Darwin's Paradigm Shift[1]

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In this research paper, Tim Berra explains the history of Darwin's theory of evolution. Then, he goes on to discuss one of this theory's implications and impacts on science. The discussion is mostly factual with minimal opinion included. Look closely at the author's strategies for staying objective about a controversial issue.

Charles Darwin (1809–1882) was an extraordinary man by any standard. The theory of evolution by natural selection, as elaborated in his book *On the Origin of Species* (1859) (Figure 1.1), is considered by historians and philosophers of science to be one of the most important far-reaching ideas ever had by the human mind (Dennett 1995). Before exploring this grandiose statement, a brief review of Darwin's life and scientific accomplishments is in order. Then I will address the implications of his very useful insights that extend beyond science and profoundly impact the progress of humanity

An Outline of Darwin's Life

Charles Darwin was born into a wealthy English family on 12 February 1809. His father, Robert Waring Darwin (1766–1848), was a prominent physician, as was his grandfather Erasmus Darwin (1731–1802). His mother was Susannah Wedgwood (1765–1817), the daughter of Josiah Wedgwood (1730–1795), the pottery manufacturer and entrepreneur. Josiah was also a close friend of Erasmus Darwin.

Darwin's father sent Charles to medical school at Edinburgh University in 1825 and removed him in 1827, when it became obvious that Charles was not interested in a medical career. Robert Darwin then decided that Charles should study to be a clergyman in the Church of England, sending him to Cambridge University in 1828. In 1831 Charles graduated tenth in his class among those who did not take an honors degree. He then received an invitation orchestrated by his professor, John Stevens Henslow (1796–1861), to be an unpaid naturalist-companion to Captain Robert FitzRoy (1805–1865) on a surveying voyage around the world on the H.M.S. *Beagle* (1831–1836). Darwin later described this opportunity as "the first real training or education of my mind."

On his return from the nearly five-year *Beagle* voyage, Darwin found that he was accepted as a serious scientist, and he had no desire to become a clergyman. He began working on the specimens collected during the voyage. He married his first cousin, Emma Wedgwood (1808–1896), and they eventually moved from London to Down House in Kent. They had 10 children, seven of whom survived to adulthood. In the years after the voyage, Charles was often ill, but nevertheless highly productive. He entered his ideas about how species form in a series of notebooks. This included a branching, treelike diagram that reflected the common origin and relatedness of organisms. This early evolutionary tree showed that classification should be genealogical (Pietsch 2012; Mindell 2013).

This tree's implications, however, extended far 5
beyond taxonomy. Darwin kept his revolutionary

[1]Berra, Tim M. 2013. *Darwin & His Children: His Other Legacy*. Oxford University Press, New York.

ideas private for 20 years, except to broach them to his closet scientific colleagues: geologist Charles Lyell (1797–1875), botanist Joseph Dalton Hooker (1817–1911), and his American botanist correspondent at Harvard University, Asa Gray (1810–1888) (Porter 1993). In 1858 Darwin received a letter from naturalist Alfred Russel Wallace (1823–1913), who, like Darwin, was inspired by the writings of Thomas Malthus (1766–1834). Wallace outlined ideas on natural selection and speciation that were nearly identical to Darwin's. This letter, combined with urging from Lyell and Hooker, prompted him to complete and publish *On the Origin of Species* in 1859. Darwin continued to perform experiments and publish on a variety of topics right up to the time of his death, of heart disease, on 19 April 1882. He was laid to rest with pomp and ceremony in Westminster Abbey, a few feet from Isaac Newton. Further details can be pursued in two of the most comprehensive biographies of Darwin (Desmond and Moore 1991; Browne 1995, 2002), a concise biography (Berra 2009), and, of course, Darwin's autobiography (Barlow 1958).

Synopsis of Darwin's Scientific Achievements

Educated citizens are generally aware of *On the Origin of Species,* as well as Darwin's account of his voyage around the world in the H.M.S. *Beagle* through his *Journal of Researches* (1839) (Figure 1.1), a book now universally known as *The Voyage of the Beagle*. *The Voyage* and *The Origin* have never been out of print. Almost all of Darwin's books have been translated into multiple foreign languages, numbering 33 by last count (Freeman 1977). *The Origin* itself has been published in at least 29 languages, 11 in Darwin's lifetime. Only his work on barnacles appears solely in English.

Most people are surprised to learn that Darwin also made many other major contributions to geology, zoology, and botany through his observations, experiments, and writings. His books have been chronicled (Berra 2009), so I will just briefly outline the breadth of his influence. Darwin explained how coral reefs form (1842) and contributed to geological observations on movements within the earth (1844) and the deformation theory of metamorphic rock (1846). In a pioneering four-volume work that took eight years to complete, he described all known fossil and living barnacle species (1851–1854). Darwin explained how orchids are pollinated by insects (1862) and how plants climb (1865), and he catalogued the bewildering amount of variation in domestic plants and animals (1868) (Figure 1.1). He delineated human origins and sexual selection (a special form of natural selection) in multiple species in ways never before articulated (1870–1871), and discussed human and animal emotions in the same terms (1872). The latter work was one of the first books to use photographs to illustrate a point (Prodger 2009).

Darwin showed how insectivorous plants on poor-quality soils utilize nitrogen-rich insects to provide that essential nutrient (1875), and demonstrated that the offspring of cross-pollinated plants were more numerous and vigorous than self-pollinated ones (1876, 1877). His observations of growth within plants laid the foundation for the field of plant growth hormones (1880). His work on earthworms (1881) is a classic study in ecology. Any one of these achievements, by itself, could constitute a life's work for most scientists.

Darwin's Legacy

Darwin was born and educated at a time when "special creation" was the prevailing scientific view. That is, God created the universe and all species a few thousand years ago, and they were unchangeable. "Revelation," not research, provided this view. Darwin began the H.M.S. *Beagle* voyage with this belief. During his lifetime the age of the earth was increasingly recognized as much more ancient, a concept suggested by James Hutton (1769–1797), Georges Cuvier (1769–1832), and Charles Lyell (1797–1875) (Bowler 1984; Larson 2004). Observations made during the voyage led Darwin to question the Genesis creation myth and the immutability of species. He found marine fossils thousands of feet above sea level and reasoned that the land had been elevated by movements within the earth, not inundated in great biblical flood. The fossil mammals he uncovered in South America resembled living mammals from the same area. He wondered why this should be if each species

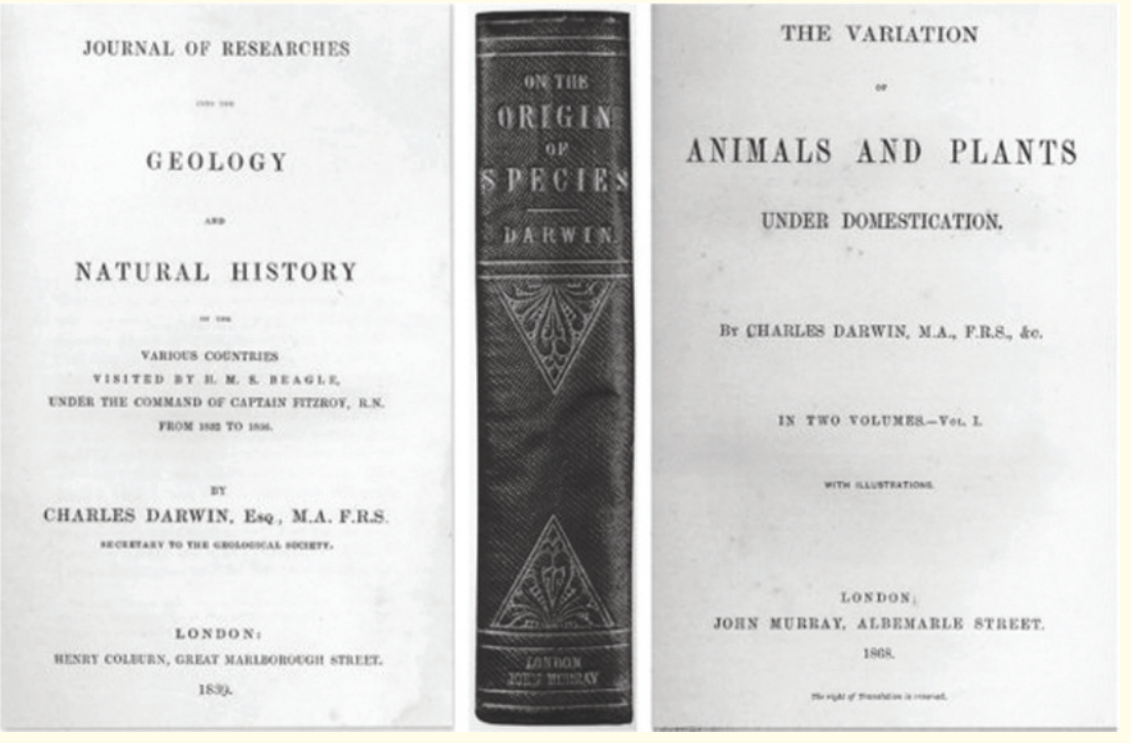

FIGURE 1.1

Left: The title page of Darwin's Journal of Researches, *published in its own right as a stand-alone book. It was originally published as volume 3 of Captain FitzRoy's narrative.* The Voyage of the Beagle *was first used as the title in 1905. Center: The spine of the first edition of* On the Origin of Species, *by Charles Darwin, published by John Murray of London on 24 November 1859. All 1,500 copies of the first printing were ordered before the official date of publication. Right: The title page of the first edition of* The Variation of Animals and Plants. *Herbert Spencer's phrase "survival of the fittest" is used by Darwin for the first time here. The material included in this book extends the first chapter of* The Origin.

was specially created. Extinction was barely recognized in those days. If each species was created in place, why did the animals on islands off continental areas resemble those on the nearest landmass? Why were there so many species in an island group that looked very similar but had slight differences from island to island? In *The Voyage of the Beagle*, Darwin concluded that it was as if "one species had been taken and modified for different ends." None of these things made sense from a creationist perspective. As he wrote to Hooker in 1844, "I am almost convinced (quite contrary to the opinion I started with) that species are not (it is like confessing a murder) immutable" (Burkhardt et al. 1985-, 3:2).

The elegant simplicity of Darwin's reasoning 10
can be distilled as follows. There is variation in nature, and many more offspring are generated than can survive; therefore there is a struggle for life in which favorable variations are preserved and unfavorable variations are removed. This leads to evolution, which he defined as "descent with modification," and to the formation of new species. Nature is doing the selecting for the forms best adapted to a particular environment, so Darwin called the process natural selection—as

opposed to the artificial selection that breeders impose. We now know that mutation, chromosomal rearrangements, the indiscriminateness of sexual reproduction, and the like are the sources of genetic variation, but Darwin had no knowledge of such topics. Today we can speak of the descent with modification of organisms as a change in gene frequency within populations; natural selection is simply the differential reproduction of heritable traits, that is, one genetic variant leaving more offspring than another (Berra 1990). Darwin borrowed the expression "survival of the fittest" from economist/philosopher/sociologist Herbert Spencer (1820–1903)—who published it in 1864—as a substitute for natural selection. Evolutionary fitness means reproductive fitness. In modern terms, the fittest is the one most likely to pass on the most genes to the next generation, not necessarily the biggest or the strongest individual.

By the time of Darwin's death in 1882, most scientists thoughout the world had accepted the concept of common descent, but some were still skeptical of natural selection as a creative mechanism (Bowler 1984). The public was less accepting.

When the first printing of *On the Origin of Species* appeared on 24 November 1859, it precipitated one of those rare events in the history of science: a paradigm shift. Philosopher Thomas Kuhn (1962) used this term to refer to the replacement of one world view by another. Examples of a paradigm shift in science include the replacement of the earth-centered Ptolemaic system by the sun-centered Copernican system, and of Newtonian physics by relativity and quantum physics.

Darwin's work neatly dovetailed into the wider pattern of scientific advances that were occurring during his lifetime. Lyell and others had provided the necessary geological time frame for evolution to operate. The writings of Georges Cuvier, Thomas Malthus, Robert Chambers (1802–1871), Herbert Spencer, Alfred Russel Wallace, and many others helped set the evolutionary stage. By 1859 evolution by natural selection was an idea ready to burst forth. Darwin and the publication of *The Origin* made it happen. Darwin, through *The Origin* and his books that followed, changed the way humans view their place in nature. He showed that humans were not above nature, but a part of it. He supplied the explanation for the great diversity of life and showed that all life—including human—is related by descent from a common ancestor. His explanation of evolution via natural selection is the basis for all of biology and its applied subdisciplines of medicine, agriculture, and biotechnology. No other biologist in the history of our species has had an impact of this magnitude. In the words of the eminent geneticist Theodosius Dobzhansky (1973), "Nothing in biology makes sense except in the light of evolution."

The paradigm shift from creation to evolution has moved intellectual endeavors from untestable beliefs to rational understandings that flow from the scientific method. This, in turn, has allowed a vast array of advances in knowledge.

Darwinian Implications

One of the attributes of a powerful scientific theory is that it enables future research and understanding. Darwinian (or evolutionary) medicine, as formulated by Nesse and Williams (1996) and expanded by Stearns and Koella (2008) and Gluckman et al. (2009), explains how some disease symptoms, such as fever, may be a response favored by natural selection as a defense against pathogens. Some conditions generally considered to be genetic diseases, such as sickle cell anemia, may allow differential survival of its victims in malarial zones, a phenomenon called balanced polymorphism (Berra 1990). Evolutionary thinking explains the arms race waged by pathogens and hosts that prevents either from being completely eliminated. The development of resistant bacteria through the flagrant overuse of antibiotics is easily explained by Darwinian reasoning. A drug will kill the susceptible bacteria, but bacteria with a preexisting resistant mutation are unaffected and can build up the next generation. Then, when that antibiotic is later needed for a bacterial infection, the drug is ineffective. This is evolution, pure and simple. 15

A similar process occurs in agriculture with the overapplication of pesticides and the formation of pesticide-resistant pathogens, insects, and noxious plants. Australians are very familiar with warfare between myxomatosis and rabbits:

the virus initially killed 99 percent of the rabbits (an invasive, or nonnative, species in Australia), but, given enough time, the surviving rabbits returned in force, since the virus evolved in the direction of less virulence and the process of natural selection among the rabbits resulted in more resistance to the virus (Berra 1998).

Evolutionary psychology and evolutionary ethics, as explored by Barkow et al. (1992) and popularized by Wright (1994), help explain the origin of morality. Peacemaking among nonhuman primates, through the calming effect of mutual grooming to diffuse aggression, may be seen as the precursor of what became morality in humans (de Waal 1989). Modern religions are recent human inventions––a mere few thousand years old. The antecedents of morality, on the other hand clearly evolved before humanity, as reflected in the empathy exhibited by bonobos (*Pan paniscus)* and the reciprocity of chimpanzees (*P. troglodytes*) (de Waal 2005). The awareness and sensitivity demonstrated by humans' closest relatives may be the underlying driver of prosocial behavior (de Waal 2012, 2013). Kin selection, where an individual voluntarily sacrifices for a close genetic relative, makes sense in an evolutionary context, because some of the same genes of the individual making the sacrifice will be passed on by the kin who survives. Hamilton (1972) refers to this as inclusive fitness. A realization that humans share kinship with all animal life has helped to raise consciousness about how we treat other animals (Singer 1977).

The ancestry of the AIDS virus, HIV-1 (human immunodeficiency virus-1), has been traced to SIVcpz (simian immunodeficiency virus) carried by our closest living relative, the chimpanzees, *P. troglodytes* (Bailes et al. 2003). This is not surprising from an evolutionary perspective. Somewhere in high school today there is a student whose future research may contribute to better control of the AIDS epidemic. What chance of that would there be if evolution weren't taught properly in high school?

Even religion is now being explained as having an evolutionary origin: a natural phenomenon that arose once the brain evolved a critical mass and complexity (Dennett 2006). Bloch (2008) suggested that the evolution of imagination was a requisite for the emergence of religion, which he considered a logical extension of human sociality. Previously, this emergence of modern human behavior was thought to have occurred about 35,000-40,000 years ago, the time of the Upper Paleolithic "revolution," as manifested by an explosion of image making and cultural transformations (White 2003). However, recent discoveries in South Africa of engraved ochres (Henshilwood et al. 2002) and of small bladelets made from heat-treated stone (K. Brown et al. 2012) demonstrate that humans had already evolved the capacity for complex thought at least 70,000 years ago. Acceptance of authority (necessary for group cohesion and survival), enforced by tool use and language, and combined with a confusion between coincidence and cause and effect, can result in the establishment of a religious belief that becomes dominant in a culture (Wolpert 2007). Religion encourages beliefs and rituals—which may appear absurd to outsiders—that unite in-group cohesiveness but also promote conflict with out-groups (Atran and Ginges 2012).

Those whose religion requires a literal in- 20
terpretation of the Bible fear that a paradigm shift from supernaturalism to methodological naturalism (a naturalistic causation for nature's phenomena) threatens their beliefs. The 1925 Scopes trial—nicknamed the "monkey trial" and the "trial of the century"—in Dayton, Tennessee, has come to symbolize the struggle of religion against science in popular culture; the trial later inspired the play and film *Inherit the Wind* (Larson 1997). Such creationists are particularly vocal in America, which has a longstanding tradition of anti-intellectualism (Pigliucci 2002; Numbers 2006). This has resulted in a series of creationist legal challenges to evolution that have been decided in favor of evolution (Berra 1990). The most important legal cases are against creationists or government entities that have adopted creationist policies, thus violating part of the US Constitution. These legal decisions include *Epperson v. Arkansas, McLean v. Arkansas, Edwards v. Aguillard,* and *Kitzmiller v. Dover.* In the latter case, intelligent design (ID) creationists influenced the Dover, Pennsylvania, School Board to adopt their ideas, an action that was challenged in the courts by a

group of parents. The ID creationist philosophy, which posits that life is too complex to have arisen by natural means and therefore had a supernatural origin, has been critiqued in Pennock (2001) and exposed as a threat to science education by Forrest and Gross (2004). In the concluding portion of his decision, Judge John E. Jones III (2005) determined that the school board's policy of teaching intelligent design violated the Establishment Clause (the separation of church and state) of the First Amendment to the US Constitution. He wrote: "In making this determination, we have addressed the seminal question whether ID is science. We have concluded that it is not and moreover that ID cannot uncouple itself from its creationist, and thus religious, antecedents. . . . The breathtaking inanity of the board's decision is evident when considered against the factual backdrop which has now been fully revealed though this trial." For those who want to dive deeper into the miracle-strewn world of the anti-science crowd and explore this interesting case further, Padian (2007) reviewed three books based on the Dover trial.

Modern Evolutionary Synthesis

Darwin, of course, had no knowledge of genes, chromosomes, or how inheritance worked. This required additional input, arising from an understanding of Gregor Mendel's (1822–1884) genetic work. Biotechnology, whether in the form of genetically modified crops, designer drugs, gene therapy, or the human genome project, derives from Darwin's and Mendel's profound insights into how nature operates.

The modern evolutionary synthesis grew from Darwin's explanation of natural selection and Mendel's demonstration that inheritance was particulate—that is, that it can be passed from generation to generation by "particles," now known as genes (Dobzhansky 1937)—augmented by the research of mathematically oriented population geneticists such as J. B. S. Haldane, Ronald A. Fisher, Sewall Wright, Thomas Hunt Morgan, Theodosius Dobzhansky; paleontologist George Gaylord Simpson; botanist G. Ledyard Stebbins Jr.; biologist Julian Huxley (Thomas Henry Huxley's grandson); and the most important evolutionary biologist since Darwin, Ernst Mayr. This fusion of knowledge moved evolutionary science forward to the middle of the twentieth century (Larson 2004). James D. Watson and Francis Crick's 1953 demonstration that the molecular structure of DNA (deoxyribonucleic acid) allowed for genetic coding was a huge breakthrough, one that ultimately made it possible to sequence the three billion chemical base pairs that compose the human genome and identify the approximately 20,000–25,000 genes in human DNA (Lander et al. 2001; Venter et al. 2001).

TV viewers are familiar with DNA analysis, popularized on various CSI (crime scene investigation) programs. DNA-sequencing techniques—where the arrangements of the A-T-C-G nucleotides are compared—can convict or exonerate people accused of crimes. Similar techniques can confirm or deny paternity in disputed cases, or can ensure that the expensive grouper fillets you purchase are not flesh from a lesser species. Such evolutionary tests are accepted by the judicial system because they pass the Daubert standard for scientific evidence: the techniques were subject to empirical testing, published in peer-reviewed journals, and accepted by the scientific community (Mindell 2009).

Recent discoveries in evolutionary developmental biology, known as evo-devo, have shown that very similar genes are present in very dissimilar animals. These body-shaping genes are controlled by DNA switches (called enhancers) that turn them on or off at various times during development. Such enhancers are a major factor in the development of morphology, the branch of biology that deals with the form of living organisms and with relationships between their structure (Carroll 2005). The above examples are just a smattering of the benefits to society that flow directly from the creative power of Charles Darwin's theory of evolution by means of natural selection.

The Human Genome Project spawned 25
ENCODE (Encyclopedia of DNA Elements), whose mission was to describe all of the functional elements encoded in our genome. The 6 September 2012 issue of *Nature* published six coordinated ENCODE papers, while 24 related papers were published elsewhere in the same week. (Further exploration of this complicated, state-of-the-art

topic is facilitated at www.nature.com/encode/.) In addition to well-known coding elements, ENCODE explained the hidden genetic switches that regulate development and turn other genes on and off. This new knowledge showed that the term "junk DNA" was just a manifestation of our incomplete understanding. Today's biologists are fortunate to have the very broad shoulders of Charles Darwin to support and make possible their elaboration of how biology works.

The paradigm shift (Berra 2008) instigated by Darwin has made more obvious the superiority of the scientific method as a means of understanding the world around us. It is ironic that the legacy of a man once destined for the church has been to replace supernaturalism with methodological naturalism.

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A CLOSER LOOK AT
Darwin's Paradigm Shift

1. In this research paper, Berra writes, "By the time of Darwin's death in 1882, most scientists throughout the world had accepted the concept of common descent, but some were still skeptical of natural selection as a creative mechanism." According to the author, why were scientists and the public skeptical of Darwin's theories, and why are many people skeptical today?

2. The author includes a great amount of historical information. How is he using this historical information to lay the groundwork for discussing the importance and implications of Darwin's theories?
3. This research paper could be classified as an "expository" research paper, because it mostly explains and offers factual information, while not making an overt argument. Nevertheless, it is argumentative in places. Locate three of those "argumentative" moments in this research paper. How is the author using argument in this otherwise expository research paper?

IDEAS FOR Writing

1. The cornerstone of Darwin's theory of evolution is the concept of "natural selection." According to the author, what is natural selection and why is it critical to Darwin's theory of evolution? Write a brief in which you explain the concept of natural selection and explain why it is necessary in Darwinian evolution.
2. Create a five-source annotated bibliography about the history of Darwin's theory of evolution. Include only sources that discuss the history of this theory. Do not include articles or books that argue for or against the theory. Combine your annotated bibliography with the bibliographies from your group in class. How many sources did all of you have in common? How many sources were unique to your list? Talk about why you came up with the same or different sources on this topic.

A FEW IDEAS FOR Composing a Research Paper

1. **Write a research paper about a contemporary issue.** Choose an issue that is prominent in the national or local media right now. Your research paper's topic does not need to be new, but you should find a new angle that makes this issue fresh and interesting. Your research paper should be about an issue that you care about but also something you can write about in an informed way. You should ask your professor whether you need to write an "expository" or "argumentative" research paper for this assignment.
2. **Write a research paper that responds to someone else's argument.** Look for an article that makes an argument you consider wrongheaded or at least misinformed. Then, do research on this topic and explain why the facts support a different conclusion and undercut the article you are responding to. Your research paper should use the original article as a starting place, but you should go beyond simply writing a rebuttal. Instead, write a full research paper on the subject that explores the issue in depth.
3. **Develop a research Web site.** In many situations a research Web site is actually more useful than a research paper. These kinds of Web sites collect or make links to sources that readers can use to inform themselves and do their own research on the topic. The Web site you create should gather these sources of information into a usable form. It should also offer some discussion about which sources you found most useful (or not). Try to provide materials and links that address all sides of the issue, not just sources that agree with your opinion.