AP BIOLOGY SUMMER ASSIGNMENT
JUNE 2009 - SEPTEMBER 2009

Evolution is a fundamental concept that is a recurring theme in all of biology. It will be our starting point this summer and continue throughout the course. Your summer assignment will contain 3 parts. Each will deal with the concept of evolution and will require you to do some research. We will begin our course on evolution and will go over the summer assignment before it is due the second week of September.

Assignment #1 - Stephen J. Gould Essay

Read the article by Stephen J. Gould entitled, "The Gift of New Questions". Answer the following questions thoroughly, with detailed explanations using the article as well as any other resources necessary:

1. On page 6 1st column Dr. Gould writes, "All animals of a related group can be represented as graded variations of a single archetype…". Describe how this statement shows Darwinian gradualism and compare it to the idea of punctuated equilibrium.

2. On page 6 2nd column Dr. Gould writes, "…form comes first and must then seek its function." Describe how this statement supports Darwin's idea of natural selection.

3. Create a Darwinian explanation for how the splint bones in horses evolved from a 5 toed ancestor or how mammal's inner ears evolved from the jawbones of reptiles.

Assignment #2 - AP Free Response Questions

The AP exam contains 4 free response questions. In order to prepare you for the exam it is necessary to practice as much as possible in the writing of free response questions. In a scientific free response you must be sure to support your explanations with examples and data. It is not sufficient to just state a fact; it must be supported. For example, when speaking of natural selection, define it, discuss the relative components of the theory and give examples of each component. You may use any resources necessary to answer the following free response questions on evolution.

Charles Darwin proposed that evolution by natural selection was the basis for the differences that he saw in similar organisms as he traveled and collected specimens in South America and on the Galapagos Islands.

a) Explain the theory of evolution by natural selection as presented by Darwin.
b) Each of the following relates to an aspect of evolution by natural selection. Explain the following:
    - Convergent evolution and the similarities among species (ecological equivalents) in a particular biome (e.g., tundra, taiga, etc.)
    - Natural selection and the formation of insecticide-resistant insects or antibiotic-resistant bacteria
    - Speciation and isolation.

c) Assignment #3 - Photo Journal

Biology is a science that deals with numerous themes. Below are the themes you will deal with throughout the course.

Emergent Properties
Cells Structures and Functions
Heritable Information of DNA
Correlation of Structure and Function
Organisms Interacting with their Environment (Ecology)
Regulatory Mechanisms used to ensure a homeostasis
Evolution
Unity in the Diversity of Life
Scientific Inquiry
Science, technology, and society

You are to create a photo journal utilizing these themes. For each page of the journal you need to explain in detail how the specimen you "shot" follows the themes in biology. Some of the themes you will have to make inferences about and some you will be able to tell directly from your photos. (For example, a picture of a squirrel foraging along the forest floor for food would be an example of an organism interacting with its environment or you could use the picture of a squirrel holding an acorn in its paws to show structure and function.)

Each page in your photo journal should cover at least one theme. Along with a picture of the organism(s) you will write a description of the theme and explain how it pertains to the specimen. For the last theme, science as a process, list any problems that you had in taking the photos as well as describe how and why you decided on your specimen. This means, for each photo you need to have two themes one being "science as a process". So a complete journal will have at least 9 pages making sure that you include all 10 themes.

Journals can be completed in paper form or as a power point presentation. The material involved in the journals will be reviewed during the first day of classes.

We hope each of you have a wonderful and fun (bio) filled summer.

Ellen Pollina
Brian Newburger

The Gift of New Questions

By adding the dimension of history, Darwin cooled a hot debate among nineteenth-century scientists

by Stephen Jay Gould

Galileo's telescope was not much superior to a modern birder's field glasses, but he magnified the heavens for the first time and therefore discovered the four large moons of Jupiter, the phases of Venus, and the fine structure of lunar architecture. What could possibly serve as a better example of the dream for which any scientist would kill, die, or sell his soul—an opportunity for pure, unsullied observation of the utterly unknown and the mightily important. In one night, and one peek, the wisdom of a thousand years might be reversed and reconstituted.

Galileo's telescopic observations therefore stand as a paradigm for our primary scientific ideal of objectivity—freedom from the constraints of culturally biased expectation, combined with obedience to nature's factual dictates. After all, you can't be much subject to the shackles of anticipation if you haven't the slightest idea of what you are going to see.

But Galileo also turned his telescope on Saturn—and made a fascinating error that also explodes the beguiling (and self-serving) image of humble and rigorous objectivity. We must approach nature by asking questions of her, and we cannot pose a question without some structure of anticipation. Galileo looked at Saturn, observed the rings as through a glass darkly (for his optics were no great shakes), and thought that he had seen three spheres in a line—a large central body surrounded by two smaller globes.

Following a peculiar custom of his time, Galileo encoded his conclusion in a Latin anagram, which he then sent to his friend Johannes Kepler. (Priority in discovery has always been a touchy issue in science. Seventeenth-century standards were even more fluid and confused than in our own day, and copyright protection scarcely existed at all. Scientists wanted to record their discoveries without fear of usurpation, but with minimal damage should their claims subsequently prove wrong. Hiding a message within a difficult anagram provided a ready solution. With luck, no one would decode the claim properly, and an incorrect hypothesis could therefore remain forever hidden. But if someone later tried to steal your idea, you could publish the dated anagram with your intended solution—and prove your priority.)

Kepler may have been the most brilliant man of his age, but he misread Galileo's anagram as a statement about the planet Mars. Galileo had encoded the following message: *altissimum planetam tergeminum observavi*—"I have observed that the furthest planet is threefold." (Saturn is the most distant of the visible planets; Galileo referred to his misperception of three spheres by designating the ringed planet as *tergeminum*.)

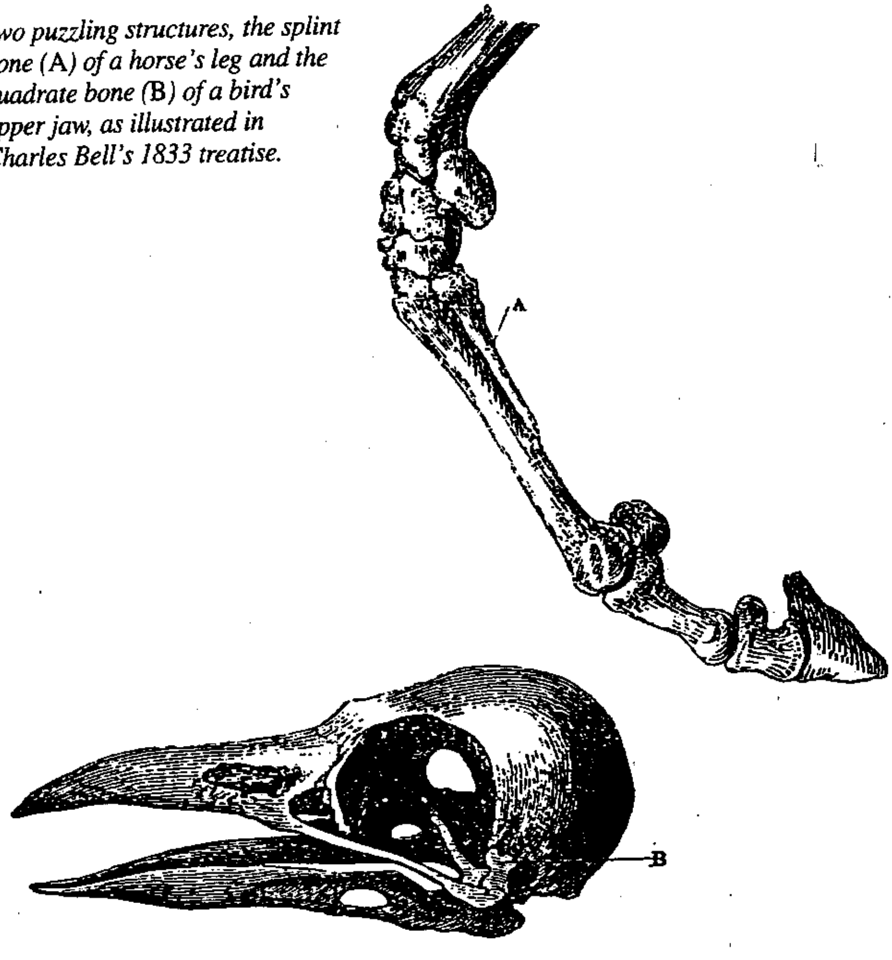
As refutation of a myth, this example has always struck me with particular force. Galileo is so clear and so sure. He does not say "I infer," "I suppose," or "I reason." He states simply: "I have observed"—*observavi*. I have seen it with my eyes, and that is that. But Galileo viewed Saturn through his brain, for we cannot bypass this central focus and filter, this magnificent device crammed full of biases both evolutionarily encoded and socially constructed. I don't think that Galileo had any conceptual space for planets with rings. He was a brilliant and adequately flexible man. Excellent optics might have revealed a ring too obvious to be denied. But Galileo read a fuzzy Saturn in the light of his preexisting knowledge. Planetary masses are spherical. Symmetrical bulges on either side must be subsidiary globes.

All good and useful observation must be embedded within a theory. Science gains its strength by structuring observations as continual tests of a theory's power. Objectivity does not reside in theory-free perception; such a pipe dream can lead only to spheres in a line or some other fancy falsely construed as secure because we have not scrutinized our constraining biases. Objectivity lies in the flexibility to reject a cherished theory when an anticipated observation cannot be affirmed, and a perception of contrary meaning—a ringed planet, for example—delights us instead.

Theory must guide observation. If we do not cast our theoretical net widely enough, we will not see what lies before our eyes, for the conceptual tools will be unavailable to us. This essay tells a story of observations that could not be made because a fine scientist could not formulate the theoretical structure that held the right question. He did not query nature properly and therefore could not see her forms.

In the generation before Darwin changed biology forever, most British naturalists interpreted the anatomy of animals as proofs and expressions of God's wisdom and benevolence. Animals were viewed as marvels of biomechanical design, with each feature meticulously adapted in all details to the organism's ecology and mode of life. Only an omnipotent God could have created such organic perfection. This "argument from design," or "natural theology"—the inference of God's existence and attributes from the products of his creation—had been the mainstay of British natural history from John Ray in the seventeenth century through an apogee in William Paley's *Natural Theology* (1802) to a last gasp (more accurately a whoosh) in the eight Bridgewater Treatises of the 1830s.

Two puzzling structures, the splint bone (A) of a horse's leg and the quadrate bone (B) of a bird's upper jaw, as illustrated in Charles Bell's 1833 treatise.



(I have frequently discussed natural theology in these essays if only because Darwin developed his theory of natural selection as a specific refutation of this previous orthodoxy.)

While natural theology dominated in Britain, a very different approach to morphology arose in France and Germany and provoked an interesting debate that the formulation of evolution would later resolve. These "structural," or "transcendental," morphologists tried to explain the differences between organisms as expressions of "laws of form." All animals of a related group can be represented as graded variations of a single archetype. Structures may be reduced, intensified, specialized, or altered in function, but the fundamental relationships of order and position among parts are maintained, and the sequence of changes among organisms follows simple rules of transformation. Thus, the fin bones of a lungfish match the leg bones of a horse, while the jawbones of a reptile may correspond with hearing bones of the mammalian middle ear.

The two schools differed primarily in their attitude toward adaptation. For natural theologians, adaptation served as the basis of organic form. God made organisms with optimal designs for their functions. For structural morphologists, adaptation existed only as a secondary phenomenon, not as the source and *raison d'être* of creation, as the natural theologians insisted. Laws of form and rules of transformation govern the graded series of related animals, and adaptation can represent only a subsidiary fit. Laws of form imply "slots" for certain anatomical arrangements, and animals so endowed must then find an environment to put their forms to good use. In other words, form comes first and must then seek its function. (For natural theologians, function comes first, and God creates optimal anatomies for appointed roles.)

In practice, natural theologians denied graded order and interpreted related animals as functional variations on a common theme. Among mammals with the same bones, some swim, some run, some fly, and some burrow, but no axes of gradation unite these creatures. Each is a paragon of adaptation in its own functional world. Structural morphologists, on the other hand, sought to represent mammals as sequences of gradational changes along a few axes of transformation. The laws of gradation establish the series; adaptation can only be epiphenomenal and must often remain far from optimal (as constraints of the ordered series preclude tinkering to optimal adjustment).

Theoretical structures can act as mental prisons when the most productive question cannot be asked or even conceptualized within an accepted world view. In such cases, new theories must break the mental lock, for "pure" observation is a myth and the perception of vital facts requires the conception of novel questions. In this essay, I will take two puzzles from the last great work of natural theology and show that the factual solution seems to stare the author in the face, yet remains unperceived as outside the range of questions that natural theology could ask.

Sir Charles Bell (1774–1842) was the greatest neurologist of his day. His *New Idea of Anatomy of the Brain,* first published in 1811, is revered as a founding document of the profession. Bell was a pioneer in establishing the fundamental distinction between sensory nerves that convey impulses to the brain and motor nerves that send neural messages to responding parts of the body. Since the Earl of Bridgewater had specifically requested a volume on the "construction of the hand of man" as a contribution to his endowed series of treatises "on the power, wisdom, and goodness of God, as manifested in the Creation," Bell seemed an obvious choice—for he was an artist with words as well as with bodies, and he certainly understood the coordinated functions of brain and hand.

Bell's 1833 Bridgewater Treatise, *The Hand: Its Mechanism and Vital Endowments as Evincing Design,* is the last great statement of natural theology applied to anatomy. I discussed this work in my column of March 1993 to contrast Bell and Darwin on nature's grandeur. In this essay, I will take two specific examples from Bell's book to illustrate a question that natural theology could not ask, thereby foreclosing the possibility of grasping an important side of nature's construction. What other sides are we missing today because our theoretical "certainties" preclude the posing of other fruitful questions?

Bell's book certainly holds the orthodox line on natural theology and the predominance of adaptation as illustrating God's benevolent creation of the organic world. Bell begins by writing:

If we select any object from the whole extent of animated nature, and contemplate it fully and in all its bearings, we shall certainly come to this conclusion: that there is design in the mechanical construction, benevolence in the endowments of the living properties, and that good on the whole is the result.

He then continues by stressing adaptation as the primary proof of God's action and intent:

> The principle then....is, that there is an adaptation, an established and universal relation between the instincts, organization, and instruments of animals on the one hand, and the element in which they are to live, the position which they are to hold, and their means of obtaining food on the other.... We have seen no accidental deviation or deformity, but every change has been for a purpose, and every part has had its just relation. We have witnessed all the varieties molded to such a perfect accommodation.

Bell explicitly contrasts this adaptationist vision with the structural alternative then gaining popularity in continental Europe. He writes of the opposition:

> It is proposed that the same elementary parts belong to all animals, and that the varieties of structure are attributable to the transposition and molding of these elementary parts. I find it utterly impossible to follow up on this system.... I object to it as a means of engaging us in very trifling pursuits—and of diverting the mind from the truth.

He then expresses his perception of truth in the credo of adaptation and the argument from design: "The function or use of a part determines its form."

As an example, Bell contrasts adaptational and structural approaches for interpreting the two long, thin splint bones surrounding the so-called cannon bone (actually an elongated foot bone) that forms the lower part of a horse's leg. We now know that these splints are vestiges of full ancestral toes. Horses once had three functional toes on each foot (more distant ancestors maintained the full mammalian complement of five). In a classic story of evolutionary change, modern horses reduced the series of three to a single, strong central toe—while vestiges of the two side toes remain as the splint bones, now invisible from the exterior, and making horses effectively one-toed animals.

But this evolutionary solution did not exist in Bell's conceptual world; such an interpretation could not enter his thoughts or inform his questions. For Bell, all features of anatomy required an explanation in terms of immediate, optimal function. He therefore had no alternative but to ask his usual question: All structures exist for a purpose. What, therefore, do the side splints do? When I discover what they do, I will know why they exist.

Bell begins by ridiculing the structuralist alternative—actually correct in this case—that splint bones should be interpreted as part of a gradational series comparable with fully functional toes of other mammals:

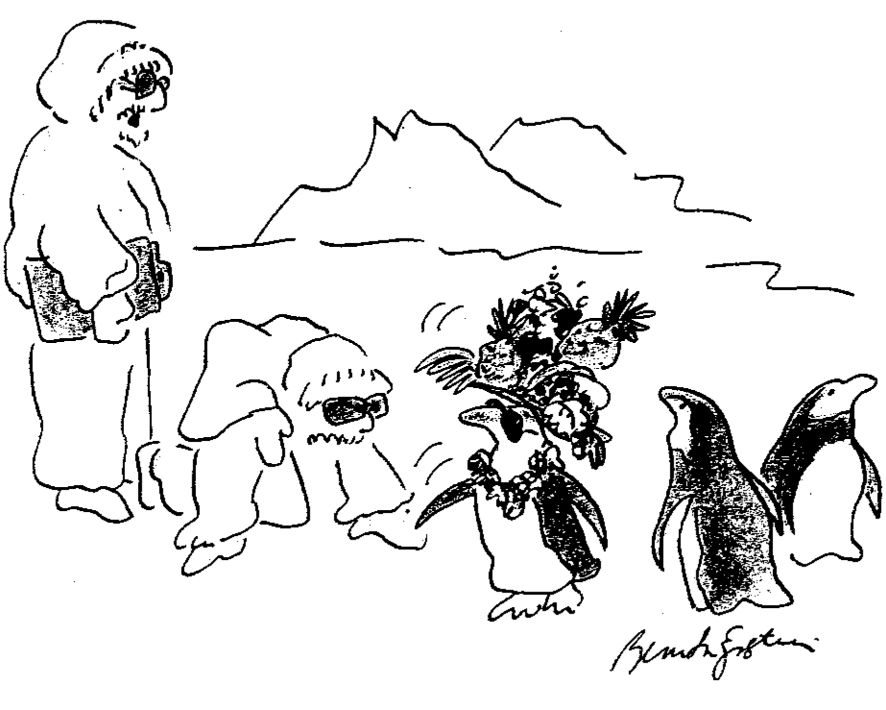
> Lovers of system...delight to trace the gradual subtraction of the bones of the hand.... To me, this appears to be losing the sense in the love of system. There is no regular gradation, but a variety most curiously adapting, as I have often to repeat, the same system of parts to every necessary purpose.

Bell then proposes to prove the superiority of natural theology by showing that all bones of the horse's foot, including the splints, are exquisite adaptations:

> In a comparative view of these bones, we are led more particularly to take notice of the foot of the horse. It is universally admitted to be of beautiful design, and calculated for strength and elasticity, and especially provided against concussion.

Bell's entire discussion then focuses upon the search for a functional explanation of splint bones. He never considers any possible alternative reason for their presence. He cites some disagreement among experts, but only within the adaptionist paradigm. He states, for example, that some "veterinary surgeons...imagine that these movable splint bones, by playing up and down as the foot is alternatively raised or pressed to the ground, bestow elasticity and prevent concussion."

Bell denies this view, for he can conceive of no mechanical means whereby the splints can "add to the elasticity of the foot." He proposes, instead, that the splints "act as a spring to throw out the foot, when it is raised at the knee-joint bend." But he never asks a crucial question: suppose that the splints are present for a reason other than optimal function for present purposes? And you cannot get the right solution until you pose a problem within the framework of a proper theory.



"It's either a global warming trend or merely a fad."

In an even more striking example, Bell considers the two small bones (called quadrate and articular) that form the jaw joint in birds and reptiles. Bell confronts the following problem: Mammals employ a strikingly different system by articulating the jaw between two large bones, called squamosal (upper) and dentary (lower), that also form major portions of the upper and lower jaw. (The dentary builds the entire lower jaw in mammals, whereas several bones form this structure in reptiles, including the tiny articular at the joint itself.) Moreover—and now the story becomes even more curious—the reptilian jaw-joint bones look suspiciously like two bones in the mammalian middle ear, the *malleus* (hammer) and the *incus* (anvil). (The third mammalian hearing bone, the *stapes*, or stirrup, then seems to correspond with the single hearing bone of birds and reptiles.) Bell's nemesis, the continental structural morphologists, had therefore proposed that the jaw-articulation bones of birds and reptiles *are* the same structures as mammalian hearing bones. We now know that this view is correct (but we attribute the differences to historical transformation, or evolutionary change, rather than to abstract rules of gradation among a series of created objects, as most structural morphologists held).

Bell therefore begins his discussion by ridiculing the structural view (now considered clearly correct in this case)—I mean, after all, who could possibly credit such a reverie as comparability between bones of such different function: chewing and hearing. The morphological resemblance can only be accidental. Bell writes of structural morphology:

> This new theory has been brought forward with the highest pretensions; the authors of it have called upon us to mark the moment of its conception as the commencement of a new era! They speak of…"a new principle of connection," and "a new theory of analysis…." The hypothesis essentially is this, that when a part, which belongs to one animal, is missed in another, we are to seek for it in some neighboring organ: and on such grounds they affirm, that this surpasses all former systems as a means of discovery.

Bell then poses the specific problem and pooh-poohs the proposed solution of his enemies:

> The matter to be explained is simply this:—the chain of bones in the ear, which is so curiously adapted in the mammalia to convey the vibrations of the membrane of the tympanum to the nerve of hearing, is not found in the organ of hearing in birds; but there is substituted a mechanism entirely different. They [the structural morphologists] choose to say that the incus, one of the bones of the chain, is wanting in the bird. Where shall we find it?—they ask. Here it is in the apparatus of the jaw; in that bone which is called *os quadratum* [quadrate]. I believe that the slight and accidental resemblance which this bone in the bird has to the incus, is the real origin of this fancy.

Bell then contrasts this supposed nonsense with his own, righteous way. He asks once more in ridicule: "Shall we follow a system which informs us that when a bone is wanting in the cavity of the ear we are to seek for it in the jaw?" He then reasserts the only and proper way to truth: we must "on the contrary, take the principle that parts are formed or withdrawn, with a never failing relation to the function which is to be performed." Finally, in a statement almost eerily reminiscent of Galileo's claim for theory-free objectivity in pure observation, Bell states that adaptation represents evident truth, whereas structural morphology can only be a mind-blocking impediment:

> The only effect of this hypothesis [structural morphology] is to make us lose sight of the principle [adaptation] which ought to direct us in the observation of such curious structures, as well as of the conclusions to which an unbiased mind would come.

In his technical discussion, Bell raises only two points to support his adaptationist perspective, and supposedly to deny that the jaw bones of birds could be compared with mammalian hearing bones:

1. Birds hear as acutely with their single bone as mammals do with three:

> The first step of the investigation ought to be to inquire into the fact, if there be any imperfection in the hearing of birds. That is easily answered—the hearing of birds is most acute; the slightest noise alarms; and the nightingale…in a summer evening, will answer to the note of his rival…. The sense of hearing is enjoyed in an exquisite degree in birds: the organ of the sense is not imperfect, but is adapted to a new construction, and a varied apparatus—suited to the condition of the bird.

2. The jaw articulation of birds works remarkably well for its immediate function. Bell points out that, in mammals, only the lower jaw opens and shuts against a rigid upper jaw, usually fused to the skull—whereas, in birds, both jaws are mobile. Bell imagines, no doubt correctly, that this additional mobility has adaptive value in birds. The bird's jaw, he states,

> is withal a fly trap—hence, its motions must be rapid: and the velocity is increased by the most obvious means imaginable,—that is, by giving motion to both mandibles, instead of to one.

Bell then argues that the presence of two small bones at the articulation aids in this most useful mobility.

Satisfied that he had slain the enemy of structural morphology, with its implication of absent or less-than-optimal adaptation, Bell reasserts the real motive behind his own advocacy—and the Earl of Bridgewater's largess in commissioning, at handsome fees, such a set of treatises on divine

> It is, above all, surprising with what perverse ingenuity men seek to obscure the conception of a Divine Author, an intelligent, designing, and benevolent Being—rather clinging to the greatest absurdities, or interposing the cold and inanimate influence of the mere "elements," in a manner to extinguish all feelings of dependence in our minds, and all emotions of gratitude.

Readers may be forgiven for some puzzlement in considering Bell's two arguments for lack of correspondence between mammalian hearing and bird jawbones. From a modern perspective of evolutionary theory, Bell's points are potentially true but entirely irrelevant. Yes, the hearing of birds may be acute; and, yes again, the two jaw-articulation bones may have eminently useful function. But how do such observations preclude an evolutionary origin for these bones or their later transformation into hearing bones in mammals? After all, the bones may work well in a bird and still be transformed to some other function in a set of evolved relatives. My hands are doing a good job in typing this essay, but their ancestral structures worked quite well for navigation (and still do) in fishes.

We can resolve this puzzle by considering the conceptual limitations of Bell's world—the questions he could not ask and the resolutions that therefore and necessarily eluded him. History and evolutionary transformation did not exist as an option for Bell. In his world, all parts of organisms were created as we find them. Therefore, Bell faced only two possibilities for interpretation: an organ was either created to be used in a certain way or created as one step of gradation in a larger plan for sensible relationships among species. Bell thought that perfection of design proved the former alternative—for creation in the interest of graded order would necessarily fill the world with suboptimal structures, made to hold a place in a series, not to function in intricate and exquisite ways. In Bell's limited world, one need only illustrate excellence of function to prove the adaptationist side of the dichotomy. If the splint bones work well, if the jaw-articulation bones of a bird do something important, then God must have made them as adaptations for their current use.

Then Darwin stepped in and changed Bell's world forever. In the vital style of all intellectual revolutions, Darwin gave science the most precious gift of new questions that could not have been posed, or even imagined, before. Just add the possibility of history and genealogical change, and a novel world opens. The old dichotomy—function versus graded order—may now be collapsed into a single, integrated explanation: a structure may arise then be retained (often in a reduced or vestigial state) by simple inheritance in descendants. Thus, we may note a graded series, with limited or even absent adaptation in descendants, yet the organ in question may have originated as an optimal adaptation in the ancestor that anchors the series.

The side splints of a modern horse may have originated as fully functional toes in ancestors and may now be vestiges of limited utility, retained by inheritance. An evolutionary explanation may—in fact, usually does—include both adaptation and gradation. The two warring sides of Bell's dichotomy are harmonized in Darwin's world. Darwin probably had the side splints of horses in mind when he wrote his crucial passage on this subject in the *Origin of Species* (pages 199–200 of the first edition of 1859):

> But by far the most important consideration is that the chief part of the organization of every being is simply due to inheritance; and consequently, though each being assuredly is well fitted for its place in nature, many structures now have no direct relation to the habits of life of each species.... We cannot believe that the same bones in the arm of a monkey, in the fore leg of the horse, in the wing of the bat, and in the flipper of the seal, are of special use to these animals. We may safely attribute these structures to inheritance.

I find this story particularly compelling because it illustrates the nub and essence of intellectual revolution in such an incisive, almost joyous, manner. Consider the two possibilities of Bell's conceptual domain as a classic dichotomy—opposite ends of single line. His world is one-dimensional. An organ is either created for function at one end of the line, or created as a step in an ordered series at the other end. Darwin's revolution is so simple in one way, so profound in another: he literally added a new dimension—the dimension of history. Darwin freed himself from the restricted world of Bell's line: he lifted himself above, into a space that did not exist for Bell. By adding a dimension of historical change, Darwin realized that an organ might arise as an adaptation and then, in descendants, be transformed to some other function (jawbones to ear bones), or inherited as a vestige of reduced utility (splint bones of horses).

Our literature's best illustration of conceptual revolution as added dimensionality may be found in a great classic of nineteenth-century science fiction—E. A. Abbot's *Flattland.* The inhabitants of Flattland live on a surface in a two-dimensional world. They have no concept of our third dimension or of anything else beyond. They know their own world adequately well, though often by means that seem inefficient or indirect to those who live in a universe of three dimensions. (For example, Flattlanders cannot "see" the shapes of objects all at once, and must learn which of their members are squares, and which pentagons or hexagons, by feeling their way all around.) One day, a sphere from the world of three dimensions visits Flattland. (He enters by passing through their plane and is therefore perceived by them as a circle that first grows bigger and then smaller.) The sphere eventually lifts the leader of Flattland off the surface of his world into the third dimension, where he can view the entire plane of his former universe all at once. Imagine the thrill, and the confusion, of such a novel perspective!

Darwin added this new, bird's-eye view to the domain of biology. Evolution gave us the dimension of history, thereby enriching our conceptual world through one of the most elegant and beautiful revolutions in all human thought. We are still struggling to make our peace with this new dimension of nature's truth. What else are we missing—what else have we yet to see as we confront multifaceted nature with that genealogically restricted, yet somehow remarkable, tool called the human brain?

Stephen Jay Gould teaches biology, geology, and the history of science at Harvard University.