal (and paternal) behavior is not as cut and dried as once thought – even in humans. She contends that mothers are “strategic planners and decisions makers” and rather than being reflexively nurturing, they make choices about parental investment dependent upon circumstances. They constantly make trade-offs between quantity and quality in their decisions to allocate resources to their children, which can result, for instance, in brood manipulation, the abandonment of the last-born, and even infanticide (Hrdy, 1999). Fitness is more than blindly sacrificing oneself for one’s offspring, or being the survivor of every battle, as emphasized in the Triumph of Life. Assumptions like this fly in the face of critical thinking, and border on dogma. Once you place your brain in a box, it is hard to get it out. Carl Sagan called this the “fallacy of assuming the answer”, without considering if there is any evidence to support an argument (213).

However, the rest of Why Sex? does question assumptions, and takes us on a wild ride through different mating strategies throughout the world. Why are males necessary? Neeson asks. With images of men doing “manly” things, he tells us that “questioning the

necessity of males is rare.” But one lizard species in the desert Southwest seems to do just fine without them. Rapid selection is illustrated in the example of certain fish species where the proportion of sexual fish increase compared to asexual fish (clones) in pools when parasites invade, because the asexuals have less heterogeneity in their genome and less ability to fight potential pathogens. But the answer is not that simple when the dynamics change, and the sexuals start becoming more homogenous and susceptible to disease. Why Sex? effectively illustrates how scientists formulate and test new hypotheses in the face of changing populations.

The episode tries to explain male and female parental investment strategies via differences in the size of the gametes (small in males; large in females), which Neeson tells us is a matter of quantity versus quality. But the producers portray the sperm and eggs with stereotypical male and female gender roles, colors (blue and pink), secondary sex characteristics, and even a necklace for the egg! They do a disservice to viewers by assigning the gametes these conventional features, because even if the stereotypes held true, the path between chromosomal sex and the development of gender results from a complex interaction of genes and environment (Low, 2000: 63). Using this kind of “harmless” humor for illustrative purposes misrepresents and oversimplifies, and only reinforces essentialistic views of male and female, while robbing the audience the opportunity to explore the true complexity of sex and gender in a scientific environment. Relying on “givens” about sex and gender, no matter how humorous, comes across as incontrovertible and has no place in a science documentary that otherwise promotes critical thinking and an understanding of the nature of science. The film later contradicts

its own essentialism by providing evidence that gender roles are *not* fixed universals after all, as in the case of the Jacana (a subtropical bird), where high nest predation has led to the evolution of females that control resources and defend their territories against other females, lay eggs in several nests incubated by harems of males, and destroy the eggs of other females.

The film tends to accentuate behavioral differences between species, while minimizing them within species. But it is intraspecific variation that natural selection acts on and results in adaptations and speciation, the subject of the series (Darwin, 1997: 14). In the discussion of evolutionary psychology, an essentialistic view of mate choice is adopted: we “all” perceive certain body types as more beautiful, for instance. While there may be statistically significant preferences, there is likely variation between individuals in degree (otherwise, the human population would look much more homogenous!). This is balanced by the inclusion in the film of ideas on the cutting edge of science that challenge conventional theories. For instance, evolutionary biologist Jeffrey Miller’s hypothesis that the human brain has evolved far beyond the mental capacity required in order to persist on the African savannah. Instead, our brains might be the result of runaway sexual selection – intelligence being an honest signal of mate quality. While such ideas are new and difficult to test, Miller believes that experimental methods will become more sophisticated, and eventually we’ll be able to find out if his hypothesis carries any weight. It is this kind of creative thinking that spawns the fodder for falsification and the future progress of science.

In Evolution: What About God?, a young fundamentalist Christian geology student named Nathan Baird attends Wheaton College, where instructors must sign an oath of their belief in Adam and Eve as the first humans. He begins to question his family's belief in a literal interpretation of Genesis: "I was indoctrinated in Genesis I and II. Evolution was Satan's doing in church." His mother describes Nathan as a boy who always asked the "difficult questions," unwilling to accept anything he was told as dogma: the sign of a budding critical thinker. Nathan must face his family and argue for his growing convictions about evolution, and he is frustrated by how easily people bash what they do not understand. His father reiterates a common misunderstanding about science: "If a scientist's whole goal in life is to prove Darwinism is the way we got here, he's going to die a very disappointed man." But Nathan maintains that evolution is the "best fit to the data."

A similar drama is played out at Jefferson High School in Indiana in a battle between students and teachers over the teaching of alternatives origin "theories" in addition to evolution. The students wore T-shirts that say: "Teach us the facts, let us decide," while the teachers lament that they have failed in their job to educate students about what science is and what science is not.

But in a sense, the students may be right. There is much disagreement in academia over whether scientists should debate creationists (Pigliucci: 273). The public science classroom is not the appropriate place to teach alternatives to evolution, but that does not mean teachers (who often shy away from controversy), should avoid illustrating the nature of science by discussing the difference between science and non-science (280).

By attending debates, Pigliucci points out that those with creationist views are unlikely to be swayed instantly by rational arguments for evolution, but “by planting the seeds of doubt”, cognitive dissonance may build up in the brain over time, and slowly, entrenched beliefs may be replaced (273). The Indiana teachers’ perspective is that they have failed their students, whom they see as blind sheep following the flock of ignorance. But the students’ appeal to be presented with the alternatives could also be seen as a rebellion against the authoritarian tradition of science teaching! If these same students attended evolution-creationism debates, perhaps their brains would duke it out and eventually process the conflicting information. Some might even become evolutionists one day. The same goes for pseudoscience and extraordinary claims. What better way to illustrate the nature and process of science than by putting paranormal claims, astrology, myths, Bigfoot, homeopathy, and a variety of fringe ideas to the test to see if they hold up to falsification? Alan Alda was a pioneer in this kind of skeptical television, by showing, for example, how one schoolgirl’s simple science project quickly debunked therapeutic touch (healing touch that doesn’t involve actually touching *anything*) in Scientific American Frontiers: Beyond Science?

It may be at the edges of science that we learn the most about what it is and what it is not. Two recent additions to the genre of science television have adopted this skeptical approach and have applied it in innovative ways to create compelling television. The Discovery Channel’s MythBusters is an extremely popular show that questions assumptions: it takes urban legends and puts them to the test. And National Geographic’s Is It Real? scrutinizes cryptozoology and other contested phenomena. Could these two

shows appeal to the same wide audience that also consumes credulous pseudoscience programming? Can their approach to balancing content with process succeed in saving science television from itself?

The direct approach to exposing the public to science, purely through the exposition of “facts” and science content, may ultimately fail:

“If you are one of those who are stubbornly trying to improve critical thinking skills around the world and feel frustrated by the wave of nonsense that regularly hits the airwaves and the media (of which creationism is of course just one example), you are not alone. But if you insist on thinking that all you need to do is explain things just a little bit better and people will see the light, you are committing the rationalistic fallacy.” (Pigliucci: 234)

To the uninitiated, MythBusters may appear at first glance to be just another show about crazy guys blowing things up. The show is hosted by two special effects experts, not scientists, far from the authoritative “experts” serving as hosts or interviewees on many science shows. The goal of MythBusters is not to “preach to the converted,” instead, they reach a large, diverse audience, and 47% of viewers are under the age of 35. In addition to producing television that has wide appeal with a younger crowd, hosts Adam Savage and Jamie Hyneman and producer Peter Rees have an ulterior motive. “Our mission is to make people think critically. It’s not really about whether we’re right or wrong, it’s about the way you think about the world you’re in.” (Peter Rees, in Loxton, 2005). Their modus operandi is to replicate myths and urban legends using their extensive special effects arsenal, and duplicate those results.

Falsifiability is at the heart of everything MythBusters tests, whether they are trying to discover if the human voice can shatter glass or if people could actually survive being buried alive. They don’t try to bust myths of UFOs or ghosts because according to

Savage, “it’s extremely hard to prove a negative” (Loxton). There are limits to how scientific the MythBusters tests can be. For instance, the team admits that given the expense and time constraints of television, it is difficult to get an adequate sample size. Occasionally, they reach their conclusions based on shaky evidence, because the conventions of television demand resolutions to their hypotheses. But amid the exhibitionism and despite the limitations, they expose the realities of the scientific process and the creativity required in order to ask productive questions and learn from one’s mistakes. According to Savage, “It’s very hard to design an experiment in the right way. Often, it takes two or three tries just to understand how to frame the question. There’s nothing more scientific than that struggle to ask the right questions.” (Loxton).

Mainstream science would not touch the subjects MythBusters tests. Many of their experiments examine things that people take for granted in their daily lives, like whether its better to run than walk in the rain (busted) but never bother to question. In a culture driven by entertainment, the science popularizer Richard Dawkins is skeptical of the need to make science “fun” in order to draw in an audience. Isn’t it enough, he asks, to make it interesting (23)? But MythBusters co-host Jamie Hyneman suggests that while it is a distraction to getting the job done, “all the clowning around helps peopled get to watch the show. Then, before they know what hit ‘em, they’re actually learning something, or seeing some decent engineering” (Loxton). Dawkins does admit that “practical demonstrations” of science can leave lasting impressions, which is exactly the point of MythBusters. “Our secret mission,” Savage tells us, “is to

encourage scientific thinking” (Loxton). By going where mainstream science will not tread, Mythbusters applies “how we know what we know” to our mundane, daily lives.

Carl Sagan suggested a show called Solved Mysteries that uses scientific methods of investigation to find rational explanations for phenomena involving “tremendous speculations” (377). Along similar lines, National Geographic’s Is It Real? series scrutinizes the truth claims of conspiracies (ie. The Da Vinci Code), mythological and equivocal beings (Bigfoot, the Loch Ness Monster, ghosts) and other controversial phenomena (National Geographic). It could be described as a more sophisticated version of Mythbusters, featuring Ph.D. scientists using DNA techniques instead of special effects artists and their warehouse of tools.

Is It Real? Ape-Man, concerns the legend of a one-meter tall Sumatran biped ape called Orang Pendek, which has never been confirmed by modern science. Villagers as well as foreigners swear to its existence in “eyewitness” reports, but scientists have dismissed them as fantasy in the absence of solid evidence. But partially due to the 2003 discovery of a tiny hominid skeleton, Homo floresiensis, that only recently went extinct on a nearby Indonesian island, the possibility of an undescribed (to science) primate species on Sumatra became less remote.

Dr. Peter Tse travels to Sumatra on a National Geographic grant to investigate the claim. A skeptic, he sets up camera traps to try and photograph the creature. Meanwhile, hair samples are sent to labs for cellular analysis and DNA testing, and footprint castings go for analysis. The hopes and dreams of several interested parties ride on the results, and they have the support of a well-respected British anthropologist. Other scientists tell

the audience how folklore is transmitted and how even thousands of eyewitness reports mean nothing without solid evidence. The episode also recounts the history of the Piltodown Man hoax, when wishful thinking persuaded intelligent scientists to abandon reason and belief on the basis of scant evidence. The stakes grow high: depending on the outcome, Orang Pendek could be just another case of overzealous imaginings, or it could radically change our understanding of human evolution. When the footprint casts are taken to a paleoanthropologist at The American Museum of Natural History, he carefully explains for the audience why the big toe of one cast could not be from an “efficient biped” and how the shape of the other doesn’t look like a foot at all, certain not of a creature that walks on two feet. Myth debunked.

In the DNA lab, geneticist Todd Disotell finds the Orang Pendek “hair” sample, the morphological structure of which had not matched that of any known ape in earlier tests, to be 100% genetic match to human DNA. This skeptic tells us this does not rule out contamination of the sample by collection methods, or degradation, but warns that field techniques will have to improve greatly in order to be of any value.

Meanwhile Dr. Peter Tse checks his camera traps. After only a month, he obtains beautiful images of a variety of forest animals, some of them very rare, but no Orang Pendek. However, Sagan also tells us that absence of evidence is not evidence of absence, and the limitations of the film’s schedule and budget conflicted with the ten-year time frame Tse set for himself – clearly a month is hardly enough time to gather compelling evidence *against* the existence of something.

In the end, the believers hold fast to their cherished myth, despite the falsifying evidence. It seems they are not interested in scientific explanations, because they are convinced that seeing is proof alone: anyone who walks into the forest and sees the creature will be persuaded.

Both MythBusters and Is It Real? succeed in questioning assumptions and discouraging gullibility. Their falsification strategies are easily applied to their subject matter, which inhabits the fringes of science. In the case of MythBusters, urban legends are ideal avenues for storytelling and exhibitionism, which are a big part of its appeal. Is It Real? offers a refreshingly empirical approach to subjects that have previously been treated with a great deal of credulity in the media and disdain by science (Sagan: 374). But can such techniques be applied to mainstream science? What about evolution? The success of Mythbusters is not so much in the answers but the audience appeal of how they are answered. The success of Is It Real? I suspect has less to do with whether Ape-Man or Bigfoot or the Loch Ness Monster exist, but the excitement of applying modern forensic technology to subjects that have become hackneyed in popular culture. This may be an indirect side-effect of the extreme popularity of the science-oriented forensic crime show, CSI (Nielsenmedia, Yahoo).

Science and natural history television addresses “how we know what we know” to varying degrees, from very little in many “blue-chip” films, to incorporating the nature of science into the very fabric of a series, as in Mythbusters or Is It Real? If producers wish to apply a similar approach to mainstream science topics including evolution, they are going to have to get very creative in their thinking. Using genetics to solve the mysteries

of evolution is one example of how this can be accomplished, but in the absence of sexy, explosive or mysterious material, the challenges are many.

REFLECTIONS ON MY THESIS FILM

When I set out to make a film about avian malaria and the Biocomplexity of Introduced Avian Diseases project in Hawai'i, I wanted to create a scientific mystery story to answer the question of why the Amakihi, a native honeycreeper, was surviving in the lowland forests in the presence of dense mosquito populations. The idea was to take the viewer along as clues were gathered from different disciplines that each illuminated a different piece of the puzzle: the result of that goal was the Montana PBS documentary, Survivors in Paradise. The Biocomplexity Project addressed an ecosystem in crisis on a scale and scope that few research programs have been able to tackle. By measuring the parasite, host, vector and environmental dynamics at three elevations, with tools from parasitology to genetics, the researchers developed a predictive model of the disease system that will be applied to conservation efforts (Woodworth, et al., 2005). Because of the nature of the Biocomplexity project, Survivors in Paradise had to cover a large amount of material a short time. The most interesting feature of the project for me was the idea that avian malaria seemed to be exerting selective pressure on the Amakihi wherever mosquito populations were dense. This explains in part why the Amakihi are doing so well at low elevations. The genetics portion of the project used molecular tools to study evolution in these birds, and this became the subject of my thesis film, A Matter of Life and Death: Evolution in Action. In this film, I wanted to delve more deeply into the science of genetics and show viewers how natural selection could occur faster than they might think. My challenge was to make the subject simple enough to be

understandable to high school students, yet not sacrifice the science content. But I also wanted to emphasize why rapid evolution is not just an abstract concept, but has real-world consequences, and de-mystify the process by which DNA is taken from a bird and turned into genetic data that can be analyzed and interpreted. In some respects I feel I succeeded in this goal, but during the process there are many things I discovered that I would have done differently. After writing my thesis, I now must ask myself, does my own thesis film pass my new litmus test by addressing “how we know what we know”?

I felt that showing young volunteers in the field could help students identify with field biology as something they might eventually participate in. I looked for ways to capture interactions and dialogue between the field technicians, while not forcing unnatural situations. In retrospect, this kind of coverage was opportunistic more often than planned, and I could have used much more of it to add a human dimension to the film.

I used a very traditional approach in this film. This was due mostly to two reasons: the film was funded by the National Science Foundation/EPSCoR specifically to address the Biocomplexity project. In order to be true to the project, it was necessary to cover how a problem is addressed from many different directions. While this is fairly unique among research programs, it meant that Survivors in Paradise had to carefully balance these different approaches. There was very little structural leeway to use anything but an expository mode of filmmaking. Since the pool of footage for A Matter of Life and Death was limited by what I shot for Survivors in Paradise, the thesis film

does not diverge radically from that mode, although there was more freedom to experiment.

I felt that I would have liked to capture more compelling evidence on tape of why genetic diversity could be an indicator of disease resistance. While I was writing my narration, I felt my statements were too authoritative for the evidence presented. Why should the audience believe that variation alone is good for the birds? The geneticists speak of “cloning and sequencing” the genes involved to see what they are, and whether they have anything to do with the immune system. I would have liked to show footage of them actually doing this and interpreting the results. I think viewers should be given the opportunity to question what is presented to them, and not accept what is fed to them as dogma. This is a more challenging task than it originally seemed. While I prepared my questions very carefully before filming, I feel I could have done a better job of questioning the results myself, until I was satisfied with the connection between diversity and resistance to disease. Also, at filming, the project was halfway completed, but as I finalized editing, genetic evidence for immune system involvement was growing. When fully available, this evidence could be integrated into the film at a later date.

A fine line also existed between describing too much technique to the point where the words became jargon, and not enough, as if a magic wand had been waved over the lab, resulting in data. I would have liked to show how frustrating experiments can be, how hard it is to get an adequate sample size when populations are small, and the magnitude of effort that actually goes into gathering and analyzing all that genetic data, but I did not have the footage to support this, and was unsure how I would fit it in.

Conservation genetics is a bold new field. It holds much promise, but is also poorly understood. I used the Amakihi as a protagonist that represented a positive rather than negative conservation story. The film advocates for a greater understanding of conservation through science, but was not meant primarily as an advocacy film per se. I attempted to show good science, which hopefully will be used as a basis for good policy decisions.

Finally, I would have made the film more interesting. The straightforward expository mode seems to me rather dull and pedestrian. This approach was certainly adequate as a learning experience for a first-time filmmaker in the field. But there were definitely drawbacks to being completely in charge of an entire project. I feel there is much to be gained through collaboration, and through creative checks and balances. I felt myself too close to my material at times, which slowed down the process, and it was difficult to step back and abdicate control over any part of it. There is much to be said for working collaboratively on films to which one has less personal attachment, to truly apprentice oneself to other filmmakers to see how they work, instead of just inventing the experience for myself.

CONCLUSION

“Since science is a method, not a body of results, the very statement that it leads to truth is misleading and misses the point of what a scientist’s activity is all about.” (Pigliucci: 138)

There is a growing need for an evolutionary education because it affects our daily lives. But teaching it, or effectively portraying it on television requires more than just enlightenment.

Documentaries appear on the surface to be non-fiction, to tell the truth (Nichols). But like science itself, science documentaries tell no more truth than what we know now: provisional and probabilistic knowledge (Nisbet, et al.). It is not a matter of being objective or subjective: according to the logic of Karl Popper, statements about the world are only scientific if they are falsifiable (Popper, 2002: 48). If we agree with Popper that this is how we distinguish science from non-science, shouldn’t the same apply to what we represent as science on television? Instead, science on television is often reduced to a form of non-science: authoritative narratives (especially in some of the higher budget “blue-chip” films) that resist falsification, and avoid rupturing their structural integrity by mentioning alternative explanations. Both science and natural history documentaries fall easily into this dogmatic style. And films about evolution lend themselves particularly well to voice-of-god narrations because they tend to have a linear framework situated in the past.

Documentaries do not have a monopoly on this approach. Students are rarely exposed to how science is actually done, or taught to think critically. According to

Pigliucci, only a tiny fraction of the pages of the average introductory biology or psychology college textbook actually explain how the content and conclusions presented are actually arrived at. We might turn to educational theory to discover how science lodges itself in our minds, and how evolution goes from being completely rejected at the age of eight, to being blindly accepted by some and dismissed by others in adulthood, with many shades of acceptance and understanding in-between. And just as going beyond content in the classroom prepares students for richer lives, by exposing viewers to more than just content, by giving them the tools to question their assumptions about the world around them, science and evolution television has the potential to leave a lasting impression on viewers.

Several recent shows such as MythBusters and Is It Real? have begun to adopt this approach on the fringes of science, but the challenge remains for mainstream science shows to embrace the kind of hypothesis testing model they use so successfully.

Passing the “how we know what we know” test is not just a matter of using the words “may be” or “could have been” in place of “is” or “was”. It requires more than distinguishing between speculation and well-supported hypotheses and theories, more than just using scientifically sound language. It requires that science filmmakers become critical thinkers themselves, and ask how the information came to be, before delving in to any promising project. Then they must let that understanding influence the film every step along the way.

The Darwin family was populated with dissenters and critical thinkers (Keynes, 2001: 128). Perhaps filmmakers could take a lesson from them.

REFERENCES CITED

Aldridge, Meryl and Robert Dingwall. "Teleology on television? Implicit models of evolution in broadcast wildlife and nature programmes." European Journal of Communication 18 (4): 435-453, 2003.

A Matter of Life and Death. Prod: Susanne Bard. Thesis Film. Montana State University, 2006.

Anderson, Dianne L., Fisher, Kathleen M. and Gregory J. Norman. "Development and evaluation of the conceptual inventory of natural selection." Journal of Research in Science Teaching 39 (10) 952-978, 2002.

Ape to Man. Prod: Anna Thomson. A&E Television Networks/The History Channel, 2005.

Bousé, Derek. Wildlife Films. Philadelphia: University of Pennsylvania Press, 2000.

Brem, Sarah K., Ranney, Michael, and Jennifer Schindel. Perceived consequences of evolution: College students' perceive negative personal and social impact in evolutionary theory." Science Education, 87 (2): 181-206, 2003.

Brooks, Deborah Jordan. "Substantial numbers of Americans continue to doubt evolution as explanation for origins of humans. Some Americans appear uncertain to meaning of terms". The Gallup Organization, Gallup News Service Poll, 5 March 2001. <<http://www.gallup.com/poll/content/print.aspx?ci=1942>> 2 October 2004.

Brumby, Margaret N. "Misconceptions about the concept of natural selection by medical biology students." Science Education 68 (4): 493-503, 1984.

Darwin, Charles. "Extract from an unpublished work on species." In Ridley, Mark, ed., Evolution. Oxford: Oxford University Press, 1997.

Dawkins, Richard. Unweaving the Rainbow: Science, Delusion and the Appetite for Wonder. New York: Mariner Books, 2000.

Dinosaur Secrets Revealed. A&E Television Networks/The History Channel, 2001.

Dobzhansky, Theodosius. "Nothing in biology makes sense except in light of evolution." American Biology Teacher 35: 125-129, 1973.

Duschl, Richard A. Restructuring science education: the importance of theories and their development. New York: Teachers College Press: 1990.

Evans, E. Margaret. "Cognitive and contextual factors in the emergence of diverse belief systems: Creation versus evolution." Cognitive Psychology 42: 217-288, 2001.

Evolution: Darwin's Dangerous Idea Prod: Clear Blue Sky Productions/WGBH-Boston. PBS, 2001.

Evolution (the series) Website: "Evolution Library: What is Science?"
<http://www.pbs.org/wgbh/evolution/library/09/index.html#nature_and_process_of_science> Accessed 24 June 2006.

Evolution: What About God? Prod: Clear Blue Sky Productions/WGBH-Boston. PBS, 2001.

Evolution: Why Sex? Prod: Clear Blue Sky Productions/WGBH-Boston. PBS, 2001.

Greene, Edgar D., Jr. "The logic of university students' misunderstanding of natural selection." Journal of Research in Science Teaching 27: 875-885, 1990.

Herberman, Ethan. "Update to Program." NOVA: Cracking the Code of Life Website. August 2002. <<http://www.pbs.org/wgbh/nova/genome/update.html>> 24 June 2006.

Hrdy, Sarah Blaffer. Mother Nature: Maternal Instincts and How They Shape the Human Species. New York: Ballantine Books, 1999.

Is It Real? Ape-Man. Prod: Cara Biega. National Geographic, 2006.

Jimenez Aleixandre, Maria Pilar. "Darwinian and Lamarckian models used by students and their representation." In Fisher, Kathleen M., and Michael R. Kibby, eds., Knowledge Acquisition, Organization, and Use in Biology. Berlin/Heidelberg: Springer, 1996.

"Karl Popper." Wikipedia, The Free Encyclopedia. 20 June 2006, 23:13 UTC. Wikimedia Foundation, Inc. 24 Jun 2006 <http://en.wikipedia.org/wiki/Karl_Popper>

Keynes, Randal. Darwin, His Daughter and Human Evolution. New York: Riverhead Books, 2001.

Long, M., and Jocelyn Steinke. "The thrill of everyday science: Images of science and scientists on children's educational science shows in the United States." Public Understanding of Science 5: 101-120, 1996.

Low, Bobbi S. Why Sex Matters. Princeton, New Jersey: Princeton University Press, 2000.

Loxton, Daniel. "MythBusters exposed: How a special effects crew opened the most important new front in the battle for science literacy." Skeptic 12 (1): 34-42, 2005.

March of the Penguins. Prod: Yves Darondeau, Christophe Lioud and Emmanuel Priou. Warner Independent Pictures/National Geographic Feature Films/Bonne Pioche/Wild Bunch, 2005.

Maynard Smith, John. "Weismann and modern biology" in Ridley, M. ed., Evolution. Oxford: Oxford University Press, 1997.

Mitman, Gregg. Reel Nature: America's Romance with Wildlife on Film. Cambridge: Harvard University Press, 1999.

Moore, David W. "Americans support teaching creationism as well as evolution in public schools; divided on origins of human species." Gallup Poll New Service, The Gallup Organization, 30 August 1999.
<<http://www.gallup.com/poll/content/print.aspx?ci=3625>> 2 October 2004.

MythBusters (Season One). Prod: Peter Rees. The Discovery Channel, 2003.

Nationalgeographic.com. Is It Real? Episodes.
<<http://channel.nationalgeographic.com/channel/isitreall/episodes.html>> 25 June 2006.

Nesse, Randolph M. and George C. Williams. Why We Get Sick: The New Science of Darwinian Medicine. New York: Vintage Books, 1996.

Nichols, Bill. Representing Reality. Bloomington: Indiana University Press, 1991.

Nielsen Media Research Top 20. 20-26 March, 2006. <<http://tv.yahoo.com/nielsen/>> 25 June 2006.

Nisbet, Matthew C., Scheufele, Dietram A., Shanahan, James, Moy, Patricia, Brossard, Dominique and Bruce V. Lewenstein. "Knowledge, reservations, or promise? A media effects model for public perceptions of science and technology." Communication Research 29 (5): 584-608, 2002.

NOVA: Cracking the Code of Life. Prod: Elizabeth Arledge and Julia Corf/Clear Blue Sky Productions/WGBH-Boston. PBS, 2001.

NOVA: Cracking the Code of Life online survey.
<<http://www.pbs.org/wgbh/nova/genome/survey.html>> 24 June 2006.

- Pigliucci, Massimo. Denying Evolution: Creationism, Scientism, and the Nature of Science. Sunderland, Massachusetts: Sinauer Associates, 2002.
- Popper, Karl. The Logic of Scientific Discovery. New York: Routledge, 2002.
- Rincon, Paul. "CSI shows give 'unrealistic view.'" 21 February, 2005, 13:57 GMT. <<http://news.bbc.co.uk/1/hi/sci/tech/4284335.stm>> 25 June 2006.
- Quammen, David. "Darwin's big idea." National Geographic, 206 (5): 4-35, 2004.
- Sagan, Carl. The Demon-Haunted World: Science as a Candle in The Dark. New York: Ballantine Books, 1995.
- Sandoval, William A. and Kathryn Morrison. "High school students' ideas about theories and theory change after a biological inquiry unit." Journal of Research in Science Teaching 40 (4): 369-392, 2003.
- Sandoval, William A. and Brian J. Reiser. "Explanation-driven inquiry: Integrating conceptual and epistemic scaffolds for scientific inquiry." Science Education 88: 345-372, 2004.
- "Sarah Blaffer Hrdy." Wikipedia, The Free Encyclopedia. 12 June 2006, 01:58 UTC. Wikimedia Foundation, Inc. 24 Jun 2006. 24 Jun 2006 <http://en.wikipedia.org/wiki/Sarah_Hrdy>
- Scientific American Frontiers: Beyond Science? Prod: Alan Alda. PBS, 1997.
- Scientific American Frontiers: Life's Really Big Questions. Prod: Alan Alda. PBS, 2001.
- Scott, Karen D. and Anne M. White. "Unnatural history? Deconstructing the Walking with Dinosaurs phenomenon." Media, Culture & Society 25: 315-332, 2003.
- Sinatra, Gale M., Southerland, Sherry A., McConaughy, Frances and James W. Demastes. "Intentions and beliefs in students' understanding and acceptance of biological evolution." Journal of Research in Science Teaching, 40(5): 510-528, 2003.
- SuperCroc. Prod: Simon Boyce. National Geographic, 2002.
- Survivors in Paradise. Prod: Susanne Bard. Montana PBS, 2005.
- The Ascent of Man: Knowledge or Certainty? Prod: Dick Gilling and Adrian Malone. BBC/TimeLife Films, 1973.

The Future is Wild: Hothouse World. Prod: Paul Reddish and Steve Nichols. The Future is Wild Limited, 2002.

The Trials of Life. Prod: Sir David Attenborough. BBC/Ambrose Video Publishing, 1987.

Top Ten Primetime Broadcast TV Programs. 7-13 November, 2005.
<http://www.nielsenmedia.com/ratings/broadcast_programs.html> 25 June 2006.

Triumph of Life: The Four Billion Year War. Prod: Nick Upton. PBS, 2001.

When Dinosaurs Roamed America. Prod: Discovery Communications/BBC, 2001.

Wooding, Stephen. "Natural selection: Sign, sign, everywhere a sign." Current Biology, 14: R700-701, 2004.

Woodworth, Bethany L., Atkinson, Carter T., LaPointe, Dennis A., Hart, Patrick J., Spiegel, C.S., Tweed, Erik J., Henneman, Carlie, LeBrun, J., Denette, T., DeMots, R., Kozar, K.L., Triglia, D., Lease, D., Gregor, A., Smith, T., and David Duffy. "Host population persistence in the face of introduced vector-borne diseases: Hawaii amakihi and avian malaria." Proceedings of the National Academy of Sciences, 102: 1531-1536, 2005.

Yang, Wa, Bielawski, Joseph P. and Ziheng Yang. "Widespread adaptive evolution in the Human Immunodeficiency Virus Type 1 genome." Journal of Molecular Evolution 57 (2): 212-221, 2003.

Zimmer, Carl. "Testing Darwin." Discover, 26 (2): 28-35, 2005.