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Review Article

Integrating Symbiosis into Mainstream Science Education: Penetrating the Curricular Membrane

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Abstract

The evolving discipline of symbiosis has long been overlooked in both pre-college and college teaching. Mainstream science education will benefit from symbiosis integration in that entire ecosystems familiar to young students are dependent on microbial-based symbioses, such as mycorrhizae, nitrogen-fixers, and photosynthate-transferring algae. Concepts of evolution can no longer afford to ignore the symbiotic foundation of the eukaryotic cell and the growing notion of symbiogenesis as a major augment to natural selection. Fundamental school biology concepts, such as physiology, can link strongly to the megascopic organisms being habitats with symbiotic communities. Moreover, symbiosis in mainstream curriculum will create new perspectives for students, including the realization that selection in nature frequently results in intimate "cooperative" associations. All involved in symbiosis-related research and teaching must help science educators, especially at pre-college grades, integrate symbiosis into everyday life science curriculum.

Keywords: science education, biology education, symbiosis, science standards, curriculum development

1. Introduction

Each week new research articles within the science education community reach publication stage. Studies within this frequently overlooked discipline

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highlight instruments that measure, for example, what students know or believe they know, assess appropriate pedagogy for understanding science, and shed light on how a more scientifically literate citizenry in all countries can be promoted. Yet, too often, science education researchers ignore key concepts, terms, understandings. A current example rests within the realm of evolution education. Everyone seems to agree that biology teaching at high school and college levels without a firm focus on evolution makes little sense (Dobzhansky, 1973; AAAS, 1989; National Research Council, p. 23, 1990). But, those conducting evolution education research are unaware of the importance of symbiosis in both macro evolution and natural selection. The symbiotic void so pronounced in evolution education expands further throughout the biology curricula. The science education community is likely reflecting in delayed fashion the previously slow recognition of the science research community to symbiosis and its pervasive importance. The integration of symbiosis into mainstream life science education among pre-college middle and secondary grade levels and in the universities is a growing necessity if we are to truly have science classrooms that bring us closer to understanding the planet and ourselves.

What are the justifications for greater symbiosis realization in life science curricula, and what implications would result from such an integration? A look at the fundamental concepts in biology classrooms show a potentially strong but unrecognized symbiosis influence that extends well beyond its perennial designation as a biological curiosity or even supplementary behavior.

2. Sample Curriculum Domains

Ecology

Students are exposed to primary, secondary trophic levels, successional change in habitats, ecosystem definitions, and so on. Ecology is an evolving science that strives to show connections among life forms. The inter-relationship focus on the discipline can hardly be disputed. It is then profoundly more ironic that the most common and potentially most influential and potent inter-relationships are the ones most ignored in ecology lessons.

The foundation and even maintenance of most recognized ecosystems relies on symbioses. Examples include forest zones, coral reefs, and grasslands. If an imaginary intensive probe from some alien life form ventured to earth, one of its potentially strongest conclusions would be the dominance of the microbial thread network throughout much of the land features of the planet. Mycorrhizal fungi are now known to be so common and significant in nutrient uptake (Melin, 1958; Harley and Smith, 1983), root extension (Smith and Douglas, 1987), and territorial expansion (Smith and Daft, 1978) of many plants that one could make a case for the alien form to report to its leaders that there are frequent outgrowths from such a hyphal network – outgrowths known as "trees"! Ecology has too often treated the tree in its web of understandings as an individual, as a single genomic expression interacting with other individuals. Symbiosis research teaches us that both we, as teachers and researchers, have veered off the track. Many plants, including the most essential tree species in boreal, temperate, and rainforest regions, are truly communities in and of themselves. Their relationship with mycorrhizae is so intimate that saying "tree" may be tantamount to looking at a human circulatory system and designating it as an individual. Forests simply do not evolve to anywhere near their growth potential and survivability without their "partner" subterranean fungi or in some cases without symbiotic filamentous bacteria. On a cellular or tissue level, sections of what we call a tree may have proteins or other products exchanged with the mycorrhizae. Fungi are commonly seen by ecologists as saprophytes or mainly decomposers but many fungi are actually sinks (Harley and Smith, 1983) that may help drive photosynthesis and carbon dioxide uptake in their companion tree leaves. There is even some thought that mycorrhizae may have been implicated in the establishment of land plants from the sea (Pirozynski and Malloch, 1975). We may then certainly label this an ancient co-evolution. But at what point does co-evolution blur to fundamentally define the organisms involved? Co-evolution of mycorrhizae and trees may be more like co-evolution of leaf parenchyma and stoma cells than paralleling life forms.

Rainforests are defined through special characteristics such as climate and rainfall. A major physical characteristic is their canopy, the result of extensive epiphytic growth. These epiphytic plants that make up the vast upper stories of rainforests result in large part from massive colonization of bark regions by symbiotic lichens (Forsyth and Miyata, 1984). Lichenic acids metabolize bark surfaces and thereby convert hardened surface tissue to a soil-like humus, such that seeds from wind and animal transfer can land and take root. Furthermore, the mycorrhizal basis of many rainforest plants, including dominant epiphytes like orchids is well known (Alexander and Hadley, 1985).

Students learn that grassland features are not as diverse in species and that such regions are dominated by single bladed photosynthesizers we call "grasses." Yet, many grasses are also intimately connected to the root infections and extensions known as mycorrhizae (Fitter, 1977). Some plants in grassland areas even possess substantial populations of nitrogen-fixing symbiotic associations (Douglas, 1994). The consumers of the grass are hardly individuals or even groups of separate individuals. Ungulates – whether they be wild elephants or domestic cows – have huge, essential symbiotic life forms on their bodies, in the anal and oral cavities and particularly in specialized multi-stomach and gut regions (Hungate, 1975). There is little meaning in the continued discussion of the cow as an individual consumer. It only promotes misconceptions. The ungulate is a vast and diverse symbiotic community accessing and utilizing another vast, albeit less diverse symbiotic community. Through their dung droppings, gas expulsions, belching, and drool, many ungulates also can be seen as communities dispersing symbiotic microbial consortia in the symbiotic grass-mycorrhizae habitats.

Coral reefs are another dramatic reflection of the animal-centered, individualistic orientation of biological science. Reefs as we have come to know them, are not made by corals at all. Rather the reef is the result of a dynamic symbiosis among dinomastigote (or dinoflagellate) microbial algae and hermatypic corals (Smith and Douglas, 1987). Here we have one of the most prominent ecosystems in the water-dominated globe driven and maintained by a symbiotic acquisition and subsequent intimacy repeated millions of times. These huge exoskeletons are products of multi-kingdom, polygenomic life forms – the protoctistan *Gymnodinium* and the animal coral. The implications for lessening the role and recognition of the "sequestered" photosynthesizer became evident in recent years with the discovery of "bleached corals" (Williams and Bunkley-Williams, 1988; Wilson, 1992, pp. 270–271), an oxymoron at best. Coral reefs are recognized as one of the most diverse habitats on earth (Wilson, 1992, pp. 179, 199), a center of myriad life forms and metabolic processes, a home to millions of organisms and behaviors and potentially a key sink for calcium and carbon deposition and thus earth system maintenance. This calcium carbonate structure so dominant in ecology is a symbiotic product.

An ongoing recognition of symbioses in these and other ecosystems, based solely on what is generally recognized and not even on larger speculations and the newest research, would still more realistically portray the planet and help build necessary holistic approaches.

Cell biology

Whether the more educator friendly five kingdom classification of Whittaker (1959) and Margulis and Schwartz (1988) is used or the more recent three domain concepts of Woese (1987), Woese et al. (1990) and others (Sogin, 1993), there is little controversy over the fundamental distinction of prokaryotic and eukaryotic forms. The pronouncement of Stanier et al. (1970) over 20 years ago holds today: "The numerous fundamental differences between eukaryotic and prokaryotic organisms... probably represents the greatest single evolutionary discontinuity to be found in the present-day living world."

We learn in college and high school classrooms that eukaryotes are defined primarily by the membrane bound organelles they possess. Each cell that makes up animals, plants, fungi, and protoctists is a highly organized network of storage and receptacle centers, moving about via microtubule and microfilament matrices. Most eukaryotes are powered through the membrane-centered exchanges of the mitochondrion organelle and all photosynthesizing eukaryotes have their light absorbing pigments sequestered in highly membranous regions we call plastids. While eukaryote cells within the kingdoms are much more than any one or two organelles, any biologist would be hard pressed to underestimate the significance of these two systems. Only the nucleus with its pore system and genetic organization approaches the intricate and complicated beauty of the photosynthetic systems within plastids and the cristae membranous folds of the mitochondrion. These latter two structures essential for all the megascopic life on the planet and a large portion of the microscopic, as symbiology researchers know, evolved through symbiosis.

The well-established symbiotic basis for eukaryotic cell evolution (Dyer and Obar, 1994; Gray, 1983; Margulis, 1993) has the potential to be a central curriculum force in shaping our understanding of living organisms on the planet. It also serves as an excellent vehicle to reflect on the historical development of a scientific idea (Khakina, 1992; Taylor, 1987). The symbiotic origin of cells or cell parts was proposed in the early 20th century (Mereschkovsky, 1909; Wilson, 1959), particularly within the Russian scientific community (Khakina, 1992). Its resurrection from hypothesis to the Serial Endosymbiotic Theory (SET) (Taylor, 1974) and the resultant thousands of research experiments have led to a new recognition of the importance of symbiosis. Furthermore, the very fact of symbiosis research, no matter what its outcome may have been with respect to cell evolution, resulted in fundamental new understandings within several sub-fields of biology. Within the "less is more" framework advocated in science education reform (AAAS Project 2061, 1974; NAS, 1994), the evolution of eukaryotic cell organelles via symbiosis offers a potentially rich focus. Students would use the SET concept as a centerpiece for discovering physiology concepts, fundamental genetics, natural selection, phylogeny and classification, diversity, biochemistry, history of science, and research skills.

Vertebrate biology

With students' natural focus on themselves and their own human species, quite natural at the middle and high school ages, the study of animals in general and vertebrates in particular, continues to dominate life science classes. A recent report from the United States' National Research Council (1990) emphasized that this human-centered physiological approach makes sense if students are to invest more in biology and see it as relevant. Within this vertebrate context, symbiosis offers a dynamic opportunity for seeing ourselves and our closest mammalian relatives in a different and enlightening perspective.

What would the view of ourselves be if we truly learned from a paradigm that emphasized the human body as a community or even ecosystem. Adult primates can harbor up to a kilogram of microbes constantly in and on their bodies. These microbial communities appear to be fairly well defined and need to be acquired through immediate sensory contact at birth and shortly thereafter. As the adult mammal grows, so do the distributions, functions, and diversity of its microbial populations (Schaedler, et al., 1965; Skinner and Carr, 1974). Intestines, moist cavities, and skin surfaces become specialized habitats. Some prokaryotic populations appear to even require human or other vertebrate substrates for their continued growth. Moreover, the literature well supports, albeit reluctantly, the understanding that humans and indeed most vertebrates require microbial populations (Skinner and Carr, 1974; Savage, 1977). This ubiquitous relationship in which the large vertebrate forms function as moving habitats or microbial dispersal mechanisms, is not simply based on immunological advantages. Microbes are intimately involved with animals in a variety of metabolic functions including vitamin production, pH maintenance, digestion, (Brock and Madigan, 1988, pp. 392–399) and skin surface maintenance (Marples, 1965). The sub-discipline of "gnotobiology," as well as studies utilizing aposymbiotic life forms indicate the central dependency mammals have on their microbial populations (Phillips and Smith, 1959; Brock and Madigan, pp. 400–401), most of which have traditionally been considered neutral, commensal, or "pathogenic."

Our vast traditional concern with isolation and life forms that can readily be seen with the naked eye have skewed the very understanding of our own bodies. In a somewhat obvious symbiosis connection but seldom realized in the classroom, much of our element-based structure as a living entity may have likely come from or at least passed through a symbiotic system. Students never really focus on element flow as a central tenet of the planet's biology. Where did the calcium that make up our bones and brains come from? Through what systems has it passed? Is its origin and flow as an element solely within a trail of grocery stores, milk bottles, cows, and grasses? It is of course quite likely that significant calcium in each of our bodies have at least passed through major symbiotic entities such as coral reefs, coccoliths or algal harboring forams and after initial roots in volcanism and rock weathering. Symbiosis integration within the context of vertebrate anatomy and physiology is long overdue. Its application would help build new understandings and help human cultures confront not simply their ecology but their very polygenomic existence.

3. Conclusions: Science Education Pedagogy

The implications for symbiosis integration within science education extend beyond biological content disciplines. The very concept of vastly different life forms evolving such that each becomes intimately interdependent does not in any way challenge the central evolutionary vehicle of natural selection, but it does dent the simplistic notion of a dominantly competitive "dog-eat-dog" planet. The commonness of symbiosis throughout all habitats and systems suggests that selection often favors divergent forms tightly co-existing. This is a message that reflects the natural world, and students need to hear and understand it. Research data continues to indicate that life does not exist due to isolation from other life forms, but rather it is due to its ability over time to incorporate other selected life forms into itself (Margulis and Fester, 1991). This story is seldom a part of curriculum and remains an uptapped guide for biology education pedagogy.

A symbiosis focus in curriculum would allow students to further uncover the nature of science, a concept strongly advocated in science education reform efforts (AAAS Project 2061, 1993; NAS, 1994). For example, frequently science is portrayed in classrooms as an endless series of facts. Scientists in history are seen as being right and therefore important or wrong and therefore the subject of ridicule. Symbiosis studies could help prevent the development of such erroneous attitudes and move students away from simple, sound-byte mentality understandings of evolution and scientific process so pervasive in schools today (Bishop and Anderson, 1990; Bizzo, 1994). The very study of the history of symbiosis research and thinking promotes the notion that scientists frequently speculate, seldom seek or come up with absolute or even firm answers, and often work in collaboration. Moreover, students can learn that someone such as Charles Darwin, credited as almost a genius figure for his evolutionary theory work, conducted experiments and developed written ideas as part of the sum total of others' work. This concept is fundamental to science, but seldom understood by students. There is some Hooker and Huxley, Bates and Lyell, Lamarck and Gray in Darwin (Desmond and Moore, 1991). Indeed, with a renewed emphasis on symbiosis, students see that 19th century thinkers like Lamarck (1809) who promoted ideas of acquisition of traits may not have been so far off the mark (Taylor, 1983); symbiotic events frequently appear to evolve through one organism acquiring another organism with its genome. While this is not specifically what Lamarck had in mind, the point for students (and teachers) is that it is unfair and inaccurate to relegate scientists and other hard working scholars to a ridiculed status by looking narrowly at their work. Students need to explore in their curriculum and discover that the nature of science is more change than static, more a series of accumulated knowledge rather than any single discovery, more an accommodation of tested ideas rather than purposeful proofs.

Science education researchers and science educators who train teachers must find ways to update their understandings and make room for important, central, and evolving concepts like symbiosis. And, the responsibility rests as well with the symbiosis/endocytobiology community to create some time and commitment to ensure that our younger generations have a chance to discover what is fundamentally a symbiotic planet.

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