Hugh’s book and Krogh’s animals: biodiversity and textbook examples in teaching

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Robischon M. Hugh’s book and Krogh’s animals: biodiversity and textbook examples in teaching. Adv Physiol Educ 38: 195–198, 2014; doi:10.1152/advan.00042.2014.—The medieval simile of the world as a book seems to anticipate modern notions of biodiversity as a key to insights and learning. This thought is translated into the practice of research in the August Krogh principle, which provides argumentative support for researchers who dare to venture beyond the range of commonly used models by choosing a new experimental organism for a particular scientific question. Established model organisms often hold high exploratory power to the researcher yet little explanatory power to the student, in particular when represented in a secondary source. This essay puts forward the suggestion that Krogh’s principle applies to the use of organisms as instructional models and textbook examples too and encourages educators to continuously venture beyond established illustrative teaching examples in a continuous exploration of the “book of the world” and the “treasure house of nature.”

August Krogh; Hugh of St. Victor; model organisms; instructional examples; textbook examples; illustrative and explanatory models; biodiversity; Lamarck’s giraffe; construction of knowledge

“THE WORLD IS A BOOK…” Hugh of St. Victor (c. 1097–1141) writes, “in which every creature is a word charged with meaning” (33). The words of the 12th century scholar strikingly anticipate the modern view of the value of biodiversity as a source of insights. A translation of this notion into the practice of research, phrased in a 1929 article (17) by Danish physiologist August Krogh (1874–1949) and relaunched into scientific discourse by Hans Krebs (1900–1981) in the 1970s (14, 15) says that “For a large number of problems there will be some animal of choice, or a few such animals, on which it can be most conveniently studied.” What became known as “Krogh’s principle” and is increasingly quoted in current papers (12, 22, 28, 29, 38) is but one expression of reasoning found in the work of other authors too (16) and that was, while not formulated verbally, exemplified in practice all through the history of science. It manifests itself in Marcello Malpighi’s work on guinea pigs in the 17th century, in Abraham Trembley’s use of the Hydra in the 18th century, in Marie von Chauvin’s studies with axolotl in the 19th century, or Ernest Castle’s first experiments on Drosophila at the onset of the 20th century. Still well into the 21st century, as addressed by Jørgensen (12), the success in finding “the solution of a physiological problem often depended on ‘the happy choice of an animal,’” quasi-paraphrasing Gregor Mendel’s statement that “the value and utility of any experiment are determined by the fitness of the material to the purpose for which it is used…” (21).

In taking the first steps in a given field, it is, in many cases, advisable to think big. Krebs (14) in his discussion of the August Krogh principle names several examples of experimental organisms in which “one of the decisive advantages is the mere size of the material, so that manipulations can become easier,” including giant water bugs, the giant unicellular alga Acetabularia, Bufo marinus (also known as the giant Neotropical toad), and the three-spined stickleback (the largest of all sticklebacks), Diptera for their giant chromosomes, and squids for their giant axons. “Standing on the shoulders of giants…,” we can obtain an overview and insights into a world otherwise invisible to us. Sometimes, however, considering the practicalities of laboratory work, small is also beautiful (37). Yet it is not only size that matters. Any organism’s phenotype tells a tale of the ecological and evolutionary forces shaping it. “It often turns out that animals living under extreme conditions provide excellent avenues to understand a given scientific problem” by virtue of their phenotypes (31). Researchers who add yet another unusual research object frequently refer to “the August Krogh principle at work” (22). So did, for example, Hochachka (9), in discussing work on the protein biochemistry of abyssal organisms, so did Gerhold et al. (6), in working “in the spirit of this approach” on such an exquisite example as the star-nosed mole, and so did this author, as the sole PhD student working on hybrid poplar in a department where virtually everyone else was studying Arabidopsis.

Physiology’s Next Top Model

Some of these experimental organisms historically developed into genuine model organisms. Traits that qualify for such a role include an ease of propagation and simple maintenance, short generation times, or a small genome. These include Drosophila (“the fly”), Arabidopsis (“the weed”), and Caenorhabditis elegans (“the worm”) as well as proverbial laboratory rats, the fungus Neurospora crassa (“an early darling of formal geneticists”) (5), and Escherichia coli (“the workhorse of recombinant DNA technology”) (10). They are joined by an increasing, although still relatively small, number of other species that contribute to opening new pages in the history of biology. Many modern model organisms are, according to Satterlie et al. (29), “rather strange and obscure to non-biologists,” yet they are often less spectacular, sometimes quite unprepossessing, and, in fact, not too memorable to the non-expert.

Some of them are easy enough to work with in classroom teaching, blending in with a suite of organisms that provide for classical demonstration and teaching laboratory experiments, such as the red onion, with its peel being used for demonstrating plasmolysis and deplasmolysis and for calculations of...
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osalxic, for its stomatal opening after poisoning with fusicoccin, or wheat sprouts, for the ease of measuring nitrate oxidase activity.

Even though there is a great potential to develop new classroom models, the number of organisms that can be brought into the classroom in real life will always be limited due to mere practicalities but also as a result of growing concern for animal welfare and the respective legislation.

Textbook Examples

In a teaching context, it is often impossible to provide real-life experience to generate knowledge from direct observation. In many cases, therefore, the underlying concepts and theories are taught without observations or empiric systems. Oftentimes, the central tool for students to explore the world is a book.

With the knowledge generated in original research diffusing via university- and college-level teaching into other domains of education, the “picture” of the respective experimental system or chosen experimental model organism also migrates into classroom teaching and college or high school textbooks.

Teaching, or the presentation and communication of new concepts in physiology and biology, has always involved choosing certain organisms as models to explain theoretically and to illustrate the respective theory detached from experimental and empiric data in texts or drawings. What brings life to such theoretical contents is the “happy choice” of examples, which are referred to by some authors as instructional examples and by others as illustrative models, “exemplary organisms,” “representative models,” “case studies,” or “type organisms” (7, 11, 39). All these terms are not too well defined, and usage by different authors certainly overlaps. In the cases that are addressed here, a good description would be the term “textbook example.” Closely correlated appears the term of a “living model,” which typically appears in a paleobiological context (34). Bonobos, according to Moscovice (24), “may provide one of the best living models to explore the evolution of flexible social bonding in humans.” Their chimpanzee relatives “are the best living model” for the last common ancestor of humans and apes (25) and, therefore, “are commonly used as a living model for the ancestors of our genus” (8).

Teaching further into our past, paleoanthropologist Ian Tattersall (35) pointed up the family tree, where we may spot in the heights of distant branches an arboreal creature resembling the tree shrew, an animal that has “regularly been held up as a ‘living model’ of the ‘ancestral primate’.”

The term “living model” for an organism that embodies a living image of something that we cannot see directly, that serves as a model after which we construct a mental picture, may well be figuratively used with reference to textbook examples and in the context of representation of a theoretical concept that has to be brought to life and has to brought close to a reader or student. While it is a disadvantage for model organisms in experimental work to be “emotive” (23, 37), quite the opposite is surely true for textbook examples. In fact, ideally, both teacher and student should be captivated by that particular organism, for emotions color our thinking of living organisms and trigger epistemic curiosity.

The Long Shadow of the Giraffe

An outstanding example is the giraffe, as shown by Jean-Baptiste Lamarck (1744–1829), in a situation that “requires the animal to browse on the foliage of trees and constantly to try hard to reach that foliage. As a result of this habit, maintained for a long time in all the individuals of its race, the animal’s front limbs have become longer than those at the back, and its neck has grown longer...”

Hardly any contemporary reader of the Philosophie Zoologique would have seen a live giraffe when the book was first published. Even its author probably never did either. Tragically, when the much-beloved Zarafa arrived in the Jardin des Plantes, Lamarck had already been blind for years (1, 4).

Nevertheless, the giraffe turned out to be more memorable than the equally charming hydrophobic shorebird with its telescopic neck and feet, which “wishing to act in such a way that its body does not sink in liquid, makes every effort to extend and lengthen its feet” and “wishing to fish without getting its body wet, is required to make continual efforts to lengthen its neck” (18).

The heritability of acquired features, long considered a far stretch, appears now, in the light of recent epigenetic insights, not too unreasonable. The giraffe, however, is from our current standpoint a suboptimal model to illustrate such phenomena. In the 19th century however, it was surely a brilliant explanatory example, which is also evident from the fact that it is used to illustrate Lamarckian thinking to our days. In their textbooks, students still encounter shorebirds and giraffes, the former for their system of maintaining thermobalance when wading in icy water and the latter for its blood pressure and the number of its vertebrae being equal to the one in a mouse.

Most of today’s students of biology have not seen a live Darwin finch, let alone the full baker’s dozen of their species fanning out in adaptive radiation over the Galapagos archipelago. Nevertheless, Geospizinae belong to the collection of classic textbook example organisms that students are likely to remember, perhaps alongside other “adaptive radiators,” such as the Hawaiian Honeycreepers or African ciclidls, or tenrecs, porcupines, hedgehogs, and echidnas for convergent evolution. Students are not likely to encounter those either, depending on where they live, and are thus dependent on secondary representations.

Sometimes--horribile dictu!--the most plausible and most memorable examples do not stand the test of science. Typically, the circumpolar herring gull complex is used to explain the phenomenon of ring species and the concept of “speciation by force of distance” (20), even though this is, as molecular data have shown, not strictly a ring species (19). The peppered moth’s industrial melanism as an example for “survival of the best fitted” is equally debated. Although it is a good model in terms of being easy memorable, there may be others that fit more to the current state of the art in evolutionary biology.

These and many more are already classic “instructional examples” worldwide. However, similar to experimental or model organisms in research and model organisms used in class, those presented in the form of textbook examples are also limited to a relatively small collection.
**The Storehouse of Adaptive Solutions**

Many authors call for consideration of a larger variety of experimental and model organisms in research and particularly research funding (3, 37, 38). “There’s more to life than rats and flies,” Jessica Bolker (2) commented, arguing that “studying only a few organisms limits science to the answers that those organisms can provide,” pointing to a “need to broaden our range of models to include species such as the Antarctic ice fish, comb jellies, cichlids, dune mice and finches...” This list could be expanded ad libitum.

However, even scientists are “often unaware of the possibilities offered by biodiversity,” as Schwenk et al. (30) pointed out, calling for “utilizing the functional diversity of organisms,” referring to “biodiversity as a storehouse of adaptive solutions to environmental and other problems.” In the words of Schwenck et al. (30), “biodiversity represents a vast, irreplaceable repository of genetic, biochemical, physiological, anatomical, functional and behavioural strategies with high intrinsic interest and demonstrated value”—and one may add “demonstrative value.” Tranter (36) translated this into a call for a wider range of organisms used in laboratory classes, criticizing that “In too many schools, the wealth of living or once-living organisms which pupils are required to study is often reduced to little more than the geranium and the potato.”

Often, the value and utility of a class or lecture are determined by the fitness of the example to the purpose for which it is used. Wishing to act in such a way that we support any student in his or her work in constructing their knowledge, we make every effort to provide the very best examples and models on which a given topic can be most conveniently studied. In this effort, the potential of unusual models to open an avenue to understanding a given scientific problem has to be recognized not only by researcher but also by educators.

While a number of superb examples are commonly used and proven in the practice of any experienced teacher or lecturer, it must not be forgotten that “studying only a few organisms” limits not only science but also teaching “to the answers that those organisms can provide” and that not only research but also teaching will greatly profit from an ongoing search for better examples in parallel and fuelled by the continuous arising of new topics in science. Just as with research model organisms, or organisms used for coursework, the variety of textbook example organisms needs to be expanded and developed.

In the spirit of Krogh’s principle and bearing in mind Hugh’s metaphor of the world as a book it is suggested here, that for any given biological topic, there may be one or more organisms by which this problem can be most conveniently taught.

**Brought Up in Contact With the Treasure House of Nature**

“How do we get hold of the most suitable species?” Krebs (14) asks, with respect to experimental research. Köppel and Manley (13) echoed “How does one decide which animal is the ‘right’ one?” Krebs (1975) referred this question to J. W. S. Pringle (27), who stated that “zoological, rather than physiological and biochemical training, helps because a zoologist has been brought up in contact with the ‘treasure house of nature’...” “We must apply to the zoologist to find them,” Krogh (17) answered, and, surely, one must add, to the botanist and microbiologist, as contacts to turn to for finding the best textbook examples.

Dialogue between research and teaching at all levels is the key in finding a good type organism in which a theoretical model is recognized and represented. Such a dialogue is at least partly achieved by journals such as this one. To make this dialogue truly fruitful in terms of providing the best illustrative examples for teaching, it needs critical questioning of examples in current use and acceptance of the fact that principles that may have been discovered in one model organism are potentially better explained in a different one.

It needs enthusiasm for the weird and wonderful, and an appreciation for the fearsome reptile, the bizarre beauty of mollusks, or the discomforting behavior of certain spiders and praying mantises. It calls for “biological literacy” and the ability to translate hard science into a captivating and colourful story. It requires biology teachers to be exceptionally curious and to “make every effort to extend” their knowledge of the odd and exceptional and to constantly search for those “mechanisms and adaptations of exquisite beauty and the most surprising character” admired by Krogh (17). It will turn the teacher or educator at times into an armchair traveller and explorer, searching in the most unusual ecological niches and among the creatures showing the most extraordinary adaptations and habits, and often, again, the gateway to the variety of the biological world is a book.

Wishing to fish for the best examples, one may find the giant lungfish, which lives in the interior of Africa and dwells in waters that are warm and low in oxygen, or may reach down deep into the icy and oxygen-rich circumantarctic ocean, where the icefish lives. Lungfish and icefish are quite impossible to bring into a lecture theatre or teaching laboratory alive, and nothing is in fact conveniently studied about them. They do, however, generously lend themselves to be used as a teaching example for diffusion in biological systems (28).

So does the blobfish, as a beautiful example of adaptation to high ambient pressure. Removed from its hyperbaric environment, its body is as deformed and collapsed, as shown in pictures of the allegedly ugliest creature on earth (23).

Or the flightless birds of oceanic islands, supported by the New Zealand short-tailed bats, which are slow flying but fast walking, as an example of ecological naiveté and for the evolution of energy-efficient lifestyles.

Or in the plant world, the shoot- or root-promoting effect of growth regulators cytokinin and auxin, as illustrated by the higher or lower levels in shootless orchids and rootless bromeliads, respectively (26).

Like the necks and legs of the Lamarckian giraffes and shorebirds, this series of examples could be extended on and on and over endless pages. Any one species, any one organism, will one day, once appropriate techniques of research are available and the right scientific questions have been asked, show a unique feature and reveal another word in the book of the world. It could be concluded, in the words of Hugh of St. Victor (33), “All nature teaches the human being. All of nature brings forth reason.”

**DISCLOSURES**

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AUTHOR CONTRIBUTIONS

Author contributions: M.R. conception and design of research; M.R. performed experiments; M.R. analyzed data; M.R. interpreted results of experiments; M.R. prepared figures; M.R. drafted manuscript; M.R. edited and revised manuscript; M.R. approved final version of manuscript.

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