The Discovery & Nature of Evolution by Natural Selection: Misconceptions & Lessons from the History of Science

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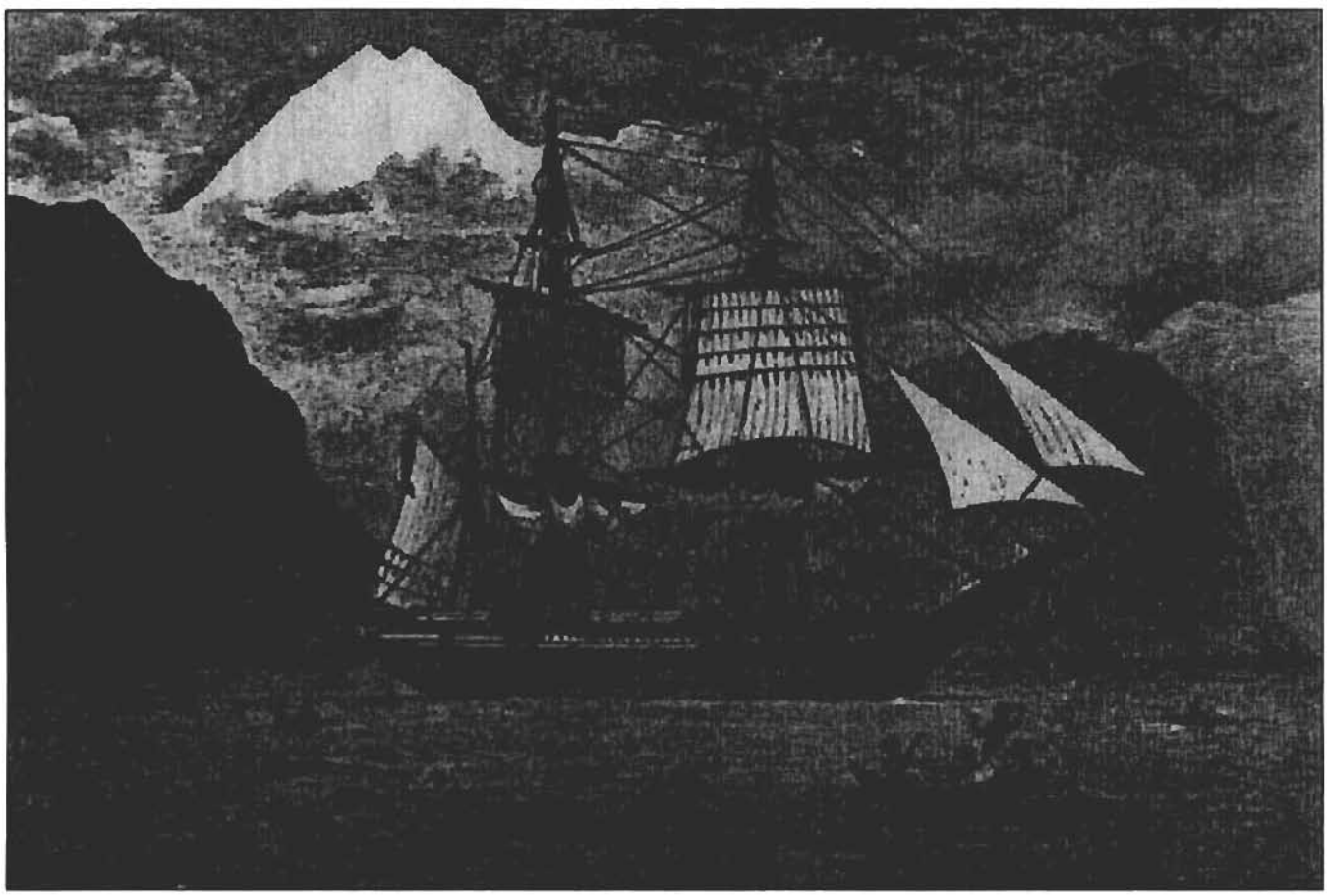

Figure 1. The HMS Beagle in the Straits of Magellan near Tierra del Fuego, late in 1832, from a painting by Conrad Martens appearing in Robert FitzRoy's *Narrative of the Voyage of the Beagle* (1839).[1]

Few biology texts published in the past century fail to mention Charles Darwin, his voyage, and the subsequent discovery of the natural selection mechanism for evolution. Unfortunately, in most texts, the discovery and implications of evolution are presented so poorly that a veritable mythology has arisen regarding one of the most fundamental and interesting breakthroughs in the history of human thought. By confusing or paying little attention to the history and implications of the theory, even the best biology books provide little more than a caricature of what really happened and what it means.

As commonly presented, the discovery of evolution by natural selection is a somewhat ordinary story that is satisfying because it is both believable and conclusive. However, as Stephen Jay Gould said, typically "the most satisfying tales are false" (1996, p. 57). This certainly is the case here. Not only is the conventional textbook account incomplete and frequently incorrect,

[1] This image courtesy of Lightbinders' Darwin CD-ROM 2nd Edition. For further information about the Darwin CD-ROM, please contact Lightbinders, 2325 Third St., Suite 324, San Francisco, CA 94107, http://lbin.com or call 800-432-3766.

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the true story is far more interesting than the typical fiction. Texts that omit a description of the fascinating history of the discovery of evolution miss a wonderful opportunity to acquaint students with the human dimension of science while correcting many of the misconceptions that now block a full understanding—and acceptance—of organic evolution.

Using history to enhance science instruction is strongly advocated by several of the new science education standards. The *Benchmarks for Scientific Literacy* (AAAS 1993) provide two principal reasons to include historical perspectives. First, the history of science provides concrete examples of how the scientific enterprise really operates. Second, it is important that future citizens know how historical endeavors add to our cultural heritage. The *National Science Education Standards* assert that a historical approach in science will assist students "to elaborate various aspects of scientific inquiry, the nature of science and science in different historical and cultural perspectives" (National Research Council 1996, p. 200). Finally, the *New Standards Project* (Learning Research and Development Center 1995) suggests that for students to meet the "scientific connections and applications standard," they must "understand the historical and contemporary impact of science" (p. 336). While it is clear that science education is being asked to move toward the inclusion of historical approaches, we must tell historical tales correctly. The lessons these stories teach when told accurately far exceed the examples provided by the inaccurate versions which so often accompany biology text books.

The History of Evolution by Natural Selection: The Myth

Virtually all of the biology texts reviewed for this article provide so brief and incomplete a picture of the important issue of the discovery of evolution by natural selection that teachers and students are forced to seek out a fuller account elsewhere—a task undertaken only by the most dedicated.

The standard textbook account that follows is synthesized from a number of the top-selling secondary and college biology texts. As typically stated, young scientist and beetle-lover, Charles Darwin, having shunned a career in medicine and working hard to reject the ministry as a potential profession, was recruited by Captain Robert Fitzroy to become the naturalist of the survey ship *H. M. S. Beagle* (Figures 1 & 2). During this five-year round-the-world voyage on the *Beagle*, Darwin gained important insights from the finches of the Galápagos Islands, culminating in a eureka-like discovery of the natural selection mechanism for evolution. Darwin returned home, wrote out his theory, and became famous for solving one of the great mysteries of science.

That is a good story, but it is less than accurate. What really happened and what it means will be recounted here in a description of several of the misconceptions typically held about evolution and its discovery.

What Is "Evolution"?

It may seem unnecessary to provide a definition of evolution, but the word *evolution* represents two different things—at once the term implies both a fact of nature and a theory of how the process occurs. This issue has resulted in considerable confusion. Failing to make the distinction between the two ways the word is used has caused many of the battles faced by schools, teachers and textbook authors who properly believe that the inclusion of evolution in the biology curriculum is vital. Before discussing the specific misunderstanding, it is useful to define a few terms.

There are three kinds of knowledge in science: facts, laws and theories. Facts are empirical data representing individual "peculiar events" (Carnap 1995, p. 5)

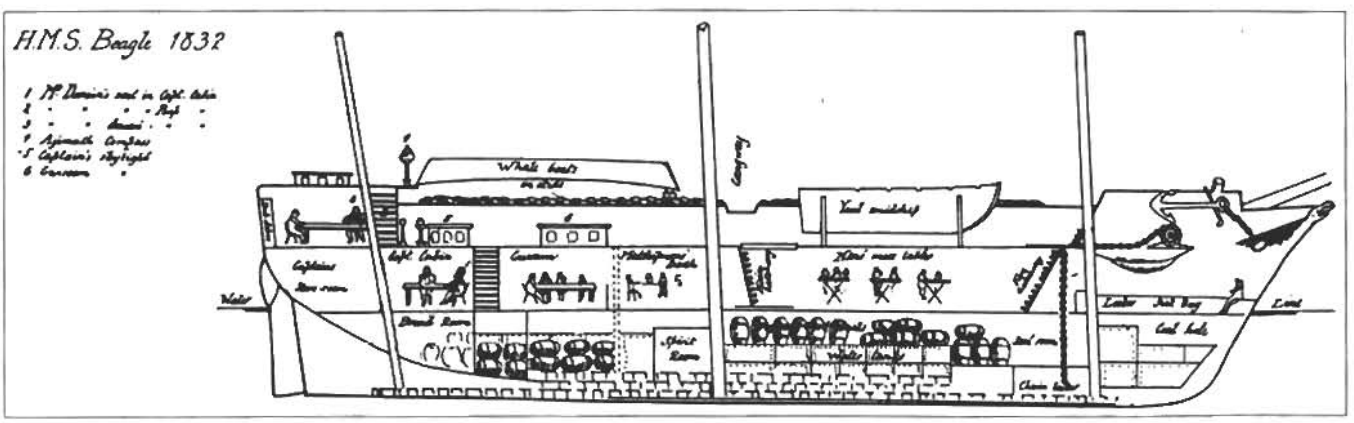

Figure 2. Cutaway view of the Beagle. Only 28 meters in length, this "good little vessel" set sail on its five-year voyage with 74 people aboard. Darwin shared the poop cabin (upper left) with the artist, midshipman Phillip Gidley King, and surveyor John Stokes.

that are the raw material of science. Laws and theories are formed from facts, but are not the same kind of knowledge. In spite of the popular misconception, theories do not become laws even with increased evidence (McComas 1996). A scientific law is a generalization, rule, principle or pattern while a theory is an explanation for why a particular generalization operates in the way that it does (Dilworth 1994; Rhodes & Schaible 1989; Trusted 1979; Horner & Rubba 1979; Campbell 1953). Laws explain instances while theories explain laws.

The standard definition of biological evolution is that all living things have developed from some common ancestor through a long series of natural changes (Bowler 1989). Gould states that, "... evolution is ... a fact of nature, as well established as the fact that the earth revolves around the Sun" (Gould 1987, p. 65). In this sense, it seems clear that the principle of evolution is a fact of nature. Even if one rejects Darwin's mechanism, it would be hard to deny the reality of both change and relationships when looking at the pattern of the fossils preserved in the rocks. That is the fact of evolution.

The mechanism of how evolution occurs is the theory of evolution by natural selection. Although we have both the fact of evolution and the theory of natural selection, few make the distinction as deliberately as they should. Gould addresses this issue when he says that: "... evolution is a theory. It is also a fact. And facts and theories are different things, not rungs in a hierarchy of increasing complexity" (1983, p. 254).

Darwin did not discover evolution any more than Newton discovered gravity. In fact, the Ionian Greek philosophers at work on what is now the west coast of Turkey developed the concept of the great chain of being, linking all creatures on a scale of nature with one creature related to the next. Heraclitus of Ephesus (535-473 B.C.E.) and Anaximander of Miletus (611-547 B.C.E.) stated that animal species are mutable or changeable. Although these early Greek scientists did not have a mechanism to explain the process of evolution, it is clear that they added the concept of evolution to our intellectual heritage millennia ago. What Darwin did was to suggest how evolution operates with his invention of the theory of evolution by natural selection. By providing a mechanism to explain a natural pattern noticed for centuries, Darwin made it both possible and reasonable to accept that organisms change through time. Fossil evidence illustrates that organisms changed through time, the fact of evolution. Natural selection explains how evolution likely occurred.

What many fail to understand is that there is virtually no debate among biologists that evolution has occurred. Even without a mechanism, evolution would still be the greatest unifying idea in the biological sciences in the same way that gravity, which still has no universally-accepted mechanism, is central to physics. What debate there is regarding evolution is at the level of the theory, not the fact. There may be some disagreement about the ultimate mechanism of evolution but such conversation is aimed at fine tuning our understanding rather than rejecting evolution. As biologist John Maynard Smith said recently regarding this issue, "I have no doubt that, basically, Darwin got it right" (Campbell 1996, p. 412). Those who reject evolution typically cite disagreement among scientists regarding evolution as one reason for their rejection. However, most people fail to note the focus of such disagreement. The fact of evolution is not debated, only the intricate details of Darwin's mechanism—the theory—are really up for discussion. So, with the distinction between the fact and theory of evolution in mind, we can turn our attention to other myths and misconceptions of what Darwin called descent with modification.

Myth: Darwin Was the Naturalist of the H.M.S. Beagle

Darwin is so frequently called the naturalist of the *Beagle* in biology textbooks that few would doubt it. It was the practice of the Royal Navy to gain maximum benefit from lengthy voyages. To accomplish this goal, naturalists and artists were commonly found on board. In the case of the survey ship *Beagle*, as on many other such ships, the man officially assigned the task of collecting specimens and recording information about the natural world was the ship's surgeon. Robert MacCormick was the *Beagle*'s surgeon, and he fully expected that he would be the chief collector (Gruber 1968-69). What then was Darwin doing on board during the 1831–36 voyage?

Darwin was a supernumerary who paid his own way and was not an official member of the crew. He was invited to travel with the ship primarily because he had the same social status as Captain Fitzroy, a man almost the same age as 22-year-old Darwin. As was the custom, Fitzroy would have been limited in his social interactions to the few officers on board. Since there was a history of suicide in his family—unfortunately his ultimate fate—Fitzroy was apparently concerned that isolation might take its toll during the long voyage. With a few notable exceptions during the trip, both Darwin and Fitzroy got along well and engaged in a variety of spirited conversations.

The story does not end there, however. MacCormick, the real naturalist of the *Beagle*, felt that his role had been usurped by Darwin and apparently was not of the most agreeable disposition anyway. He left the ship in Rio de Janeiro in April of 1832 just a few months after the voyage began. At this point, Darwin became the de facto, but still unpaid, naturalist of the

H.M.S. Beagle. The legend grew when Fitzroy, in his account of the expedition, described Darwin as the ship's naturalist and as a "young man of promising ability, extremely fond of geology, and indeed of all branches of natural history" (1839, pp. 18–19). Darwin was long appreciative that Fitzroy had extended the invitation to join the voyage. However, Fitzroy, who considered Darwin's work on evolution nothing less than heresy, later regretted that he had played such a pivotal role in the development of the theory of evolution by natural selection.

Myth: Darwin Discovered Natural Selection While on the Voyage

When Darwin embarked on the *Beagle* he was a creationist—as were most of his contemporaries—it was the prevailing view at the time. In brief, creationists believed that species were each created by the deity as individual unchanging entities. This view, sometimes called special creation, was so widespread that even scientific arguments were framed with reference to it. Consider this selection from one of the standard works in zoology in the early 19th century:

> *It appears that various tribes of organized beings were originally placed by the Creator in certain regions, for which they are by their nature peculiarly adapted* (Swainson 1835, p. 9).

Darwin himself admits favoring religious explanations during the voyage. In his autobiography, he states that he was quite orthodox, "being heartily laughed at by several of the officers (though themselves orthodox) for quoting the Bible as an unanswerable authority of some point of morality" (1958, p. 85). When Darwin returned from the voyage he was no longer a creationist since he rejected the prevailing view that each species was created by a supernatural force as fixed and unchanging. However, that does not mean that he had yet discovered the mechanism by which evolution occurs. This is an important distinction that few texts make. One notable exception is found in Schraer and Stoltze (1995) in which the authors state, "although he recorded many observations that supported such a hypothesis [that species could change] he could offer no explanation of how evolution occurred" (p. 601).

Contrary to popular belief, there was no single moment of discovery in which Darwin developed the theory of evolution by natural selection. In March of 1837, after arriving back in England, Darwin started his first notebook containing his speculations on the mechanism of what he called the "mutability of species." By May of 1842 he had enough evidence to write his first formal essay on the subject and shared the news with his friend and colleague Joseph Hooker in January of 1844. In a letter to Hooker, Darwin states:

> *. . . I am almost convinced . . . that species are not (it is like confessing a murder) immutable . . . I think I have found out (here's presumption!) the simple way by which species become exquisitely adapted to various ends . . .* (Darwin, 1996, p. 80).

Work continued toward an enlarged sketch of the theory early in 1844 but progressed only slightly until May of 1856. In mid-1856, Darwin started work on his major opus on speciation to be called *Natural Selection* or, in Darwin's own terminology, the *Big Book*. Of course, the book that eventually changed our thinking about the nature of evolution was the *Origin of Species* first published in November of 1859—decades after Darwin's return from the Voyage.

Of course, the evidence Darwin collected on the voyage convinced him that species were not fixed. This evidence, in fact, stimulated the thinking process that eventually led to the development of a mechanism to explain how species could change through time. However, Darwin did not make that discovery while on board the *Beagle*.

Myth: The Galápagos Islands Were Pivotal to Darwin's Discovery

It is a common notion that the Galápagos Islands, which Darwin visited between mid-September and mid-October 1835, played a vital role in the development of evolution by natural selection. This legend probably began early with ornithologist Osbert Salvin (1876) who called the Islands "classic ground" in the history of biology. This notion was picked up by textbook authors who have consistently highlighted Darwin's time in the Galápagos Islands while ignoring virtually all of the other sites Darwin visited during his lengthy trip. Biggs, Kapicka and Lundgren (1995) state that Darwin's Galápagos observations were among his most important, and Schraer and Stoltze (1995) concur with their statement by saying, "[t]he most significant of Darwin's observations were those he made on the Galápagos Islands. . ." (p. 601). These statements are misleading. The Galápagos Islands were important because they helped to substantiate observations that Darwin had already made elsewhere, but these islands, while fascinating, were hardly vital.

The Galápagos Islands provided more evidence of a recurring pattern Darwin observed rather than contributing a missing piece to the puzzle of evolution by natural selection. Remember that because Darwin was a creationist, it was first necessary for him to accept that species could change before he could consider the process by which species do change. Having visited the Galápagos Islands rather late in the trip, Darwin already had been confronted with the reality of evolution by previous visits to other islands. The Galápagos Islands simply removed the final impediments to Darwin becoming an evolutionist.

Oceanic islands are interesting in that their inhabitants are typically more similar to those found on the closest mainland than they are to other creatures on other comparable islands. This makes the special creation of each organism highly suspect. If organisms were created especially for life in a particular environment, one would expect them to be quite specialized for that environment and are always found in that environment.

Since the Galápagos Islands are a barren volcanic archipelago, one would expect that the species there would either be unique to Galápagos or at least be related to creatures on other volcanic islands. Rather, the majority of Galápagos species are most closely allied with those in the lush tropics of nearby South America. If one were going to design creatures specifically for life in Galápagos with a full complement of characteristics for their existence there, why start with a body plan and life style much more attuned to a tropical existence? What Darwin saw on the various islands during his voyage would make little sense when considered from a creationist frame of reference, but is perfectly understandable when viewed from the perspective of evolution. However, had Darwin's travels not taken him to both islands and the mainland, it is unlikely that he would have questioned his earlier creationist beliefs. As Darwin wrote in the *Voyage of the Beagle* (2nd edition):

> *Why, on these small points of land, which within a late geological period must have been covered by the ocean, which are formed by basaltic lava, and therefore differ in geological character from the American continent, and which are placed under a peculiar climate—why were their aboriginal inhabitants . . . created on American types of organization.* (1845, p. 416)

He concludes by saying that: *[I]t is probable that the islands of the Cape de Verd [sic] (Cape Verde) group resemble, in all their physical conditions, far more closely the Galápagos Islands, than these later physically resemble the coast of America, yet the aboriginal inhabitants of the two groups are totally unlike; those of the Cape de Verd Islands bearing the physical impress of Africa, as the inhabitants of the Galápagos Archipelago are stamped with that of South America* (1845, p. 417).

The reality that organisms are related to pre-existing forms helped to convince Darwin that evolution must have occurred. All that remained was to discover the mechanism—a process that begin on the voyage, but culminated 22 years later with the *Origin of Species*.

Myth: The Finches Were Central to the Development of the Theory of Natural Selection

Certainly this notion must be true, after all these birds have long been called *Darwin's Finches* and most biology texts, such as Towle (1993); Johnson and Raven (1996); Johnson (1994); Biggs, Kapicka and Daniel (1995) feature these birds prominently in discussions of Darwin's discovery. Even the highly regarded new book on evolution, *The Beak of the Finch* (Weiner 1994) seems to suggest that these animals were important in the story of how evolution occurs. To be sure, the 13 species of finches with their highly specialized beaks do represent one of the finest examples of speciation and adaptive radiation. However the significance of these birds was generally missed by the man for whom this group is so frequently named.

A careful reading of Darwin's notes, the *Origin and Species* (1859) both editions of the *Voyage of the Beagle* (1839/1845) combined with the detective work of Sulloway (1982, 1984) show that had Darwin never seen the finches, we would still have evolution by natural selection in its traditional form. Darwin simply did not pay much attention to the finches. Not only did he fail to note the name of the islands where he collected his finch specimens, he did not realize that all of the birds now known to be finches were, in fact, finches. He called the warbler finch a "wren," the large finch a "grossbeak," and the cactus finch an "icterus" (a family including the orioles, meadow larks and blackbirds). He collected only nine of the 13 known species of finches and properly identified only six as *finches*.

As Sulloway points out, Darwin was not a poor taxonomist. He was simply misled by his prior assumption that islands so close together could not have distinct species and so he saw the finches only as varieties of the same bird or as a completely different kind of bird. In his diary of the trip, and in the first edition (1839) of the *Voyage of the Beagle* (1839), Darwin mentions the finches only in passing. In his notebooks on transmutation of species and in the *Origin of Species*, these birds do not appear at all!

It seems likely that the finch legend grew for several reasons. First, the story is satisfying since the finches do represent a compelling example of evolution by natural selection. The name "Darwin's Finches" was chosen by Lack for the title of his famous book (1947) and article (1953) on evolutionary biology. Later he erroneously stated that the finches "provided one of the chief stimuli for their discoverer's theory of evolution" (1964, p. 178). In addition, a crucial error was made in the analysis of the finch specimens when Darwin returned to England and he revised his own account of the voyage and its impact. These last two issues have caused such mischief that no biology text it seems has accurately sorted out the facts.

When Darwin returned from his voyage, many of Britain's top experts took charge of and analyzed his collections. The birds were given to preeminent ornithologist John Gould. It was Gould who pointed out to Darwin that some of the Galápagos birds, previously thought to belong to several groups were, in fact, all highly variable species of finches. Gould classified

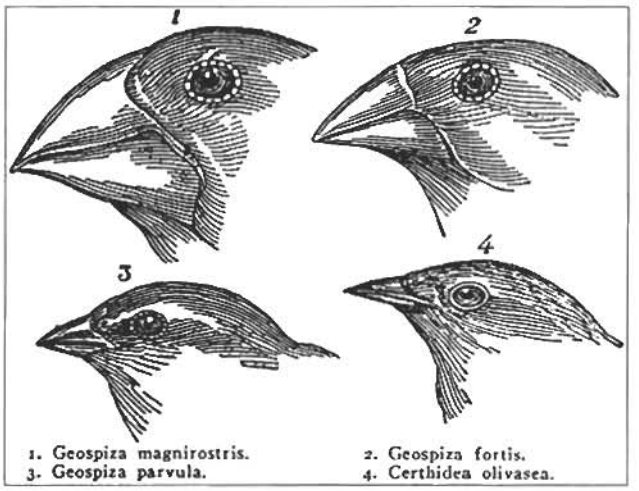

Figure 3. The four major beak types of the finch. (From the second edition of the *Voyage*, 1845).

Darwin's finch specimens into 13 species. Gould was quite correct about the importance of the finches, but wrong about the number of species Darwin collected. Subsequent studies found that Darwin collected only nine species of Galápagos finches. In fact, we now know that there are 13 species. The coincidence with respect to the number 13 has been unfortunate. Still, several current biology texts state that Darwin collected all 13 species—no easy feat since some of the birds are found only on islands that Darwin did not visit.

The other major issue that has resulted in the finch myth was caused by Darwin himself. The first edition of the *Voyage of the Beagle* was published in 1839 and became popular immediately. Within a few years, Darwin was asked to make revisions for a second edition. What Darwin did was not just to enhance the narrative, but instead he rewrote the trip and its impact on his thinking. It is astounding that Darwin chose to add additional information relative to the development of his ideas that was not even available when he was originally on board the *Beagle*. The revision was so complete that it seems as if there were two voyages of the *Beagle*. This has led to confusion about what Darwin knew and when he knew it. In the second edition of the *Voyage* (1845), Darwin includes discussion of the finches and a wonderful engraving showing the four major beak types (see Figure 3). It is this second edition that has been widely reprinted so it is no wonder that many believe that the finches were vital to his thinking. So, for these reasons, the legend took hold. Textbook authors continued to cite each other and spread the faulty idea that Darwin noted, collected and based the theory of natural selection on "his" finches.

Had Darwin really formed his theory of natural selection with help from the finches, the story would be interesting enough, but the real tale is even more captivating. While in the Islands, the vice-governor told Darwin that, "the Spaniards [living in the Islands] can at once pronounce, from which Island any Tortoise may have been brought" (Darwin 1963, p. 262). This was the first clue that something interesting was happening in terms of speciation. The second major clue came in the form of the ordinary mockingbird. Darwin paid particular attention to the mockingbirds, stating:

> *I have specimens from four of the larger Islands . . . The specimens from Chatham and Albermarle Islands appear to be the same; but the other two are different. In each Island each kind is* exclusively *found: habits of all are indistinguishable. . . . The only fact of a similar kind of which I am aware, is the . . . wolf-like Fox of East & West Falkland Islands* (Darwin 1963, p. 262).

Reflecting on the tortoises and mockingbirds, Darwin concludes by saying, "if there is the slightest foundation for these remarks the zoology of the [Galápagos] Archipelagoes will be well worth examining; for such facts would undermine the stability of Species." (Darwin 1963, p. 262). In his first notebook on the transmutation of species, Darwin returned to the particular examples of the tortoises and the mockingbirds cited here by saying: "According to this view animals of separate islands, ought to become different if kept long enough apart, with slightly different circumstances. Now Galápagos tortoises, mocking birds, Falkland fox, Chiloe fox—English and Irish Hare" (Darwin 1960–61, p. 42). So, without a finch in sight, Darwin realized that species can change and began to consider the necessary elements permitting such change. The finches are a dramatic example of speciation, but textbooks do students a disservice by misrepresenting their role while neglecting the real examples central to Darwin's thinking.

Myth: Darwin Discovered Evolution by Natural Selection

There is little doubt that Charles Darwin was the dominant force in the discovery of the mechanism for evolution, but he certainly did not do it alone and might not have done it at all except for an interesting convergence of people and events. The evidence is clear that had Darwin not developed his particular explanation for how species change we would still have evolution by natural selection, but it would not be called Darwinian.

The early development of Darwin's theory is well-known and usually represented correctly in biology texts. Darwin returned from his voyage, reviewed the conclusions of the experts analyzing his collections, read Malthus' work on population growth, and started his own notebooks (Darwin 1960–61) on what

he called the "species question." He wrote two manuscripts in 1842 and 1844 (Darwin 1986) detailing his early thoughts about descent with modification.

The 1844 essay was a 231-page overview of natural selection emphasizing the importance of external conditions in accounting for variations but without discussion of the problem of why organisms of the same stock diverge as they become modified. This issue of divergence will later become important as the story continues. At this point, Darwin penned a now-famous letter to his wife in which he says that:

> *"I have just finished my sketch of my species theory. If as I believe that my theory is true and if it be accepted even by one competent judge, it will be a considerable step in science"* (Darwin 1996, p. 82).

In this letter he instructs his wife to find someone to help edit and publish the essay upon his death. He even makes some suggestions as to who might assist in the process and provides a sum of money to facilitate the publication.

There has been much debate regarding why Darwin did not simply publish the essay in 1844. One explanation for the delay is that Darwin was anxious to avoid criticism about the theory. Although Darwin was no longer religious by the time he developed natural selection, his wife certainly was. Darwin may have hoped to spare his wife and family the adverse reaction that would likely follow the publication of his treatise on evolution. Darwin realized that his views on evolution pertained to humans and he knew that linking man to the animals would be a controversial idea in Victorian England. In addition, the last major book on evolution, *Vestiges of the Natural History of Creation* (Chambers 1844), was widely criticized. Even though the vestiges failed to include a mechanism for evolution, its central thesis that evolution had occurred was the subject of much critical and negative talk in the streets and from the pulpit. It is reasonable to assume that Darwin did not want to engage in a similar round of debate himself nor subject his family to the predictable public outcry.

On September 9, 1854, Darwin noted in his Pocket Diary that he "began sorting notes for species theory" (Darwin, 1959, p. 13). It was during this time that Darwin read a paper in the *Annals of Natural History* from a young naturalist working in Southeast Asia named Alfred Russel Wallace. In this paper, Wallace (1855) outlined his view that every species comes into existence with pre-existing allied species closely related in both space and time (Wallace 1855). This was an important clue to the nature of evolution by natural selection since it addressed the issue of divergence.

In May 1856, on the advice of colleague Charles Lyell, Darwin began work on his "big book" to be called *Natural Selection.* In October 1856, Wallace wrote to Darwin asking for some advice. In his response, Darwin states, "[b]y your letter and even still more by your paper in the Annals, a year or more ago, I can plainly see that we have thought very much alike and to a certain extent have come to similar conclusions. This summer will make the 20th year (!) since I opened my first note-book, on the question how and in what way do species and varieties differ from each other. I am now preparing my work for publication. . ." (Darwin 1996, p. 172). Many have viewed this statement as a way of telling Wallace that he had strayed into Darwin's territory. Darwin, for his part, continued work on his book, *Natural Selection.*

Not long after receiving his first letter from Wallace, Darwin wrote to Asa Gray, a Harvard botanist. This letter was essentially the outline of an 1844 essay with an added paragraph on the important principle of divergence. What happened next is one of the most interesting stories in the history of science.

In February of 1858 Wallace wrote his paper *On the Tendency of Varieties to Depart Indefinitely from the Original Type,* and sent it to Darwin. When the letter appeared at Darwin's house, Darwin was shocked and dismayed. He wrote to Lyell for advice saying:

> *He* [Wallace] *has today sent me the enclosed and asked me to forward it to you. Your words have come true with a vengeance that I should be forestalled. I never saw a more striking coincidence . . . if Wallace had my M.S.* [manuscript] *sketch written out in 1842 he could not have made a better short abstract! Even his terms now stand as heads of my chapters* (Darwin 1996, p. 188).

Within days, as Darwin stood by generally uninvolved, Lyell and Hooker completed what has been called a "delicate arrangement" (Brackman 1980). The result of this arrangement was that Darwin's 1844 essay and his letter to Gray were read along with the paper from Wallace at the Linnean society meeting in July. Although the papers made little immediate impact, Darwin's priority was secured and he was finally inspired to complete what would become his life's work. Darwin abandoned his big book, *Natural Selection,* but took sections from it to form the *Origin of Species* published at the end of 1859.

The story continues with the work of recent scholars who have indicated that Darwin's original delay was due to the fact that he did not have all of the pieces in place to make his 1844 idea viable—particularly regarding the principle of divergence. Beddall (1986, 1988) believes that Darwin received some vital ideas directly from Wallace without acknowledging them, while Brackman (1980), Brooks (1984) and McKinney (1972) all cite evidence for a conspiracy, if not outright fraud. While there is no conclusive proof for any of the assertions, there is enough evidence to make any of these interesting speculation and the basis of a wonderful detective story.

Brooks (1984) suggests that a 41-page addition on divergence was added to the 1844 manuscript just

months after Darwin would likely have read Wallace's paper in the *Annals of Natural History*. Brackman (1980) believes this as well, but there is evidence in the 1857 letter to Asa Gray that Darwin had already grasped this principle. Darwin may have gotten some ideas from Wallace's published paper, but Darwin's own marginal notes on Wallace's article indicate that he did not see much new in the paper (Kohn 1981).

Beddall (1988) makes the point that Lyell and Hooker deliberately arranged the order of the papers presented at the Linnean Society meeting to give Darwin what some consider undeserved precedence considering that Wallace's manuscript was in publication form, while Darwin's was not. Darwin's modified 1844 essay and his earlier letter to Asa Gray were read to the society before Wallace's paper. In addition, Beddall (1988) questions why Darwin added a note to his Linnean Society papers that they were not intended for publication yet still made hundreds of changes to the 1844 sketch and to the letter sent to Asa Gray. Of course, Wallace was not able to make any changes to his part of the presentation at the Linnean society, nor did he even know for many months that the paper had been presented. Given her perspective that some collusion was involved regarding the presentation to the Linnean society, Beddall claims that in the end, the occasion of the reading of the joint papers was "not an occasion of 'mutual nobility' nor was it 'a monument to the natural generosity of both the great biologists as is frequently claimed."

Finally, there is the issue of when the letter from Wallace arrived in Darwin's hands. Unfortunately, both the letter and its envelope are missing so circumstantial evidence is all that remains. By tracking historical records of the time it took for letters during that period to travel from the Malay region to London, Brooks (1984) has suggested that the letter may have arrived up to a month earlier than Darwin reported. McKinney (1972) found a letter to another one of Wallace's correspondents in England with a postmark date of July 3, 1858. Given the limited mail service from Southeast Asia to England at the time, this letter presumably must have been mailed at the same time as the one to Darwin. If this is true, the question remains, was the letter from Wallace to Darwin delivered early in July or was it delayed until July 18th as Darwin claimed?

In spite of the potential interest and utility in showing the process of scientific discovery by telling the whole story, few textbooks include more than a passing reference to Wallace. Typically he is discussed as a latecomer who, if he did anything, forced Darwin's hand and encouraged him to publish his long-held ideas regarding evolution by natural selection. Towle (1993); Johnson (1994); Oram and Hummer (1994); and Biggs, Kapicka and Lundgren (1995) all fail to mention Wallace, while Miller and Levine (1995) include him only as a footnote in the teacher's edition. Schraer and Stoltze (1995) state that, "Darwin and Wallace agreed that Wallace's essay should be published along with a summary of Darwin's theory" (p. 602). This assertion is nonsense since at the time of the Linnean presentation, Wallace was collecting specimens on one of the world's most remote islands, unable to communicate with anyone except by the steamships that carried letters several times a year. It was months before Wallace knew anything of the joint presentation and years before he realized exactly what had transpired in terms of the "delicate arrangement."

These issues of the human dimension of science and the role of ideas in scientific breakthroughs make a wonderful case study for students to explore to the social dimension of how science operates in the real world in contrast to the purified version of discovery so common in textbooks.

Conclusions

There are many lessons to be learned from this more complete telling of the history of the discovery of evolution by natural selection. First, teachers must be careful not to rely solely on their textbooks as accurate and complete sources of information. In the case of the discovery of evolution by natural selection, texts are frequently replete with errors of omission and outright inaccuracies. Second, the real story of this discovery is far more interesting and enlightening than the commonly accepted version. How many students know that we would still have evolution by natural selection in much the same form without the *Beagle*, without the Galápagos Islands, without the finches, and even without Charles Darwin? The rich written documentation in the form of letters, diaries, public accounts and commentary make natural selection perhaps the most accessible of all scientific discoveries.

Students who consult even a fraction of the available sources related to natural selection and its history will be treated to insights about the scientific process that are possible with few other discoveries. In the case of evolution by natural selection, it is almost possible to read Darwin's mind, getting a feeling for how half a lifetime of facts generated one of the most important theories of the past century. Finally, science is full of examples of simultaneous discovery with the work of one investigator informing and inspiring others. It is this human dimension that is generally missing in science instruction. We have traded people for facts. Nature does not do biology, people do. However, our students will come to know this only when we reinvigorate biology education by restoring the human dimension of science in an engaging and accurate fashion.

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