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Feature
Book Review

Integrating Concepts in Biology: A Model for More Effective Ways to Introduce Students to Biology

Review of: *Integrating Concepts in Biology*, by A. Malcolm Campbell, Laurie J. Heyer, and Christopher J. Paradise; 2014; Trunity.com eBook; www.trunity.com/products/digital-textbooks/integrating-concepts-in-biology; ISBN-13: 978-1-63097-008-6

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Integrating Concepts in Biology (*ICB*) is the apt title of this groundbreaking electronic textbook (see Supplemental Material). The target audience is students seeking an introduction to biology. It is structured to focus student attention on key concepts underlying biology at all levels of organization. In contrast to the current encyclopedic model of an introductory textbook, this e-book makes effective use of electronically linked text and online resources, selects examples to explore in depth, and offers students means to deepen their understanding. It explicitly uses current ideas about student learning, supported by evidence of best practices, to help students develop as biologically literate thinkers. The authors are colleagues at Davidson College: biologists A. Malcolm Campbell (cellular and molecular biology) and Christopher J. Paradise (ecology) and mathematician/computer scientist/bioinformaticist Laurie J. Heyer. They share a common passion for innovative pedagogy and multidisciplinarity, and *ICB* is their laudable effort to address many of the widely recognized problems evident in introductory biology texts and introductory courses and explored in recent reports such as *BIO2010* (National Research Council [NRC], 2003) and *Vision and Change in Undergraduate Biology Education* (American Association for the Advancement of Science, 2011).

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Conflict of interest: K.N.P. attended Davidson College from 1967 to 1971 and is a loyal alumnus; all the authors are Davidson College professors, but K.N.P. has never met or corresponded with any of them.
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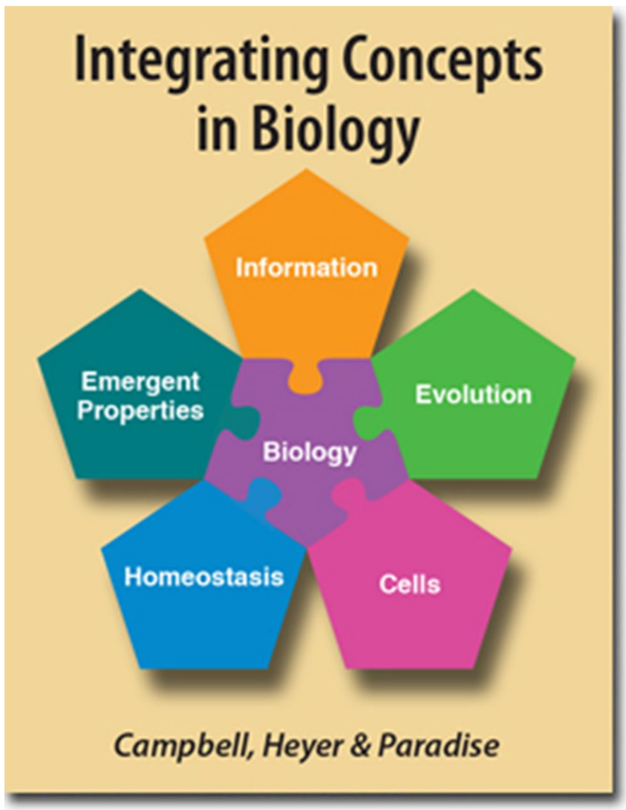
THE TEXT

ICB is organized to emphasize the unity of biological science across the size/complexity hierarchy. It focuses students on five unifying themes ("big ideas"): information, evolution, cells, homeostasis, and emergent properties. The text is divided into 10 major sections, five of which center on



A

you are here		Big Ideas of biology				
		Information	Evolution	Cells	Homeostasis	Emergent Properties
levels of the biological hierarchy	molecules	1	4	7	10	13
	cells	2	5	8	11	14
	organisms I	3	6	9	12	15
	organisms II	16	19	22	28	25
	populations	17	20	23	29	26
	ecological systems	18	21	24	30	27

B

you are here		Big Ideas of biology				
		Information	Evolution	Cells	Homeostasis	Emergent Properties
levels of the biological hierarchy	molecules	1	4	7	10	13
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	ecological systems	18	21	24	30	27

Figure 1. Graphics allow students to discern the relationship between material presently under consideration (green) with regard to the five "big ideas" (yellow) and level of the biological hierarchy (blue). Both examples are for chapters that center on information. The organization fits a two-semester course focusing first on molecular, cellular, and organismal biology (top three rows) and then on organisms and ecology (lower three rows), with each semester beginning with information and progressing to emergent properties. (A) The graphic for chapter 1, "Information in Molecules and Cells." (B) The graphic for chapter 3, "Reproduction and Cell Division."

each of the "big ideas" at the molecular, cellular, and organ system levels, with the other five examining the "big ideas" at organismal through ecosystem levels. This division is designed to allow *ICB* to be used in a typical two-semester introductory sequence. Each of the 10 sections consists of three chapters. For example, the grouping Information in Molecules and Cells contains chapters 1–3, respectively titled "Heritable Material" (molecules), "Central Dogma" (cells), and "Reproduction and Cell Division" (cells and organisms). An overview of the text's structure is encapsulated in a graphic shown at the top of the main page for each chapter (Figure 1).

Each of *ICB*'s 30 chapters is subdivided into approximately three sections of text focused on an interesting question ("Can non-living objects compete and grow?") that often has implications beyond biology ("Why is [the herbicide] paraquat used in America but illegal in Europe?"). Chapter sections contain about the right amount of material to form the nucleus of one class period. Content is focused on important examples of what the authors consider to be illustrations of the five big ideas around which the text is organized. The examples are carefully chosen, and they are expounded in a way that encourages students to engage data using the same processes as a practicing biologist. There is far less emphasis on new vocabulary and often less detail than would be seen in a more traditional text. For example, complicated pathways (e.g., glycolysis, Krebs cycle, mitochondrial electron transport, photosynthesis) are reduced to their most salient features (few individual reactions are considered). Accompanying this "bare-bones" description are some of the data used by the two Krebs and their coworkers to discover that the mitochondrial citric acid pathway was actually a cycle. Students are guided through the data and encouraged to add to what they were told about metabolism and develop a sense of how biochemists come to understand the operation of complex pathways. Likewise, the general function of ATP synthase is sketched out, but it is accompanied by a series of questions and online resources that help students understand how the structure and function of this complex molecule have been (and are being) worked out. At various points in each section, students are prompted to make connections and build on what they learned previously (e.g., apply knowledge of the mitochondrial electron transport system and chemiosmosis to interpretation of data dealing with chloroplasts and the light reactions). At the end of each section, review questions are presented. The goal is to provide gentle guidance and inspiration as students construct their own knowledge base and develop their analytical skills.

Nearly all chapters include one or more Bio-Math Explorations (BMEs), and all have at least one Ethical, Legal, Social Implications (ELSI) section. These are well integrated with the rest of the text. The BMEs introduce students to quantification, the uses of statistics to summarize and interpret data, and mathematical models and other tools. They are often accompanied with spreadsheets for making repetitive calculations and/or they make use of linked simulations. BMEs vary in difficulty from easily manageable (e.g., a worksheet calculation of a Shannon [ecological] diversity index) to challenging (e.g., "How can you quantify a pattern in a gene sequence?"), and they are unusually sophisticated for an introductory course (e.g., "How can you count animals you cannot see?" goes beyond the commonly taught Lincoln index). Likewise, the ELSI sections are thought provoking and likely to engage many students in out-of-class discussions (e.g., "What are the consequences of performance-enhancing drugs?," which is coupled with another ELSI: "If pills could make you remember or forget, would you take them?"). They are similar in construction to those seen in typical introductory texts, but they are far more central to the design of the course. Prominence and use generates student discussion; we believe that is why the ELSIs are likely to succeed and are an unflinching part of the approach taken in *ICB*—they are not an afterthought or simple enrichment exercises.

The text is written in a more colloquial style than is typical. The authors state that they hope this will improve accessibility and student engagement in the reading. We differed in our views as to whether this is appropriate. Students will likely find the informal, less jargon-burdened text easy to read. But one can argue that learning to read more difficult texts is a skill that should begin early in a student's career. And, although reduction in the number of terms introductory students encounter seems to be a worthy goal, what is appropriate for one instructional setting might be less so for another.

The use of hypertext and illustration is very effective. The illustrations are clear. They serve to advance points made by the text and are helpful in developing a student's ability to visualize processes (e.g., what happens when a three-dimensional object is shown as sliced sections). Hypertext was used to give definitions of all important terms (click on the word and see the definition); to lead a student to connected sections for review or preview; and to effectively link the text with Web-based resources such as simulations, animations, movies, and appropriate examples of primary literature (although some of these articles were not open access). The number and types of hyperlinks represented a good balance between assisting informed student discovery without simply revealing the answers. One small complaint is that it would be useful if the elements of the navigation graphic (Figure 1) were electronically linked to the corresponding chapters. Additional comments on the use of hypertext and general functionality of the e-text can be found in the Supplemental Material.

The presentation of material was, for the most part, clear and accurate. Some (perhaps inevitable) issues of accuracy or emphasis can nevertheless be found. For example, in chapter 9 ("Neurons and Muscles") the text seems (incorrectly) to attribute resting potentials to the electrogenic nature of the Na^+/K^+ ATPase—whereas a linked animation correctly explains the central role of membrane permeability and ion concentration differences. Another concern arises from the designation of the term "homeostasis" as a unifying theme. Homeostasis requires biological mechanisms that serve to confine the states of some variable to a small range of values in the face of a wider range of environmental perturbation. Chapter 29 ("Population Homeostasis") seems to lead students to conclude that population sizes are regulated homeostatically through density-dependent effects on births and deaths. Most population ecologists endorse the notion of density-dependent "equilibrial" population sizes (usually called *carrying capacities*) that exist for a specific set of environmental conditions. But change the broad environmental conditions and the carrying capacity immediately changes (think of the history of human populations and technologies), unlike what is observed in homeostasis. We suggest that a more globally unifying "big idea" is regulation; this broader term better allows concepts such as equilibrium, regulation, and homeostasis (a relatively uncommon condition) to be explored and distinguished from one another.

In a few other places, we disagree with the authors' approach to a topic. For example, in the treatment of cellular energetics, we find that it is more useful to focus on Gibbs free energy and its relationship to displacement from equilibrium than on bond energies of molecules. The free-energy approach is especially useful, because bioenergetics subsumes a broad array of processes beyond chemical reactions such as ion and electrical gradients and mechanical processes. Moreover, use of this approach facilitates (and requires) that students gain a conceptual facility with equilibria (of all types) and steady states. We recommend a short essay by Richard Feynman (2008) as an accessible starting point to a guided discovery of these important topics.

As with any endeavor, *ICB* is a product of the vision of its authors, inevitably influenced by their training and expertise. The great strengths of *ICB* are at the cellular, molecular, and ecological levels of the biological hierarchy, reflecting the authors' biological foci and the reality that most biological research is presently focused on the "small" and the "big." The authors made an honest attempt to minimize the small-versus-large divide by seeking common themes and providing for exploration of system- and organism-level mechanistic biology (see Figure 1). But it is clear that their experience (and most successful presentation) is elsewhere. For example, chapter 9 ("Neurons and Muscles"), which was intended to emphasize organisms, does an excellent job in guiding students through research on the regulation of synapse formation at the cellular and genomic levels. But the highest level of structural complexity discussed is between one cell and another. The authors miss a chance to explore emergent properties found in networks of connected neurons. The complexity and (often) flexibility of these networks allow neural computations related to perception (e.g., vision) and much of cognition and learning. Likewise, treatments of plant and animal physiology (chapters 12 and 15) focus heavily on processes at the cellular or molecular level. Chapter 28 (organism homeostasis) presents some interesting data regarding mammalian thermoregulation but without mentioning the roles of metabolism and circulation in temperature regulation. Temperature regulation is a subject that is often used to illustrate how interacting organ systems can achieve varying degrees of regulation. It can be used to briefly explore the salient features of these systems ("What must a pump do?" and "How is flow controlled?") and is an ideal subject for mathematical treatments (applications of Newton's law of cooling, surface, volume, and size) and seeing how principles from physics (e.g., diffusion and bulk flow of heat) apply to organisms. A balanced grounding in tissue/system/organism function is important to the education of beginning students.

All textbooks have problems such as the ones just mentioned. We are concerned that no content reviewers are acknowledged in the prefatory material of this text, and Trunity uses the process of "assisted publication," so it may be that the text was not subjected to as thorough a review as a traditional textbook backed by the resources of a major publishing house. However, since the electronic format permits updating at the authors' pleasure, mistakes can be easily corrected as users offer feedback.

ICB, OTHER INTRODUCTORY TEXTS, AND THE PARABLE OF THE BLIND MEN AND THE ELEPHANT

Each biologist has his or her own perspective as to how students should be introduced to biology, much as in the ancient parable wherein each wise but blind man attributed different characteristics to the elephant. One approach is to admit that other views are useful but, nevertheless, select a particular perspective. The three BSCS high school biology texts launched in the 1960s are good early examples of this approach. The more common path has been to examine the "elephant" from every possible perspective and pedagogy and produce a textbook that theoretically would meet all needs. Given the costs of traditional publication, there is logic in producing a book that has the greatest adoption potential. Thus, traditional textbook writers have compiled increasingly massive compendia, with multiple authors and expert advisors, richly detailed illustrations, numerous study questions, boxed features on applications and ethical issues, and examples of applications of mathematics and chemistry, along with an array of electronic resources and instructional aids. For example, the widely adopted introductory biology textbook that we use at Holy Cross (Sadava *et al*., 2014) has more than 1300 pages and uses multiple authors and advisors, each an expert on some range of topics.

This thoroughness is often overwhelming for both students and faculty members. Students become lost in the detail and bombardment of terms and fall prey to frustration or boredom. Instructors provide study guides to help students focus, leading students to minimize their reading and concentrate on slides presented in class, which reflect what the instructors believe to be most important.

ICB was partially designed as an antidote to the expansive text, and it effectively facilitates a path to teaching and learning that takes advantage of recent educational research promoting the benefits of student-centered active learning. For these reasons and because of its inherent strengths as a text, it is a significant contribution. But is it for everyone? The answer, of course, is no. We have a different take on what topics should be presented and how. For instance, we believe that it is not just theory and experiment that motivate students; many thrive and grow from knowledge of biological diversity. Other differences that matter to us, such as how to explain biological energetics or the importance of good treatments of organismal biology, we touched upon earlier. We also place more importance in the value of terminology than do the authors of *ICB*. So, at our institution, we are moving along a largely parallel but different path as we strive to make education more exploratory, active, and integrative—a path that owes much to that advocated by Freeman *et al*. (2011). We look for textbooks with treatments that include these perspectives. A second issue is how the introductory course fits into the entire department's curriculum. Coadaptation of introductory and advanced courses is required for a coherent student experience.

These quibbles and reservations aside, we believe that in the hands of motivated and skilled instructors, *ICB* represents the core of an approach that is likely to excite and engage students more than does a more traditional course. The text and supplemental materials are effective tools to anchor courses of guided self-discovery of biology and the scientific process. This approach is more likely to motivate students to develop a usable knowledge foundation and problem-solving skills, and it should also facilitate the development of their metacognitive skills (NRC, 2000). A study done at Davidson College the first year that the *ICB* version of first-semester introductory biology course was offered in parallel with a more traditional version showed that student performance was similar across approaches on factual content but that *ICB* students performed better and showed more improvement on tasks involving data interpretation and had a better conceptual understanding of biology as a discipline (Barsoum *et al*., 2013). Moreover, even educators who choose not to adopt *ICB* would likely benefit from studying its intent and execution. It exemplifies an innovative and enlightened new direction in education that is worthy of emulation by those who see the biology elephant with different perspectives. If we may conclude with a personal reaction, reviewer K.N.P. would have been overjoyed to have experienced the *ICB* approach when, a mere four-plus decades ago, he took introductory biology in the very same rooms as the students of Campbell, Heyer, and Paradise do today!

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