NATURAL BEHAVIOR

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The Evolution of Behavior in Humans and Animals Using Comparative Psychology and Behavioral Biology

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This book is dedicated to

E. G. Wever

and

T. C. Schneirla,

two mentors and giants of comparative study.

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Preface

The intent of this book is to present a concise history of scientific thought and the topic of evolution along with the understanding of the evolution of behavior from single cell organisms to humans with many original ideas. The ideas come from many decades of university teaching, research, and study.

Any attempt to cover such a large span of life must be a selective survey of example phyla and species because the field is immense. Any one species could occupy an entire career of study. Hopefully, this book will interest readers to pursue the topic of the evolution of behavior and specific species more intensively.

In acknowledgement, I want to thank my wife, Ruth A. Weiss, for her encouragement and enablement in the creation of this book. I also want to thank William J. Cook, Delaney Johnson, and Joseph Selm, for their assistance and advice.

To conclude, I am offering some of my animal poetry.

Rabbits
Rabbits have habits
of hopping around
my well tended ground,
while mirthfully devouring
everything flowering.

Ants
Ants have pants
that no one has seen
because they are not keen
to wrestle with the glitches
of fitting six legs into britches.

CHAPTER 1

The Subject of Nature

The Trend Away from the Egocentric View

Throughout the history of human thought, especially in Western civilization, there has been a clear trend. That trend has been away from human egocentrism, the tendency to view humanity's position in the world as primary. The trend has been led by science.

A review of the highlights of the trend could begin with the ancient Greek, Aristotle (384–322 B.C.E.), who organized the Universe with the Earth at the center and the celestial bodies revolving around it. The terrestrial world was divided into ranks ordered by degrees of perfection. The ranks placed people superior to animals and animals above plants. Each level had specific characteristics. Thus, people were rational while animals were instinctive.

About 250 B.C.E. Aristarchos of Samos proposed the heliocentric concept of the Universe with the Earth revolving around the Sun. Although, the heliocentric view was adopted by some astronomers like Seleukos of Seleukia, Aristotle's geocentric version prevailed and was preeminent into ancient Rome. After the end of the Roman Empire, Aristotle's work was lost to European knowledge. However, the civilizations of North Africa retained Aristotle's ideas, which were especially promulgated by the astronomer, Ptolemy of Alexandria, in the second century C.E. Ptolemy developed a geometric model of Aristotle's view of the central Earth and the Sun, Moon, Planets, and Stars revolving about the Earth in circular orbits. The model was cumbersome, but allowed calculation of planetary positions. Maimonides (Moses ben Maimon, 1135–1204 C.E.) incorporated Aristotelian ideas into Hebrew theology and from there they spread into Islamic doctrine. In the middle 1200's C.E. Ibn Daud translated Hebrew, Greek, and Arabic science, philosophy, and theology into Latin. The Latin translations returned the geocentric ideas of Aristotle to European civilizations, which were emerging from the dark ages. Aquinas (1225–1274 C.E.) read Maimonides and brought the thinking of Aristotle into Christian theology. He converted the linear levels into a system topped by absolute perfection, God. The next level was occupied by beings still too perfect to commit sin, angels. The following level held rational organisms, people. In the fourth level were instinctive creatures, animals. Finally, at the bottom of the order is vegetative life, plants. Modern Hebrew, Islamic, and Christian theology retain the image of rational people separate from instinctive animals.

However, Aristotelian geocentric views were questioned when Hasdai Crescas (1340–1410 C.E.) employed logic to refute them. Copernicus (Nikolai Kopernik, 1473–1543 C.E.) postulated and Galileo (1564–1642 C.E.) proved that the Earth was not the center of the universe or even the solar system, but actually orbited the sun. These discoveries, now elemental, were vehemently attacked. They were a challenge to the egocentric view of humanity as the center of the universe that had been incorporated into theology. Copernicus, fearful of persecution, hid his papers for posthumous publication. Bruno (1548–1600 C.E.) studied Copernican principles and unwisely espoused these ideas in public, for which act he was burned. Galileo was tried in Italy for heresy, forced to recant, and incarcerated for life in 1633 C.E. He was forbidden from writing further and all of his works were burned. But, Galileo's ideas had already spread beyond Italy.

So strongly held was the egocentric position that even seemingly remote challenges were met with severe sanctions. Thus, Servetus (Miguel Serveto, 1511–1553 C.E.) was burned by John Calvin for describing blood circulation as being pumped by the heart. The prevailing view was that blood ebbed and flowed like the tides as Aristotle had stated. People of the era thought the heart was the seat of the soul and conceived of health and personality as based on the balance of body fluids. We still retain many heart references for emotions. Two centuries later, Benjamin Franklin was also widely condemned by clergy for investigating such “heavenly” phenomena as lightning. That reaction to scientific exploration influenced the separation of church and state clause in the American Constitution, which Franklin helped compose. The framers of the Constitution were determined to prevent clergy from destroying people for having new ideas. Yet, the myth of devout founding fathers is still promulgated despite contrary evidence. For example, Washington opened his successful attack on Trenton and subsequently Princeton on Christmas. Had Washington been devout and not launched his campaign on Christmas, he would not have had the element of surprise necessary to defeat the better armed and trained opposition. Thus, the Colonies would have remained British. Washington would not likely have been surprised by an attack on Sunday morning like that at Pearl Harbor.

Darwin, in explaining the origin of species, challenged the extremely critical egocentric view of humanity as a direct, divine creation. Attacks on those teaching evolution are rampant and frequent even today, over a century and a half after Darwin’s initial publication. Darwin’s ideas will be considered in later text.

Einstein’s contribution to the trend away from the egocentric position was contained in his principles of relativity. Relativity challenged many concepts of absolutes in the universe. Some clergy still confuse the physical principle of relativity with the unrelated philosophical and theological position of relativism, which depicts morality as relative. Thus, opposition to the supposed concepts of relativity has grown because of lack of understanding.

Freud, in turn, demolished the egocentric view of human rationality. After Freud’s pioneering techniques of psychoanalysis have been superseded, Freud’s demonstration of the non-rational foundation of human behavior will persist as a milestone in the trend away from the egocentric view of people.

The Nature of Science

Since such a major trend in human thought has been led by science, it is cogent to question the nature of science. Also, needing questioning is how the move away from the egocentric view could be pushed against very strong resistance to new ideas. Frequently, science is linked with a lengthy history of inquiry. Certainly, the older sciences like physics and astronomy have such a history of inquiry. However, many younger sciences barely have any history of inquiry, and a new science starting tomorrow would have none. In addition, disciplines clearly not sciences, such as art and music, have a history of inquiry into their own aesthetic analysis of the worlds with which they deal. An artist or musician usually must master the history of the subject before generating original work. Therefore, a history of inquiry is not what distinguishes a science from other types of endeavor.

Sciences typically acquire a body of facts and laws. The presence of a body of facts and laws is, therefore, sometimes used to identify a science. The same objection to this differentiation of science can be raised as was for the history of inquiry definition. Namely, new or young sciences do not have bodies of facts and laws, and non-scientific disciplines such as art and music do have bodies of facts and laws. An artist or musician typically masters the facts and laws of the subject before creating original work. In a portrait, for example, the eyes are half way down the head. Further analysis of the apparently cohesive body of facts and laws of even the older sciences shows some basic flaws.

Light, for example, has been a subject of study for a long time in the science of physics. Light is defined in the psychological, not physical, terms of electromagnetic energy stimulating the human retina resulting in vision. Related energy, like infrared or ultra-violet, are not visible to humans and do not count as light. Light is also treated on at least three levels, each with distinct mathematical analyses with separate understanding. Physicists deal with light as a ray or beam with geometrical optics for the topics of reflection, refraction, and similar phenomena. Light is also considered as a wave with sinusoidal analysis for interference, diffraction, and related occurrences. Finally, light is viewed as a packet, or photon, with statistical quantum analysis for phenomena like absorption and emission of light energy and comparable events. The cohesion of this body of facts and laws is only apparent. Thus, the attempt to differentiate a science from other disciplines by any accumulated body of facts and laws must be discarded and, the question of the nature of science remains.

Sciences always deal with specific observations of events in the world and with general hypotheses about the observations. But, so also, do many non-scientific disciplines like art and music. Scientists, however, have very definite ways of developing hypotheses from observations by the method of inductive logic and, in turn, of checking hypotheses against observations by the method of deductive logic. These methods of inducing hypotheses from observations of events, and deducing observations that should follow from hypotheses are the signatures of all sciences. Science is the scientific method. Knowledge is generated by the use of the scientific method. Figure 1-1 graphically depicts the scientific method of progressively cycling from observations to hypotheses to observations, etc. The cycling may be started anywhere depending on the particular subject and the abilities of the scientists involved.

Some sciences emphasize the deductive side of the cycle. Physics articles are generally published in the deductive form of stating a particular hypothesis, then describing an experiment which generated observations bearing on the accuracy of the hypothesis. Other sciences emphasize the inductive portion of the cycle. Astronomy depends heavily on careful observations to generate hypotheses about the stellar universe. However, all sciences employ the cyclic method, and any instance of the method being employed is science.

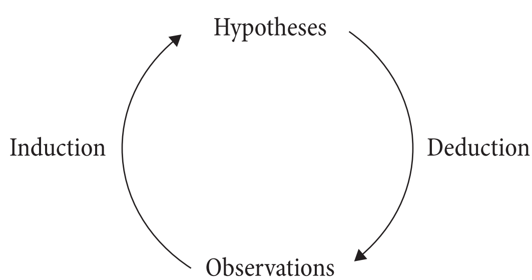

Figure 1-1 The Scientific Method of generating knowledge by employing inductive logic to generate hypotheses from observations and deductive logic to check the accuracy of hypotheses against observations.

Underlying the use of the scientific method is one basic assumption, scientific determinism. Scientific determinism is the assumption that events in the universe are predisposed toward lawful behavior. Without the assumption, science is reduced to dealing with unique occurrences unrelated in time or space. What is discovered in one place is not necessarily true in another location.

What is valid now may not have been yesterday and is uncertain tomorrow. With the assumption of scientific determinism, science studies continuing processes of events in the universe.

Scientific determinism is not the same as determinism, the philosophical idea of predestination or fatalism. The assumption of scientific determinism, that events in the universe are lawful, does not require such restrictive conditions. The only stipulation is that, all of many possible outcomes of an event are each in themselves lawful, even if at times unpredictable. Examples of lawful but unpredictable events are rolling dice, and the radioactive decay of atoms.

Dice tossing, tabulated in Table 1-1, represents the principle of scientific determinism, because all the possibilities are lawful, but not predestined. Thus, a score of seven has six possible ways to occur (five plus two, two plus five, three plus four, four plus three, six plus one, and one plus six) out of 36. The probability of a seven occurring is six in 36 or once in every six tosses. In a population of 36,000 tosses there will be 6000 sevens with very little error, and much less than a percent variation. However, if on any single toss, anyone wishes to know whether a seven will appear, only the estimate of probability (a one in six chance) can be invoked to predict. There is no certainty

Table 1-1 Tabulation of Dice Tossing.

Score	**Possible Ways**	**Probability**	**Frequency (N = 36K)**
2	1	1/36 = .0278	1000
3	2	1/18 = .0556	2000
4	3	1/12 = .0833	3000
5	4	1/9 = .1111	4000
6	5	5/36 = .1389	5000
7	6	1/6 = .1666	6000
8	5	5/36 = .1389	5000
9	4	1/9 = .1111	4000
10	3	1/12 = .0833	3000
11	2	1/18 = .0556	2000
12	1	1/36 = .0278	1000
Totals	36	36/36 = 1.0000	36,000

of predestination in individual tosses, only an estimate of probability. But, again, whatever score occurs will be a lawful event consistent with scientific determinism.

Natural phenomena, like the decay of atoms, follow the same principles as dice tossing. In a population of atoms, like a population of dice tosses, decay will follow a predictable course. Whether a particular individual atom will decay at a given moment, however, is a matter of probability, just like a single dice toss. Einstein's comment that, in atomic phenomena, "God does not play dice" ("Gott würfelt nicht") was premature, but the atomic dice are used in a subtle manner, as Einstein also observed "God is subtle, but not malicious" ("Raffiniert ist der Herrgott, aber boshaft ist er nicht."). Tracing of the understanding of the principles of evolution, later in this chapter, also reveals the role of scientific determinism.

The Science of Nature

Because the scientific method is shared by all sciences, science is essentially indivisible. Any separation among sciences is arbitrary and splits fields of study. The common demarcation between social sciences and biological sciences splits psychology. On the other hand, segregation of sciences along lines of life sciences and physical sciences divides biochemistry. Separation of sciences, however, is frequently necessary for convenience in dealing with the wide array of subjects under the scrutiny of science. This book, concerned with nature would, of course, deal particularly with those sciences studying life and not especially with those sciences whose subject is the physical world.

A basic difference between life and the physical world is the importance of the time dimension. In the physical universe events in time have relatively long duration compared to the short span of life. In view of the small importance of time in the physical world, physics has not investigated time to any great extent (Gold, 1967), until the recent spate of work over the last thirty years. Life, however, existing as it does in a rotating world, which makes the main energy source, the sun, periodic, has become time-locked. Even basic metabolic processes exhibit time cycles. Time brings rapid and important changes to life and can be considered life's most salient dimension.

Physics considers work equivalent to force acting through distance (W = Fd), while force acting through time is relegated to the status of impulse (I = Ft). Such definitions are confusing to students of life science who realize that tremendous energy expenditure can result from holding a weight in fixed position for a time (impulse) as well as from lifting a weight through a distance (work). Actually, a living organism performs work by changing chemical potential energy into kinetic energy, just to maintain its existence from moment to moment. Indeed, the best index of energy expenditure during motor behavior is the integral of force acting through time (Trotter, 1956). Force exerted through time is also a major parameter of an organism's response repertoire (Notterman and Mintz, 1965). Thus, for the purpose of life sciences, work must be reconsidered as effort acting through both distance and time, Effort = F[(d/t) + t]. The range of possible values of space (d) and time (t) are limited by the capacity of the organism. Within that range there are optimum values for d and t. To vary slightly from the optimum performance greatly increases the effort. Power (Fd/t) plus impulse (Ft) are the expression of effort for organisms. Beginning physics students have difficulty with the physical concept of work because of the intuitive understanding of their own effort. Technology has increased human power by decreasing the time of various activities. Using tools also changes the sense of how much effort is required for a task. The formulation of effort is realistic for the life sciences because both time and space become important to an organism that moves through its life.

A popular view of the difference between life sciences and physical sciences is that life sciences rely on statistics and physical sciences employ laws. The view stems from the idea that life sciences are newer, not as established, and understand less of their subject than the physical sciences. Implied in these statements is the concept that statistics is only a temporary treatment awaiting more thorough knowledge of the subject and the subsequent formulation of laws.

While the statements have some degree of accuracy, the stopgap view of statistics is incomplete. Physical sciences do use statistics. Returning to the example of the phenomena of light, laws are employed when light is treated as a ray. Thus, angle of incidence equals angle of reflection. Laws are evidenced when light is viewed as a wave. Hence, Huygen's principle stating that every point on an advancing wave front is a secondary wave source. However, statistics must be be invoked when light is considered as a photon. Thus, events, like a particular photon being absorbed by colliding with a specific electron at just the proper moment, although lawful, are necessarily only probable. Probabilistic events can only be treated with statistical estimates of the chance of their occurrence.

The example becomes even more significant by illustrating the essential difference between laws and statistical analysis. Light rays or waves are populations of photons. Laws always describe the behavior of populations. Thus, laws can describe the motion of a ball down an incline because the ball is a population of molecules. Laws can predict that only a fraction of the population of depositors of a bank will want their money at once. That enables the bank to retain just a small amount of reserve capital and invest the rest. Laws can predict the frequency of scores in the 36,000 dice tosses in Table 1-1. Whenever an individual in a population is singled out, however, the event becomes probabilistic, and a statistical estimate must be used. Individual molecules of the ball rolling down the incline could scrape off on the surface or, even, sublimate into the air. Individual bank customers could request their money. Single dice tosses are unsure. Formulation of laws or use of statistical analysis depends not on the science, but on whether the event in question is a population phenomenon or involves an individual. For example, to measure the individual size of leaves on a tree a statistical sample is employed, but to compare the populations of oak and maple leaves, only a few are needed.

The province of the life sciences is life. But, life with its conservatively estimated 1,200,000 animal species (Hanson, 1964) and 333,000 plant species (Arms and Camp, 1989) is still a relatively small population compared to phenomena in the physical universe. The ball that rolled down the incline contains more molecules than the total population of all of life's individuals on this Earth. Thus, life scientists investigating small populations, and often individuals, must frequently employ statistical techniques.

In addition to small populations, life sciences must also explain the high degree of complexity and organization of life. Physical parameters like size do not help. Measuring species size does not cope with the differences among 100 foot whales, 300 foot tall sequoias, and three-micron wide microsporidian spores. To understand the complexity and organization of life, life scientists must know the history of life. They need to comprehend life's origins and evolution to its present state, or how life came to be the way it is. Evolution provides the historical analysis and deterministic mechanism, in natural selection, that unveil the phenomena of life. Thus, evolution is the fundamental underlying principle of all the life sciences.

History of Evolutionary Theory

The concept of evolution involves the change of species through time. A comprehensive review of the history of evolutionary theory would fill volumes. However, a synopsis, of some of the major steps in the history of evolutionary theory, serves to illustrate the creative and dynamic effort of many great thinkers in formulating modern evolutionary theory, and to clarify past errors.

Among the earliest theories proposing change of species was Aristotle's linear hierarchy, already noted on the first page of the chapter. In this system each level was more perfect than the level below. Thus, in the version of Aquinas, God represented absolute perfection followed by angels, who were less perfect than God, but still too perfect to commit sin. The next rank, at the top of the real world, was humans. Humans were less perfect than angels, in that people were rational and could choose to commit sin. Heaven was reserved only for those who did not sin. After humans were animals. Animals were viewed as even less perfect because they could not reason, but only react with instinct. Finally, came plants, which were at the bottom in perfection because they merely vegetated. In addition, those in each level strove to be more like the level above. The level of understanding of life for most people, even today, reflects the idea that humans are rational, but animals respond only by instinct. The Hindu concept of the scheme of life inherent in reincarnation, also includes a similar ordering of life. It contains the idea of transmigration that includes all life in a pursuit of perfection and heaven, or nirvana.

Galileo developed a theory of impetus which held that objects maintain momentum unless stopped. The theory was influential because it avoided causal or animistic explanations for movements. Momentum kept the planets in orbit, not some unknown invisible gear system that had to be cranked. Change, not stability, was the natural state of the universe. Coupled with other later discoveries, like calculus by Leibnitz and Newton, Galileo's ideas triggered a 17th century revolution in thought, which emphasized mechanism and scientific determinism. The revolution led to great progress in the physical sciences and caused abandonment of the teleological view that the complex organization and design of the world called for the existence of a designer. Darwin was later to forsake the same teleological, no-clock-without-a-clock-maker, approach in his explanation of the origin of species. However, the teleological idea is still influential in theology.

Life science, in awe of the progress of the physical sciences, began to emulate them. Led by Linnaeus (Karl von Linne) in the 18th century, life scientists developed a complex classification system, categorizing species by anatomical and functional similarities. The rationale was that classifying would reveal organization and permit induction of laws concerning life. But, species were considered immutable entities.

Hegel originated the technique of using history as an analytic tool, rather than merely as a description of past events. He was interested in the origin of social institutions and structures. His thought had tremendous impact on the social disciplines of history, anthropology, economics, sociology, and social psychology. Hegel's new analytic approach also began a 19th century revolution in other sciences. Astronomy and physics began using Hegel's approach to explain the origin of the universe and to conceive astrophysics. Lyell employed the analytic approach in geology by using the history contained in rocks to explain the formation of the Earth. His work heretically replaced the story of Noah and the flood to explain the origin of the Earth's structures. Lyell's thought influenced the closely related field of paleontology and a young student at the time, Charles Darwin.

New ideas were accumulating rapidly in the life sciences. Buffon, in 1760, had destroyed the purposive explanation of organs, like eyes are for seeing. He observed that two of the five digits on each of a pig's feet did not touch the ground. Therefore, toes could not be for walking. The pig's vestigial digits led Buffon to explain all quadrupeds as degradation from fourteen primary types. Animals, instead of being direct divine creations, were now viewed as imperfect descendants of originally divine creations. The theory cracked the ground of life science for later seeds of historical analysis of life's origins.

By 1803 Lamarck, Buffon's student, had formulated the first theory attempting to explain life as progressive and adaptive change. Life diverged from a primal type, rather than degraded from divine forms. Lamarck's theory held that acquired characteristics, like large muscles, affected the (at that time unknown) genetic material and were inherited. Thus, a right-handed blacksmith's son should have a muscular right arm. Many a blacksmith's son did have a large arm, but not because of his father's acquired characteristics. Only in rare instances, like alteration of the sex cells by drugs or radiation, can acquired changes be inherited. Lamarckian theory could not explain how a blacksmith, who lost an arm, could subsequently have offspring with complete arms. Lamarck also used the old Aristotelian notion of striving toward perfection. He contended that the striving toward perfection of organisms led to the acquisition, through use, of improved characteristics, that were, in turn, inherited. Disuse would result in the loss of characteristics and the subsequent reduction of those characteristics in future progeny. Although such concepts mediated Lamarck's impact among life scientists, his influence was still immense. Indeed, there are even recent Lamarckians, like Lysenko (Morton, 1951), the former President of the Lenin Academy of Agricultural Sciences. Lamarckian theory adapted readily to the milieu of socialist realism in which Lysenko worked. Against the advice of knowledgeable experts like N. I. Vavilov, who was later purged and died in detention, over 3000 biologists, who disagreed with Lysenko, were dismissed, imprisoned, or executed. Lysenko made decisions affecting grain breeding in Russia. Lysenko's influence, destroyed progress in Soviet genetics and crop production. Russian influenced countries like Czechoslovakia, Poland, China and others were also affected by Lysenkoism. After Stalin's death Lysenko lost his position, and Soviet genetics again flourished. Khrushchev reinstated Lysenko, but on February 4, 1965, Lysenko followed Khrushchev in being ousted. Lysenko died in Kiev on November 20, 1976.

Lysenko illustrates the periodic resurgence of Lamarckian ideas. Historically, however, Lamarck's theory experienced difficulty from the beginning. St. Hilare, Lamarck's student, debated Cuvier in the French Academy of Science in 1830. Cuvier favored the idea that the world reached its current condition as the result of a series of catastrophic changes. Each change gave major reorganization to life forms. No mechanism for gradual accumulation of alterations was included. St. Hilare supported Lamarck's position, but used evidence linking the independent and unrelated, though similar, eyes of vertebrates and cephalopods, like the octopus. Cuvier, being knowledgeable in anatomy, caught St. Hilare's error and won the contest. The debate was extremely influential and served to suppress ideas on evolution for the next three decades. At the time, the poet Goethe was reportedly more interested in reading the result of the debate than in seeing a critical review of his own poetry. Darwin was a college student at the time. In addition to the debate and the work of Lyell, Darwin also pondered the ideas of Malthus. Malthus contended that the rapid reproduction and subsequent increase in the population of organisms would outstrip food supply, unless there were checks on the population. The next year, 1831, following graduation, Darwin joined the H. M. S. Beagle as ship's naturalist for a five-year voyage around the world to survey, record, and collect plant and animal specimens.

In 1859 Charles Darwin published his book, *The Origin of Species*. The book was the culmination of his observations on the Beagle journey and of his subsequent thought. He had presented his ideas the previous year before the Linnaean society in London along with Wallace, who offered similar concepts. The competition with Wallace finally led Darwin to publish. His work was so well anticipated that it sold out on the very first day.

Darwin had enormous impact on life science because he presented not only the idea that the evolution of life had occurred, but he also explained the process with the mechanism of natural selection. In addition, his wide travel experience enabled him to support his theory with an unequaled and unassailable array of accurate examples. The timing also favored Darwin's ideas about evolution. In 1860, Pasteur demonstrated conclusively that organisms were responsible for spoilage and fermentation, and that spontaneous generation of life did not occur. Virchow reformulated the earlier postulates of Schleiden and Schwann, that cells were the basic unit of life, and that cells came from other cells. The cell theory, coupled with Pasteur's discoveries and Darwin's work, sparked a major revolution in life science. For the first time, both the units of life, the cells, and the explanation of the origin and continuity of life were known.

But the heralds were not trumpeting. Pasteur was rejected. Not until later in the century, when called upon by the Russian Czar to stop an anthrax epidemic, would Pasteur's concepts be accepted. The cell theory was ignored until 1895, when Verworn revitalized it. Darwin's ideas became distorted into cliches like "struggle for existence" and "survival of the fittest." These phrases were wrongly employed to emphasize the survival of individuals, rather than the population principle of differential reproduction of the species. Spencer, and other Social Darwinists, usurped these cliches to excuse the inequities of the very rich and very poor of the rising industrial society. Thus, the wealthy were seen as the fittest and the poor were viewed as the unfit. Life scientists, horrified by the political distortion of their work, abandoned the pursuit of general explanations of life, like evolution. Again, laws describe the behavior of populations, not individuals.

For the next six decades evolution was taboo and reductionism reigned. Müller's followers tried to use his laws of nerve function to explain all behavior. Loeb joined the movement with his idea of taxis, the approach or avoidance of physical stimuli. He attempted to explain all behavior as the physics of taxis. Thus, a cockroach ran into darkness because of negative photo taxis. A resurgence of Lamarckian ideas, which focused on the individual, had prevailed.

Part of the difficulty was the fact that Darwin's work was lacking an important piece necessary to complete the puzzle. Darwin understood natural selection. He did not grasp the significance of sex as the mechanism for generating and preserving the population differences on which selection operates. Darwin believed that sex was a means of obscuring population variance. He thought offspring would be intermediate compared to parental extremes. Thus, a tall and a short parent should have a medium-size child. Darwin's ideas on natural selection were remarkable considering the paucity of genetic knowledge at the time.

In the 20th century, the, link that converted evolutionary theory to fact appeared. Mendel in 1866 had found the basic laws of genetics stating that parental characteristics do not blend in progeny. He found that the combination of various parental characteristics in the offspring followed the laws of statistical probability, and that dominant parental characteristics mask recessive ones in the next generation. Mendel's work, published in the Proceedings of the Brünn Natural Science Society (1866), was ignored until rediscovered independently in 1900 by Correns, deVries, and von Tschermak-Seysenegg. In 1903, Sutton realized that the chromosomes life scientists had been watching divide and reproduce through microscopes for years were the carriers of the genetic characteristics. In 1909 Nilsson-Ehle extended the understanding of qualitative gene characters, like red or white, to quantitative features having multiple genes, like the degree of redness. Chetverikov, Haldane, Fisher, and Wright in the late 1920's and early 1930's provided the mathematical basis for selection. Fisher (1930) synthesized evolution and genetics by indicating that genetic fitness was related to population variance.

Finally, life scientists knew the three features by which sex contributed to evolution. First, sexuality was a device for generating variability by rapidly creating various, and even new, parental genetic combinations in offspring. Sexual combinations were fast, compared to the slow accumulation of new features in asexual populations. Variation is also enhanced by dominant genes shielding, retaining, and preserving the variety of recessive characteristics, even, if they were fatal by themselves. Variation is important because it provides the resilience in the population to adjust to changes in selection. Second, generation of new genes by mutation, discovered by deVries, is a random occurrence with no regard for any needs of the organism, unlike Lamarck's purposive acquired characteristics. Third, the unit of evolutionary change is not the individual, as Lamarck thought, but the population's total pool of genes. To repeat, as with dice tosses, laws describe the behavior of populations,