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# Toward a Concise Definition and Perspective for Biology


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# TOWARD A CONCISE DEFINITION AND PERSPECTIVE FOR BIOLOGY

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**ABSTRACT**

The content of introductory biology courses at the high school and college levels are currently being re-examined. Many biological educators favor revision of the high school biology courses to a format that directly addresses current social issues to "promote good citizenship". We believe it would be more meaningful to teach the fundamental principles of biology, the study of living systems. Properly defining biology, by defining a living system, should help identify important topics to include in a basic biology course. Emphasis should be placed on subjects which would contribute most to the development of a basic understanding of how all living systems function. The course content should not be restricted by historical traditions or molded by social whims, but change with the development of knowledge through biological research.

## INTRODUCTION

Biology is commonly defined as the study of "life" or "living systems". However, these terms are not defined, therefore biology is left essentially undefined. Biology teachers sometimes seem to have a slight obsession with terminology; therefore it is unusual that biology itself has escaped meaningful definition. Nearly all introductory biology texts begin by stating that life is undefinable. Then, in lieu of a definition, they list and describe the basic characteristics of living organisms or the living condition. These characteristics usually include biogenesis, metabolism, growth, cellular organization, motility, irritability, adaptation, homeostasis, and perhaps others, with considerable variation among texts. This method for beginning a biology course has been popular for decades and certainly has its merits. However, the characterization method may also be the source of some problems, and is considerably out of date concerning our current knowledge of biological science, as a proper definition is no longer beyond our ability.

Students may be apprehensive about their ability to understand biology because it is a study of "life", a subject which has defied definition. A discipline that is based on the study of a subject that is undefinable may at least sumliminally seem to be shrouded in mystery. Some students and research scientists have been attracted by the mystery of biology, but teachers generally recognize a need for a concise definition. The definition should be a foundation upon which to build, and provide a proper perspective for beginning students.

## THE PROPOSED DEFINITION

During the past few years we have developed the following definition for a living system:

> *A living system is a unique set of common chemicals that is capable of utilizing energy to organize matter according to its information content in a way that results in self-perpetuation.*

Life is anything that has all the characteristics of a living system. The extent to which a chemical system (such as a virus) fits the definition is the extent to which it should be considered living.

The chemical elements (matter) composing living systems are not unusual, they are found throughout the earth's crust and atmosphere, but they do comprise a unique set. They exist in rather precise relative proportions to each other and react in predictable ways. There are numerous homeostatic mechanisms built into this system to ensure that equilibria are maintained. Variations in this set of chemicals among diverse forms of life are very small compared to their overwhelming similarities. Photosynthesis and anaerobic respiration are essentially reversible reactions, excluding the light-capturing pigments and associated photosystems, because most of the enzymes which catalyze these reactions are interchangeable. Depositional chemicals that form such things as cell walls, feathers, chitin, bone and hair are characteristic of only certain taxa, but their production probably requires only minor alterations in the universal set of metabolic pathways. The fact that living things are first and foremost a unique set of chemicals points out the importance of studying molecular relationships to understand biology.

Emphasizing the similarities among life forms to students can develop the attitude that learning biology is not such a formidable task. They realize that if they learn the basics of how one living system functions, they will have a fundamental understanding of how all living organisms function. Emphasizing similarities also encourages a feeling of companionship with other life forms, which may foster a concern for environmental protection.

Matter and energy are basically the only two components of our universe and they have interacted and continue to interact in diverse ways to produce the contents of the universe. Recently Carl Sagan in the television science-drama, Cosmos, has appealingly reminded us that we are made of cosmic dust and the light of a star. We know this to be true of everything in the universe, so it is certainly no distinction. In a very broad sense "stardust" can be construed as the matter composing the universe and "starlight" the energy with which it reacts. Science is the human endeavor to explain our perceivable universe through refined techniques of careful observation.

Living systems do not defy the Second Law of Thermodynamics as was once believed (see Denbigh 1951, Wiegert 1968). They must be capable of obtaining energy either directly from the sun as phototrophs do, or indirectly by consuming organic matter produced by photosynthesis. Energy flows through them and can only be attenuated and transformed during the use process. A substantial portion is lost with each transformation. If the energy flow is stopped, the system must become inactive or deteriorate. Many living systems are not continuously active so the phrase "is capable of" is needed in the definition. Virtually all organisms vary their metabolic rates. This is one of the tactics used by organisms to maintain a positive time and energy balance to stay alive. Some organisms become completely inactive, such as *Nostoc*, a blue-green alga which can withstand extreme dessication for extended periods. Others escape harsh environmental conditions by a combination of physiological and behavioral mechanisms which dramatically lower their metabolism, such as hibernating endotherms. Similarly many temperate zone plants become dormant during winter. Nearly all seeds and spores are capable of surviving extended periods of extremely reduced (if not zero) metabolic activity. Energy is utilized by living systems to organize matter and keep it organized by providing the driving force necessary for most of the chemical reactions in living systems. It is sometimes useful to consider energy to be that which holds matter together. Chemical bonds can be considered to be units of energy.

Perhaps the most important thing that distinguishes living from non-living matter is that living things contain information sufficient for their maintenance and self-reproduction. This information directs all of the chemical reactions and thereby determines how the systems are organized. For individual cells, information is contained in a chemical subset and is transmitted into action primarily through manufacture and activities of enzymes. In the case of more complex metazoans there is a slight shift in this responsibility to other means of information storage such as the memory banks of the central nervous system. Hormones certainly contain and transmit information also, probably to some extent in all forms of life, e.g., edcysone informs invertebrates concerning time to molt. Quantities of other specific chemicals are occasionally used to store information, for example, certain plants store phytochromes for information concerning photoperiod.

The ultimate measure of success of a biological system obviously is whether or not it remains alive, i.e., its self-perpetuation. This is equally true for individuals and species, but in a rather different way. Individuals have a relatively inflexible, solitary information set (despite repetitiveness), especially to the extent that the individual depends upon its unalterable genetic code for information. Genetic redundancy, phenotypic plasticity, the ability to store and retrieve information by the brain, and transmit information from one individual to another provide species various amounts of flexibility of information content within individuals. A species population on the other hand essentially has all the separate information sets of each of its members. The proper measure of biological success of an individual is the number of offspring it leaves in the next generation. This measure of the reproductive success of an organisms is a meaningful way to express the fitness or suitability of its information set in a particular environment (see Pianka 1983). Each genetically-controlled trait of an organism can be correctly evaluated (whether we can actually measure it or not) in terms of the contribution it makes toward keeping the organism alive and optimizing its reproduction. Evolution is the process by which species continuously remodel their information sets to accomplish self-perpetuation in their changing environments. This is, for the most part, simply a fortuitous probability because those individuals which are most fit for the environment in which they exist are most likely to survive and reproduce. Any genetic trait that results in altruistic behavior (other than within a family) does not contribute to the survival of its possessor, by definition. (Proponents of the theory of 'reciprocal altruism' would disagree of course.) Therefore there is no mechanism for the survival of such altruistic genes.

The proposed definition can be diagrammatically represented as in Fig. 1. The central circle represents the living system with its unique set of chemicals and information subset. Energy flows through the system and, while it may be temporarily stored, it is not recycled but ultimately is dissipated to the atmosphere and then outer space. Matter is cycled between the living and non-living realms as it is assimilated, rejected, secreted, shed (e.g., exuviae), etc., or when a living system fails (i.e., dies) and decomposes. The model may be thought of as representing a living cell with the boundary of the circle as the plasma membrane and the information set consisting of DNA. It can also represent an entire multicellular organism with no change in the model and little change in perspective by the viewer. This simplest version of the

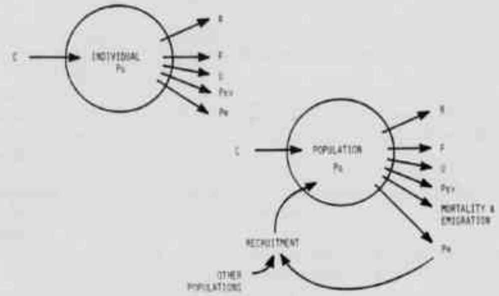


Figure 1. Diagram of living system, illustrating its interactions with non-living matter and energy.

model shows matter and energy to have somewhat independent entries and exits. In this respect the model best represents green plants and other autotrophs. Energy enters green plants in the form of light independent of any matter and exits as heat, exuviae (leaves, etc.) and fruit. Most of the matter enters green plants as $CO_2$. Heterotrophs take in practically all of their matter and energy together in the form of food, of course. Mammals and birds (endotherms) release approximately 98% of this energy as metabolic heat, which is unavailable to do meaningful work, i.e., cause useful changes in matter for their living systems. Ectotherms can retain approximately one-half of their energy intake to use for growth and reproduction (e.g., see Brown and Fitzpatrick, 1978).

The First law of Thermodynamics forms the basis for energy budget equations (Wiegert, 1968) which can be used to represent the energy flow through individuals, populations or entire communities:

$$C = P + R + F + U$$

where: C = Consumption (of energy)
P = Production (storage of chemical energy)
R = Respiration (heat loss)
F = Feces (energy not absorbed by heterotrophs)
U = Urine (energy absorbed but not assimilated)

$$A = P + R$$

where: A = Assimilation of energy, or energy flow

$$P = P_g + P_r + P_{ev}$$

where: $P_g$ = Growth
$P_r$ = Reproduction
$P_{ev}$ = Exuviae

Energy flow diagrams can be elaborated from the basic model of a living system and these energy budget equations as illustrated in Fig. 2. These diagrams can be quite useful when introducing the subject of

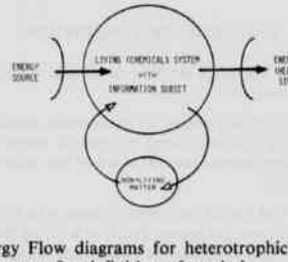


Figure 2. Energy Flow diagrams for heterotrophic individuals and populations. See text for definition of symbols.

energy flow to students. Larger hierarchial divisions of biological systems (populations, communities, ecosystems, biomes or the entire biosphere) are adequately and usefully represented by this model. However, the information content concept should shift from the individual's genotype to the gene pool at the population level and then to inter-organism and interspecific interactions at the community level (Margalef, 1958; MacMahon et al., 1981).

## CONCLUSIONS AND PERSPECTIVES

The proposed definition can be used to elucidate the most fundamental concepts for an introduction to the study of biology. It could provide a cohesive reference point for use by teachers and students when assessing the contribution of each unit in an introductory biology course to the ultimate goal of achieving knowledge of how biological systems function. The definition does not have to displace listing of the characteristics of life, but it is useful when introducing biology to students. Various subdisciplines and specific topics for study in biology can be placed in proper perspective for students by using the proposed definition and model. For example, energy flow and cycling of matter are identified as two fundamental emergent properties of living systems, and as such are basic concerns of the study of biology at all levels from molecular to ecosystem studies.

This is a purely mechanistic definition as opposed to a vitalistic one. It does not include recognition of any vital force because it is in the realm of science. Science has specific limitations, and the presence of a vital force cannot be tested by scientific means. However, the proposed definition should not be misconstrued by perceiving it as being incompatible with Christianity just as it is not correct to presume that evolution and creation are alternatives, as discussed by Moyer (1981).

The Biological Sciences Curriculum Study prepared high school texts and lab manuals (especially the Blue Version) that are problem oriented and address the topics essential to developing an understanding of how living systems function. Many college-level texts have adopted a similar format or design, but too many retain the entire phylogenetic and systemic approaches as well, and as a result have become formidably large. Moyer (1982), Yager (1982), and other biology educators are concerned that many teachers confronted with encyclopedic textbooks and/or pressures stemming from social issues are retreating to the basics (so called) of phylogenetic and/or systemic approaches to teaching biology at the high school and introductory college levels. They are encouraging teachers to confront this situation by discussing pressing social issues which relate to biology (e.g., abortion, sex education, women's rights, etc.) in biology class (Bybee, 1982; Kennedy, 1982; Patrick and Remy, 1982). This would consume valuable class time that could be used to teach biology, i.e., the study of living systems and how they function. Perhaps a retreat to the basics is the best strategy, but the basics should be those topics which contribute most to understanding how all living systems function.

Historically the beginning biology course originated as a replacement for botany, zoology and human physiology courses and as a result, studies of systematics and human organ systems have often been considered to be the "basics" of the course ever since. Perhaps the beginning college biology course can eventually come into its own and transcend its traditional bifid role as a service course for the pre-medical profession students and a survey of the variety of life forms, each of which should (and usually does) constitute separate sophomore-level courses. An essential core of content should be identified that would provide a foundation from which teachers and students could meaningfully address related socially-important issues, perhaps in some other subsequent course(s). This core of information would change with the development of biology as a science through research, not in response to the vagaries of the social, political or religious environment. By defining biology the necessary unifying theme and core content for introductory biology courses become evident.

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