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Mythology in Introductory Biology

The introductory course is the face we biologists present to the world. Far more people take introductory courses than our more specialized offerings. Both the opinion in which we are held and the character of the people who choose to pursue biology are determined by these courses.

I contend that we present a shabby façade, however great the intrinsic interest of biology or the attractive style of the instructor. I am concerned that we may present biology as a mass of terminology, revealed truth, and thinly disguised inconsistency, rather than as an honest and substantial activity. Does a bright student, on completion of a course, have some notion of how a person might find a lifetime of fascination in biology?

I am a biologist in spite of, not because of, the first college course I took; an informal poll of colleagues and graduate students indicates that my experience was typical. Although I routinely review new texts as they appear and have done editorial work for quite a few, there are none that I would recommend to someone curious about biology. To the extent that they reflect classroom and laboratory practice, I find them depressing.

It has been 20 years since I first taught a general course, and I want to mark the occasion curmudgeonly with this diatribe. Following, then, is a list of complaints about the presentation of basic biology. These are interspersed with a few positive suggestions. Little documentation is offered – offending specific authors and publishers serves little purpose.

Basic Definitions

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The term *protoplasm* is unaccountably persistent in textbooks. Garrett Hardin (1956) said this term is understandable only as a hangover of vitalism or an accident of linguistic convenience. We certainly shouldn't tacitly encourage vitalism, and we ought to avoid promulgating a bit of meaningless jargon.

Respiration is typically defined as a process involving the consumption of oxygen. Within a few pages, texts then treat *anaerobic respiration*, quite unembarrassed by having just defined the latter out of existence.

Cellular respiration is apposed to and then contrasted with photosynthesis. One is catabolic, the other anabolic; one is done by animals (and perhaps Pasteur's yeast), the other by plants. The student is commonly left with the impression that only plants can synthesize large molecules (except proteins) and that only animals respire.

The polite fiction of *high-energy bonds* is maintained. The energy is neither high nor in the bonds. (The carbon-carbon covalent bond energy is about 100 kcal/mole compared with the 7-12 kcal attending hydrolysis of ATP's terminal phosphates). In fact, it is advantageous that energy is stored in fairly small packets. Perhaps one ought just to state that the second and third phosphate groups of ATP are unusually easy to hydrolyze, thereby transferring a packet of energy of convenient size for dealing with enzymatic reactions.

Reference is continually made to *the* 20 *amino acids*. In fact, amino acids are a limitless class; what is meant is the 20 particular alpha-amino acids whose incorporation into polypeptides is directly specified by the genetic code. Gamma-amino butyric acid is, after all, an important molecule in our neurochemistry; it just is not part of any protein.

Cells and their Operation

The *cell doctrine* is often taken as the notion that organisms are made of cells. The intellectual leap of its originators was the broader idea that a cell was a fundamental functional unit with some degree of autonomy. There is more extracellular material around than we commonly admit; indeed the mass of living cells is a minor fraction of organisms such as sea anemones and trees. While organisms may not be made strictly of cells, they are clearly made by cells developmentally, and they exist for cells evolutionarily.

Even more common is a related sin of omission, the failure to ask the question: why cells? As organisms enlarged, why was cellular organization retained, with cell operation coordinated in a sort of federation? Arguments for a cellular scheme can be based on the ideas of informational economy (in making large creatures through the use of standardized sub-assemblies), on the limitations of diffusion as a transport mechanism, or on the changing ratio of membrane area to volume. But we tend to ignore abstractions, hypothetical arguments, and uncertainties in our philosophically impoverished courses.

Discussions of *diffusion* usually lead to misleading demonstrations. If a bottle of perfume is opened or a drop of dye is placed in water, convection or bulk flow, not diffusion, is primarily responsible for the spreading. A more honest demonstration shows how ineffective diffusion is over appreciable distances. At different times beginning the day before a lecture, I pour a dye solution into beakers half-filled with household gelatin or agar. During the lecture I can comment on the downward penetration of the formless dye blurs. The critical point is the peculiarity of a process in which (on the average) the time taken to get somewhere is proportional, not to the distance, but to the square of the distance.

Mitosis is typically presented in some detail and then contrasted with meiosis. There is little stress on what it accomplishes in apportioning not just an appropriate number of chromosomes to each daughter, but one of each homologous pair. No other organelles are divided up in any analogous manner. This observation is persuasive evidence for an informational role of chromosomes.

Mitochondria are introduced with a drawing or transmission electron micrograph that shows them as two to four times as long as they are wide. Forgotten is the origin of the name, meaning filamentous bodies, and the fact that the micrographs are very thin, two-dimensional slices of reality. Perhaps one ought to discuss how a thin slice of spaghetti in jello might appear, and talk further about interpretation of microscope images.

Mechanics of Life

Homeostasis is presented as some special property of living systems, despite the ubiquity of goal-directed machines involving nothing stranger than negative feedback. Furthermore, even in Cannon's (1932) original statement, it is unclear whether the word applies to a state, a process, or some odd tendency; the vitalistic odor is unmistakable. Social scientists have now discovered homeostasis. We should bequeath it to them and face up to the real world of systems analysis.

Feedback is unquestionably crucial in the operation of living systems. But even at the simplest level there are two entirely distinct sorts of feedback, negative and positive. Too often, *feedback* is equated with negative feedback. When specifically mentioned, positive feedback gets labelled as pathological. Where negative feedback is appropriate, positive is seen as clearly disastrous. But positive feedback has diverse biological applications as amplifier or synchronizer, driving a process to completion or ensuring simultaneity. Examples include the synchronizing of events prior to insect molting and in the shedding of gametes of some marine worms. In humans, it assures full and complete bouts of urination and defecation. Even evolution itself can be viewed as a positive feedback scheme – greater reproductive success increases the representation of an individual's genetic material, which can compound that success in the next generation.

The term *dynamic equilibrium* is widely used in reference to situations that are most definitely not equilibria in any physical sense. What we mean are steady states that are not at equilibrium. If we begin by introducing the notion of equilibrium, and noting its lack of biological relevance, we can be consistent with practices elsewhere in science. We can then discuss ways both active (negative feedback) and passive (isolation or buffering) processes maintain steady states.

The inverse relationship that exists between *specific metabolic rate* and *body mass* is attributed to the problem of heat loss and the similar inverse relationship between surface-to-volume ratio and body mass. That may be fine for homeotherms (or endotherms), but it conveniently ignores the similar relationship found in poikilotherms (or ectotherms). Schmidt–Nielsen (1984) has a good discussion of the matter.

Although most courses mention that organisms specifically, and biological systems more generally, span an enormous range of sizes, the usual course hardly considers the implications. Not just surface-to-volume ratios, but transport systems, weight-bearing systems, locomotory systems, behavior, and even reproductive arrangement are critically size dependent. Went (1968) wrote an engaging article on the subject; Haldane (1927) and D'Arcy Thompson (1942) are classics, and recently an accessible new account (McMahon and Bonner 1983) has appeared.

The Nervous System

Typically, more class time and text space is given to nerve axons than to synapses, a situation analogous to analyzing a radio with great attention to the way wires work and little to the operation of the components the wires connect. Enough detail is given about ionic composition and flow to obscure the main message – that with standardized impulses only the arrival of an impulse or the interpulse interval can convey information. Selection and transformation of information happens at synapses, so without a decent treatment of synaptic properties any connection between nerves and behavior is just a statement of faith.

The usual explanation of the resting potential of axons is substantially in error. It bases the potential on a separation of charge, with more positive ions outside and more negative ones inside. What is out of balance are transmembrane mobilities.

The effect of the indiffusible anions inside on the outward diffusion of potassium cations appears as a negative potential inside. (A pleasant introduction to the ionic events is Hodgkin's [1964] Nobel Prize lecture). To worsen matters, resting potentials are ascribed to neurons with little indication that they are general in living cells. A demonstration of cellular potentials with plastic pipe, silver wire, dialysis membrane, and a voltmeter (Vogel and Ewel 1972) can dispell the idea that these potentials are a special property of living cells.

Evolution

Darwin is sometimes casually considered the originator of the notion of *evolution* rather than the codiscoverer of the specific mechanism that now goes by the designation of *natural selection*. It is also unfair to hold him liable for social Darwinism.

The *Lamarckian mechanism* for *evolution* is given scornful treatment and sometimes even declared impossible. (Lamarck's actual views are put in context by Jacob [1973]). The Lamarckian mechanism is not unreasonable; it just doesn't seem to be used by known organisms. The reasons were not at all clear more than a century ago.

By contrast, the experiment in which the tails of successive generations of rats were amputated is accounted a grand success in disproving the *inheritance of acquired characteristics*. If the results had been otherwise, indeed the converse would have been demonstrated; but in inductive logic one can only falsify a general proposition. I contend that the rats were wasted, inasmuch as certain lineages of humans have been removing the foreskins of male infants for many generations without any indication of progress toward eradicating the condition.

Explanations of *adaptations* frequently hinge on arguments that organisms act for the good of their species. By using this nonobvious, nontrivial, and generally discredited extrapolation of natural selection, we obscure the absence of a real explanation. The rampant references to good-of-the-species arguments in the popular literature on biology testify to our failure in communication.

Organisms and structures are called either *primitive* or *advanced* begging several questions. In particular, someone might someday ask why, after all the evolutionary advances we describe as life ascends toward ourselves, there are any simple forms left. It would seem a far better practice to contrast *primitive* with *derived* or *generalized* with *specialized.*

The biological species concept is presented *ex cathedra*; the innumerable difficulties in its application (see, e.g. Sokal and Crovello 1970) are not mentioned, nor are ideas as to how the discreteness of species might be maintained by mechanisms such as parallel selection rather than by gene flow. And the problems of speciation are swept under the rug.

All too commonly, the only justification given for any phylogenetic reconstruction is Ernst Haeckel's old biogenetic law given as "ontogeny recapitulates phylogeny." Never mind that we beg the question of why development should not itself be subject to selection and ignore the total failure of the Haeckelian dogma in such major groups as plants and insects. Not that the issue is quite dead – Gould (1977) wrote a book on the subject. Interestingly, the anthithetical phenomenon, neoteny, is rarely mentioned, despite reasonable arguments that we are, in part, neotenously derived from our apish forebears and that neoteny is important in deriving the relationships among primitive chordates.

Pyramids

In talking of ecology, pyramids of *energy content* are confused with (or substituted for) pyramids of *energy flow*. The former are just minor variants of pyramids of biomass, and despite categorical statements in many texts, thermodynamics does not dictate any taper in successively higher levels. In fact, stable cases are known in which the standing crop at one trophic level is less than that above it. A pyramid of energy flow, by contrast, must taper. The confusion hinges on the differences between standing crop and productivity. At issue is the difference between an amount and a rate of change, one of the fundamental notions of calculus.

For another sort of pyramid, I would like to point out that a population pyramid that tapers for increasingly aged cohorts should not be presumed automatic evidence of a growing population. Although a columnar shape to ages beyond reproduction indicates a stationary population, the tapering pyramid may simply follow from relatively age-independent mortality and was almost certainly characteristic of our species through most of its history. The growth rate of humankind was slight until quite recently, as one can demonstrate by extrapolating the present rate backward. One gets the absurd result that the species originated approximately a thousand years ago!

Sex

We commonly communicate the notion that human characteristics are normal, other species are aberrant. For example, texts imply that heterogametic sex is automatically male (sperm-producing or microgametic), despite the opposite arrangements in birds and lepidoptera. They also imply that sex is inevitably determined by genetic (as opposed to epigenetic) differences, despite phenomena such as sex reversal and occasional divergence of chromosomal and phenotypic sex, even in humans. It is implied that the 1:1 sex ratio is an automatic consequence of meiosis and the apportionment of X and Y chromosomes, despite ratios other than 1:1 in many organisms with 'ordinary' systems of sex determination and despite arguments going back to population geneticist R A Fischer on the way selection commonly fixes the ratio. There is little mention of the rarity of cases in which postreproductive individuals persist. Finally, the relative rarity of species with males larger than females is ignored.

Indeed, most of the explanations of why most organisms engage in recombination or *sex* at some point in their life cycles usually reduce to the good-of-the-species. The prevailing uncertainty about the specific connection between sex and individual fitness is no reason to ignore the issue.

The Language of Biology

In general, chemistry gets far better and more extensive treatment in biology courses than does *physics*. Yet the immediate world of an organism is as much determined by physical rules as by the chemistry of the earth's surface. The applicability of the rules may be scale dependent, so discussing the biological implications of size is a decent context for talking about gravitation (big organisms find it a major matter, for the small ones it is trivial) and surface tension (with rather the opposite range of relevance). The physical side of reality is easy to explain using intuitive experience and simple demonstrations. The only difficult physical concept we need is energy, coincidentally the only one that is never ignored.

Finally, let me address the terminological jungle of introductory courses. The typical course has been said to introduce 1600 terms, a number exceeding the vocabulary of a first-year course in a foreign language. With such baggage, how can concepts and controversies ever get decent attention? Most of the names we present (e.g., the 12 cranial nerves) are inappropriate for introductory courses and most emphatically inappropriate for courses aimed at nonmajors. Because most courses use multiple-choice examinations, testing is biased (if unconsciously) towards terminology; and students inevitably (if equally unconsciously) take our examinations as powerful statements of what we consider important.

Bigger Problems

In listing relatively specific ills of introductory courses, I do not mean to imply that more general problems are lacking. But they are more controversial, and their solutions less self-evident. More difficult are the issues of what general topics to include and in what order to present them. The current crop of textbooks is of little help – they are too uniform and too encyclopedic, as if every publisher has nightmares that a bit of selectivity or eclecticism might be maladaptively maladoptive. I certainly do not mean to suggest that some high-level commission establish a new (and presumably exciting) approach. Little is gained by uniformity among versions of introductory biology, and there is always the danger of some new and merely different orthodoxy emerging. Conversely, individual instructors may benefit from the process of deciding what is worthwhile and of searching out some satisfying inner logic of the subject. What might be useful, though, is wider dissemination of the particulars of courses with unusual content or organization.

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