

What is “Integrative Biology”?¹

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We have a tiger by the tail, folks; “integrative biology” suddenly has cachet and significance. Many biologists now call themselves integrative biologists; academic units in the U.S. are changing their names to Integrative Biology (it occurred at Berkeley twelve years ago, and the department has been trying to develop wide-ranging but coherent research and teaching in integrative biology; departments at Texas, Illinois, and Basel, for example, also are deliberately “integrative biology.” National Science Foundation program areas are stressing the “integrative” aspects of research in name and practice; and scientists talk about “integrative” approaches to biodiversity (e.g., Wake, 1995, 1998), to physiology (e.g., Marden *et al.*, 1998), endocrinology and neurobiology (e.g., Vaudry *et al.*, 1998), ecology and morphology (e.g., Wainwright and Reilly, 1994), biology hierarchically (e.g., Wake, 1990; Pennisi, 2000), and even to medicine (e.g., Goldstein, 1997; Chien, 2000; Halperin and Kamel, 2000; Rudy, 2000), and many other synthetic areas that cross standard disciplinary boundaries.

The Society for Integrative and Comparative Biology has been at the forefront in developing and promoting integrative approaches to research and education. We continue and expand our emphasis on organismal biology from multiple perspectives in an attempt to evaluate issues of biological complexity and their many dimensions, including the physical and social. We realized more than a decade ago that we needed to adopt a position of leadership in advancing an integrative and comparative perspective in the study of biology. We changed our name to reflect our problem-oriented approach; several of our Divisions have changed their banners, usually adding the study of evolution to their mission, and we have added new divisions.

We have not been alone in this effort, though. As I mentioned above, academic departments and some agencies have espoused integrative approaches to science. One in particular that joined this effort is the International Union of Biological Sciences, our co-sponsor of this symposium on “The Promise of Integrative Biology.” IUBS deserves to be much better known in the USA than it is; it has been the originator of many activities that have involved U.S. biologists, such as the International Biological Program (IBP), the Decade of the Tropics, and DIVERSITAS, the inter-

national biodiversity science program. Some SICB members know of IUBS because international societies and congresses to which they belong are its Scientific Members, and IUBS encourages a strong interaction with its members; however, many SICB members participate in these activities without being aware of the IUBS role in them. For example, our Division of Comparative Physiology and Biochemistry has a major congress that is a Scientific Member of IUBS, and the Division enjoys a dual relationship with the International Union of Physiological Sciences. The international unions were created in 1919, after World War I, to provide communication among the countries of the world about their areas of science, and have maintained and expanded programs in science and education ever since. Each of the Unions also has National Members, usually the academies of science of the countries represented. In the case of the U.S., the NAS/NRC is the member, and they designate national committees for each of the unions. Several SICB members, past and present, are/have been members of the U.S. National Committee for IUBS, and for other unions.

But what is IUBS’s role in integrative biology? As the Decade of the Tropics ended, and as DIVERSITAS expanded to include additional sponsors, IUBS looked toward the burgeoning emphasis on “integrative biology” as both a philosophy and a practice of biological science and education that it could develop and promote as its next decadal theme. It has been sponsoring symposia, produced several papers, and is now involved with UNESCO in developing teaching materials that reflect an integrative approach. Its sponsorship of “integrative biology” as an international perspective is working! Several papers reflecting its program “Toward an Integrative Biology” (TAIB) have been published in its journal, *Biology International*. The members of the TAIB steering committee are bringing programmatic elements to the effort in various ways, especially via symposia and publications. A notable example is that of an Indian colleague on the steering committee, who initiated a national symposium in his country that dealt with integrative biology in terms of the “transition from classical to molecular biology,” integrating biology through computation, and in teaching at all levels—the symposium papers were published by the Indian National Science Academy (Lakhotia, 2001). This is but one example of the way that “integrative thinking” is taking hold throughout the world. Two of the symposium papers that follow are from individuals who have been much involved in, and dedicated to, the development of the

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IUBS “Towards an Integrative Biology” Program—the Past-President Jean-Claude Mounolou and one of the two Vice-Presidents, Motonori Hoshi, who chairs the steering committee for the program. Their own practice of science reflects integrative biology in very interesting ways, as you will see in their papers. As the current President of IUBS, I too have been much involved in the TAIB program. Two of our other speakers are involved in IUBS activities as well—Michael Donoghue is a member of the USNC, and David Kirk participated recently in a TAIB symposium organized by Motonori Hoshi. Thus the circle of interest in “integrative biology” extends, nationally and internationally.

All this activity is fine, but what is “integrative biology,” and what is its promise? Such questions as whether there has arisen a new approach to biology, and to science more broadly, and whether issues of biological, and scientific and societal, complexity are being addressed with a new means of approach and analysis must be considered. Let’s explore why “integrative biology” suddenly is being adopted both as a label and as a framework for research.

“Integrative Biology” at this point in its conceptual development has many different definitions (Ripoll *et al.*, 1998; Wake, 2001). To some workers, it emphasizes multidisciplinary research (cross-disciplinary, transdisciplinary; including the incorporation of physics, chemistry, engineering, sociology, economics, etc., as appropriate). Multidisciplinarity for those scientists especially emphasizes the bringing together of researchers with different, but specific, areas of expertise to address particular questions. To others, it means using a diversity of techniques and approaches in one’s own research programme; and to yet others, the emphasis is on hierarchical approaches to questions and techniques. There are almost as many conceptions of “integrative biology” as there are people interested in the idea; this results in those people considering themselves to be “integrative biologists” without any clarification of or agreement upon the central themes of the concept. Traditionally, biologists are trained, and departments and institutes organized, in a manner characterized by specific approaches, techniques, often working at a specific level of organization in the biological hierarchy, and/or organisms, and investigating model organisms or one or a very few species (see Wake, 2000, 2001).

In my opinion, integrative biology is both an approach to and an attitude about the practice of science. Integrative approaches seek both diversity and incorporation. They deal with integration across all levels of biological organization, from molecules to the biosphere, and with diversity across taxa, from viruses to plants and animals. Integrative biology provides both a philosophy and a mechanism for facilitating science at the interfaces of “horizontally” arrayed disciplines, in both research and training. Work at interfaces involves discussion of significant problems among scientists with diverse expertise and perspectives. Many

of the questions now being addressed by biologists require both reductionistic and incorporative elements, but in a framework that allows resolution of the sub-elements of the question to contribute to an answer to a larger problem. Many biologists are coming to the realization that our ability to deal with questions of biological complexity would benefit from a more integrative approach that spans the hierarchy of biological origin, and that includes techniques and theory from several subdisciplines, not just the biological. Integrative biology lays the framework for new models and new ways of investigation (see Wake, 2000, 2001).

It is often claimed that new areas of biology are developing as a consequence of the joining of subdisciplines to explore complex questions. The many manifestations of biocomplexity, from fundamental science to socioeconomic concerns, require approaches that transcend standard disciplinary lines in terms of research, funding, training, and dissemination. The inclusion of a phylogenetic framework for comparative biology of all sorts has been a highly significant step (*e.g.*, Brooks and McLennan, 1991). The problems now being addressed by many biologists require a diversity and range of expertise. That expertise can be provided by bringing together experts in several areas, but it may be better provided by biologists who are adaptable, flexible, and trained to address new questions that span levels of biological organization and extend to “non-biological” realms. An integrative approach promotes several principles and goals: the delineation of complex questions; the organization of expertise to tease apart the questions hierarchically (reductionistic approaches, the comparative method, taxa, etc., retain significant places in a hierarchical and flexible/adaptable approach); extensions of expertise into non-traditional arenas; and new educational/training modes.

Perhaps the main question, though, is whether “integrative biology” is really a new way of doing science, or a re-discovery of the life of the mind, and an interest in larger questions because we have better tools with which to explore them? I think of Charles Darwin as the quintessential integrative biologist—what he exemplified, why he was able to do it; why his was integrative biology (Wake, 2001). It is almost ironic that in our admiration of his work, we tend to deconstruct it—to recognize its parts in terms of our current, bounded subfields. We recognize with awe that Darwin did systematics, morphology, development, behavior, physiology, and ecology—and out of it all emerged a grand synthesis and a new conception that has become the foundation of much of biology—evolution through natural selection. That was integrative biology—done with a keen eye, a few small tools, and, most of all, a disciplined and inventive mind—and the time to use that mind. Many good scientists of a century and longer ago were integrative biologists, because of independence of thought and approach, lack of constraints on or even the need for extensive funding, equipment, etc. Can it be done the same way

now? No. We are prey to our need for complex equipment, the burgeoning literature and keeping pace with it, the many demands on our time. But, obviously, I believe that "integrative biology" provides a new framework, if not a new paradigm, for the practice of science, because it focuses on complex problems and their solutions, a hierarchical and cross-disciplinary approach to them, the amalgamation of expertise from different subdisciplines, and the employment of shared facilities, in both the practice of research and the practice of education in biology (Wake, 2001).

But what, then, is "integrative biology"? Is "integrative biology" a new research paradigm, or an extension and amalgamation of current, and even the best of past, practices? It doesn't really matter—it is new in the sense that it provides a refreshing, broadening, and synthetic approach to complex questions in biology, and in the society to which biology has applications. It provides some organizing principles for such research by emphasizing that research can span the hierarchy of biological and technical organization, though recognizing that all parts cannot be done at the same time by one person, so multiple expertise, often provided by multiple people, advances the field. It is old, in that it returns us to a sense of our history of search for unifying principles and the answers to complex questions through investigation of their component parts, but synthesizing those parts into a new conceptual entity. We would do well to promote integrative principles as we structure our approaches to the questions that interest us, and perhaps more significantly, to the training of our students, so that they are equipped to think independently and synthetically—well centered in a part of biology, but cognizant that they can contribute to and interface with much of biology, determined by the questions they are asking (Wake, 2001).

Consequently, I assert that the promise of integrative biology is great, but it is certainly not the only way to do biology. Though we recognize the many approaches to good science that we must maintain, I am firmly convinced that an integrative approach is likely to transform the biology of the 21st century. The papers that follow illustrate the range, the scope, and the insights into major questions in biology that can be revealed by innovative and integrative biologists.

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