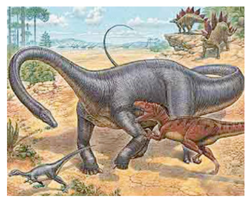
MECHANISMS OF CHANGE

Lamarck, Darwin and Wallace, and Modern Synthesis

If organisms can change, how do they do it?

In the last reading, you read about the theories of Buffon, Lamarck, and Cuvier, who all wrestled with the question of organic change. Fossils showed that there were organisms that once existed which no one had ever seen, and some modern organisms did not show up in the fossil record. Why should that be? Cuvier suggested that there had been periodic catastrophes, and that organisms from other places migrated in. It seemed possible — the whole world had not yet been explored, so who could say whether or not mastodons might exist in some unexplored corner of the world?

Lamarck, however, thought that such an explanation was insufficient. He believed that there must be a mechanism by which organisms changed over time. But could such a mechanism be discovered?

Lamarck's Theory

Lamarck's theory describes organisms climbing an evolutionary ladder with the goal of becoming more and more complex as well as more and more "perfect." Humans have reached the pinnacle of the ladder, as they presumably are the organisms that look most like God and the angels. In Lamarck's day, spontaneous generation of microbes was assumed to be true (Louis Pasteur would later show by an elegant experiment that microbes do not spontaneously generate from nutrient-rich material). People also assumed that traits acquired during one's lifetime could be passed on to one's offspring. Lamarck put these to ideas together into his theory. Lamarck proposed that after microbes spontaneously generated, they began evolving toward a goal of becoming more and more complex, essentially striving to be human. The force that drove those changes was the inheritance of acquired characteristics. As an organism used parts of its body, those parts would become more and more developed. If an organism did not use certain parts, those parts would become smaller. The environment plays a role, too, in that the environment actively shapes organisms by giving them the adaptations they will need to survive.

The theory has logical sense, and in fact, if you ask the average person on the street how evolution happens, that is the sort of explanation that most people will give.

Here is a short passage taken from Lamarck's treatise on organic change, *Philosophie Zoologique* (translation: *Zoological Philosophy*). As you read, think of how someone in Lamarck's day, with no understanding of genetics, would interpret his ideas. Then look at the passage from a modern viewpoint, using our modern understanding of genetics:

> The environment affects the shape and organization of animals, that is to say that when the environment becomes very different, it produces in course of time corresponding modifications in the shape and organization of animals.
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> If a new environment, which has become permanent for some race of animals, induces new habits in these animals, that is to say, leads them into new activities which become habitual, the result will be the use of some one part in preference to some other part, and in some cases the total disuse of some part no longer necessary. Nothing of all this can be considered as hypothesis or private opinion; on the contrary, they are truths which, in order to be made clear, only require attention and the observation of facts.
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> Snakes have adopted the habit of crawling on the ground and hiding in the grass; so that their body, as a result of continually repeated efforts at elongation for the purpose of passing through narrow spaces, has acquired a considerable length, quite out of proportion to its size. Now, legs would have been quite useless to these animals and consequently unused. Long legs would have interfered with their need of crawling, and very short legs would have been incapable of moving their body, since they could only have had four. The disuse of these parts thus became permanent in the various races of these animals, and resulted in the complete disappearance of these same parts, although legs really belong to the plan or organization of the animals of this class.
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> The frequent use of any organ, when confirmed by habit, increases the functions of that organ, leads to its development, and endows it with a size and power that it does not possess in animals which exercise it less.
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> We have seen that the disuse of any organ modifies, reduces, and finally extinguishes it. I shall now prove that the constant use of any organ, accompanied by efforts to get the most out of it, strengthens and enlarges that organ, or creates new ones to carry on the functions that have become necessary.
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> The bird which is drawn to the water by its need of finding there the prey on which it lives, separates the digits of its feet in trying to strike the water and move about on the surface. The skin which unites these digits at their base acquires the habit of being stretched by these continually repeated separations of the digits; thus in course

of time there are formed large webs which unite the digits of ducks, geese, etc. as we actually find them.

It is interesting to observe the result of habit in the peculiar shape and size of the giraffe; this animal, the largest of the mammals, is known to live in the interior of Africa in places where the soil is nearly always arid and barren, so that it is obliged to browse on the leaves of trees and to make constant efforts to reach them. From this habit long maintained in all its race, it has resulted that the animal's fore-legs have become longer than its hind legs, and that its neck is lengthened to such a degree that the giraffe, without standing up on its hind legs, attains a height of six metres (nearly twenty feet).

Philosophie Zoologique. Paris. 1809.
Translated by H. Elliott, Macmillan Company,
London. 1914.

The Darwin and Wallace Theory of Natural Selection

Charles Darwin, after graduating from college, took a position of captain's companion aboard the Beagle. The ship's mission was to survey the coast of South America, and to find out what useful resources might be there that England could use. Darwin, who was keenly interested in Natural History, took the opportunity to study everything that came his way. Darwin viewed the world not from Cuvier's Catastrophe theory, but from James Hutton's idea of Uniformitarianism — that natural laws we know today have always existed, and therefore we can understand the past by studying the present.

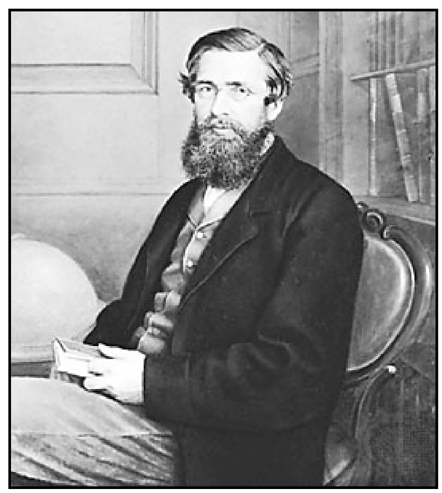
Darwin witnessed an earthquake and a volcanic eruption, and was able to compare fresh lava flows with old ones to see that indeed, one could learn about eruptions by studying old lava flows. He dug up the fossilized skeleton of an extinct giant sloth that had never been seen before, and wondered why the animal might have gone extinct. He observed birds on the Galapagos Islands that were similar to those on the mainland, and wondered why they were not exactly the same. Why the small differences? Had they descended from the mainland populations and had changed over time?

On returning from his voyage, Darwin spent years studying the specimens he had collected and pondering these questions. His ideas came together after he read an essay by the philosopher Thomas Malthus, in which Malthus stated that if people are careless and reproduce rapidly, they will use up the food and resources available. People will starve, diseases will increase, and the population will be forced to a rational level. Malthus used this as an example of the wisdom of God, that God had implemented these natural laws to punish people if they became foolish. Darwin could see nature in Malthus' descriptions. Most organisms in nature produce more offspring than can survive. What happens to most of them? Why isn't the world overrun with oysters, sparrows, or dandelions? Most offspring are eaten, dies of disease, or out-compete each other for food. Darwin described this as the "struggle for existence," and proposed that those organisms with the traits that gave them the best advantage over their neighbors would be the ones most likely to survive.

As he was preparing to publish his theory, Darwin received a letter from a young English naturalist who was working in the South Pacific. Alfred Wallace had read Darwin's *Voyage of the Beagle*, and had also read Malthus, and had written an article proposting an explanation for evolutionary change similar to Darwin's. Darwin presented his paper and Wallace's article at a scientific meeting in 1859.

Wallace's Article

The following is an excerpt from Wallace's original article that Darwin presented. In it, he makes a direct comparison with his theory and Lamarck's.



> *On the Tendency of Varieties to Depart Indefinitely from the Original Type*
> Alfred Russel Wallace (1858)
>
> *The Struggle for Existence*
> The life of wild animals is a struggle for existence. The full exertion of all their faculties and all their energies is required to preserve their own existence and provide for that of their infant offspring. The possibility of procuring food during the least favorable seasons and of escaping the attacks of their most dangerous enemies are the primary conditions which determine the existence both of individuals and of entire species. The numbers that die annually must be immense; and as the individual existence of each animal depends upon itself, those that die must be the weakest—the very young, the aged, and the diseased—while those that prolong their existence can only be the most perfect in health and vigor, those who are best able to obtain food regularly and avoid their numerous enemies. It is "a struggle for existence," in which the weakest and least perfectly organized must always succumb.
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> *Useful Variations Will Tend to Increase, Unuseful or Hurtful Variations to Diminish*

> Most or perhaps all the variations from the typical form of a species must have some definite effect, however slight, on the habits or capacities of the individuals. Even a change of color might, by rendering them more or less distinguishable, affect their safety; a greater or less development of hair might modify their habits. More important changes, such as an increase in the power or dimensions of the limbs or any of the external organs, would more or less affect their mode of procuring food or the range of country which they could inhabit. It is also evident that most changes would affect, either favorable or adversely, the powers of prolonging existence. An antelope with shorter or weaker legs must necessarily suffer more from the attacks of the feline carnivora; the passenger pigeon with less powerful wings would sooner or later be affected in its powers of procuring a regular supply of food; and in both cases the result must necessarily be a diminution of the population of the modified species.
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> If, on the other hand, any species should produce a variety having slightly increased powers of preserving existence, that variety must inevitably in time acquire a superiority in numbers.
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> *Lamarck's Hypothesis Very Different from that Now Advanced*
> The hypothesis of Lamarck—that progressive changes in species have been produced by the attempts of animals to increase the development of their own organs and thus modify their structure and habits—has been repeatedly and easily refuted by all writers on the subject of varieties and species.
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> The giraffe did not acquire its long neck by desiring to reach the foliage of the more lofty shrubs and constantly stretching its neck for the purpose, but because any varieties which occurred among its ancestors with a longer neck than usual at once secured a fresh range of pasture over the same ground as their shorter-necked companions, and on the first scarcity of food were thereby enabled to outlive them.
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> *Journal of the Proceedings of the Linnean Society*
> August 1858, London

Darwin published *The Origin*

When Darwin presented the two papers, the audience barely raised an eyebrow. This pleased Darwin. An earlier book published anonymously by another naturalist, titled *Vestiges of Creation*, had proposed a theory not too different from Darwin's, and it had been roundly criticized. However, part of the outrage over the book came from the author's use — and misuse — of other people's data, and the author's status as an amateur, armchair naturalist. Darwin took careful note of the criticisms and had spent many years carefully drawing up his theory and developing his career as a working naturalist. By the time he presented his paper and Wallace's article, he was well respected in his field. It was time to publish his Theory of Natural Selection as a book for the general public. Here is a short excerpt from the introduction to the first edition:

On the Origin of Species by Means of Natural Selection.
Charles Darwin (1859)

Introduction
When on board H.M.S. Beagle, as naturalist, I was much struck with certain facts in the distribution of the inhabitants of South America, and in the geological relations of the present to the past inhabitants of that continent. These facts seemed to me to throw some light on the origin of species—that mystery of mysteries, as it has been called by one of our greatest philosophers. On my return home, it occurred to me, in 1837, that something might perhaps be made out on this question by patiently accumulating and reflecting on all sorts of facts which could possibly have any bearing on it. After five years work
I allowed myself to speculate on the subject, and drew up some short notes; these I enlarged in 1844 into a sketch of the conclusions, which then seemed to me probable; from that period to the present day I have steadily pursued the same object. I hope that I may be excused for entering on these personal details, as I give them to show that I have not been hasty in coming to a decision.

My work is now nearly finished; but as it will take me two or three more years to complete it, and as my health is far from strong, I have been urged to publish this Abstract. I have more especially been induced to do this, as Mr. Wallace, who is now studying the natural history of the Malay archipelago, has arrived at almost exactly the same general conclusions that I have on the origin of species. Last year he sent to me a memoir on this subject, with a request that I would forward it to Sir Charles Lyell, who sent it to the Linnean Society, and it is published in the third volume of the Journal of that Society. Sir C. Lyell and Dr. Hooker, who both knew of my work—the latter having read my sketch of 1844—honoured me by thinking it advisable to publish, with Mr. Wallace's excellent memoir, some brief extracts from my manuscripts.

In considering the Origin of Species, it is quite conceivable that a naturalist, reflecting on the mutual affinities of organic beings, on their embryological relations, their geographical distribution, geological succession, and other such facts, might come to the conclusion that each species had not been independently created, but had descended, like varieties, from other species. Nevertheless, such a conclusion, even if well founded, would be unsatisfactory, until it could be shown how the innumerable species inhabiting this world have been modified, so as to acquire that perfection of structure and coadaptation which most justly excites our admiration. Naturalists continually refer to external conditions, such as climate, food, etc., as the only possible cause of variation. In one very limited sense, as we shall hereafter see, this may be true; but it is preposterous to attribute to mere external conditions, the structure, for instance, of the woodpecker, with its feet, tail, beak, and tongue, so admirable adapted to catch insects under the bark of trees. In the case of the misseltoe, which draws its nourishment from certain trees, which has seeds that must be transported by certain birds, and which has flowers with separate sexes absolutely requiring the agency of certain insects to bring pollen from one flower to the other, it is equally preposterous to account for the structure of this parasite, with its relations to several distinct organic beings, by the effects of external conditions, or of habit, or of the volition of the plant itself.

The author of the 'Vestiges of Creation' would, I presume, say that, after a certain unknown number of generations, some bird had given birth to a woodpecker, and some plant to the mistletoe, and that these had been produced perfect as we now see them; but this assumption seems to me to be no explanation, for it leaves the case of the coadaptations of organic beings to each other and to their physical condition of life, untouched and unexplained.

It is, therefore, of the highest importance to gain a clear insight into the means of modification and coadaptation. At the commencement of my observations it seemed to me probable that a careful study of domesticated animals and of cultivated plants would offer the best chance of making out this obscure problem. Nor have I been disappointed; in this and in all other perplexing cases I have invariable found that our knowledge, imperfect though it be, of variation under domestication, afforded the best and safest clue. I may venture to express my conviction of the high value of such studies, although they have been very commonly neglected by naturalists.

No one ought to feel surprise at much remaining as yet unexplained in regard to the origin of species and varieties, if he makes due allowance for our profound ignorance in regard to the mutual relations of all the beings which live around us. Who can explain why one species ranges widely and is very numerous, and why another allied species has a narrow range and is rare? Yet these relations are of the highest importance, for they determine the present welfare, and, as I believe, the future success and modification of every inhabitant of this world. Still less do we know of the mutual relations of the innumerable inhabitants of the world during the many past geological epochs in its history. Although much remains obscure, and will long remain obscure, I can entertain no doubt, after the most deliberate study and dispassionate judgment of which I am capable, that the view which most naturalists entertain, and which I formerly entertained—namely, that each species has been independently created—is erroneous. I am fully convinced that species are not immutable; but that those belonging to what are called the same genera are lineal descendants of some other and generally extinct species, in the same manner as the acknowledged varieties of any one species are the descendants of that species. Furthermore, I am convinced that Natural Selection has been the main but not exclusive means of modification.

Natural Selection

Darwin proposed the Theory of Natural Selection is one mechanism by which evolution can happen. The theory states that all natural populations have a certain amount of variation; not all individuals are exactly alike. Many more individuals are born than can survive, so all individuals are in competition with each other. “Survival of the fittest” means that most likely to survive are those that have some trait that gives them an advantage over their neighbors. Many traits can be advantageous. A big, strong individual may be out-competed by a smaller, but smarter and sneaker individual. Two individuals who cooperate may out-compete those that do not cooperate. “Success” is measured in reproduction. If an organism is able to have offspring, it is an evolutionary success.

Notice that there is no goal. Selection is directionless. Those that survive each generation and are able to reproduce pass their traits to the next generation. If environmental conditions change, different traits will be selected for, but the process *only selects for traits that are in the population*. It does not *create* new traits.

“Need” does not enter the picture, either. Just because an organism “needs” some trait to survive does not mean it will somehow “evolve” that trait. Again, selection does not *create* new traits. Those organisms that are not well-adapted to their environment are those that are most likely to die without leaving offspring.

From Natural Selection to Modern Synthesis

Darwin proposed the Theory of Natural Selection is one mechanism by which evolution can happen. The theory states that all natural populations have a certain amount of variation; not all individuals look alike. Those individuals with advantageous traits are more likely to survive and reproduce.

Darwin himself pointed out several weaknesses in his theory. The biggest was the fact that no one at his time understood heredity. The most common theory to explain inheritance could be called the “blending liquid” model, in which people believed that traits were controlled by some liquid in the blood. We still use language of this era when we talk about someone having Irish “blood” or Cherokee “blood” in referring to their heritage. People believed that the liquids of two individuals blended in their offspring, which was why the child of a light-skinned person and a dark-skinned person often had a skin color somewhere in between the two. If traits blended with each generation, how could advantageous traits be inherited?

Variation was also hard to explain. *Why* did individuals vary so much from one another? If there was a perfect form for each environment, why didn’t *all* of the individuals in the population have that perfect form?

One person did have the answer: Gregor Mendel, a Moravian monk who was a contemporary of Darwin. Mendel read Darwin, and there is some evidence that Darwin may have read Mendel's paper on patterns of heredity, but did not grasp its significance. But then, neither did most of Darwin's colleagues.

Nevertheless, Darwin's call for a better understanding of heredity eventually led to the new science of genetics. In 1900, as researchers were searching for anything that was known about heredity, Mendel's papers were rediscovered. Mendel's methods and insights gave genetics a whole new perspective, as researcher began to follow individual traits instead of trying to assess entire organisms. By the 1930's, concepts of genes and gene mutations had developed, though no one knew for certain what the hereditary molecule was. Experiments and field studies showed that Natural Selection could be observed and studied in natural populations and in the lab. Genetics supported Darwin's theory, but refuted the theory of inheritance of acquired characteristics that Lamarck had relied on. While many evolutionists still supported an idea of directional or goal-driven evolution, studies eventually supported Darwin's idea that selection is directionless.

During this time, three scientists developed what is now known as the Modern Synthesis theory of evolution. Theodosius Dobzhansky, George G. Simpson, and Ernst Mayr used genetics to understand Natural Selection, and described other natural events that could change the genetics of a population, such as genetic drift and population bottlenecks. They folded all of these natural, observed mechanisms into a unified theory of evolution that they called the Modern Synthesis theory.

Questions

After reading the original words of Lamarck, Wallace, and Darwin, can you distinguish between the two theories?

1. Give a good definition of what a scientific theory is, using what we learned in class. Explain why Lamarck's model and the Darwin-Wallace model are considered theories rather than laws or hypotheses.

2. Wooly mammoths (now extinct) and modern elephants are thought to descend from a common ancestor (though the mammoth is not the ancestor of modern elephants). How would Lamarck explain the differences between mammoths and African elephants using his "progressive ladder" model of evolution? How would Darwin and Wallace explain the differences using their model of Natural Selection? What are the key differences between the two explanations?

3. Lamarck states, "Nothing of all this can be considered as hypothesis or private opinion; on the contrary, they are truths which, in order to be made clear, only require attention

and the observation of facts." From a scientific viewpoint, what are the strengths and weaknesses contained in this statement?

4. Wallace states that, "useful variation will tend to increase, unuseful or hurtful variations tend to diminish." How does he propose this happens? What evidence does he cite? How could this be restated using terms from modern genetics?

5. In Lamarck's day, the theory of acquired characteristics was widely accepted by naturalists. Today it is not discussed in textbooks, but the theory of natural selection is described in detail. Why is natural selection accepted in science while the theory of acquired characteristics is not? How does this illustrated both the tentativeness and the enduring qualities of scientific knowledge?