Symbiosis, 25 (1998) 349–355
Balaban, Philadelphia/Rehovot

Special presentation

Symbiosis Education: The Challenge Before Us

DOUGLAS ZOOK
Boston University, School of Education, 605 Commonwealth Ave, Boston, MA 02215, USA. Tel. +.617-353-2030, Fax. +617-353-3924, E-mail. dpzook@seacoast.com

Received May 30, 1997; Accepted July 22, 1997

Abstract

Symbiosis can not only be recognized at a cellular and organismic level, but aerial and long-range satellite perspectives illustrate its dominance. As symbiosis researchers, we must begin to link with pre-college and college educators to foster more integration of symbiotic concepts into life science curricula. Following the emphases of the National Academy of Sciences' recent National Science Education Standards, we should forge strong linkages between innovative, engaging pedagogy and symbiotic science themes. A Symbiosis Visual Slide Collection effort by the Microcosmos program of Boston University is proposed as a specific resource needed for improved symbiosis teaching at all levels.

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

Scottish preacher Henry Drummond at the close of the nineteenth century emphasized that "evolution is primarily the formation of the aggregate" (Drummond, 1894, p. 36). Charles Darwin noted, "Each living being is a microcosm – a little universe" (Sapp, 1994, p. 44). Julian Huxley joined with H.G. Wells in the 1920s to create their classic text *The Science of Life* which included periodic statements such as, "The truth is that animals or plants can no more live in 'splendid isolation' than can nations" (Wells et al., 1929, p. 935).

Presented at the Second International Congress of Symbiosis, April 13–18, 1997, Woods Hole, MA

0334-5114/98/$05.50

Despite the visions of these and a surprising cast of other symbiosis-friendly naturalists over the past 150 years – names like Schimper, Watasé, Spencer, Kropotkin, Brandt, and of course the originator of the term as we know it, A.B. Frank – all likely never imagined that so many of the systems that fuel the recycling nature of the planet, that embody the very concept of survival within our atmosphere and lithosphere, proceed and succeed because of a selected gallery of microbial portraits. Organisms living within other organisms, penetrating but not killing, entering but not digesting, covering but not smothering, exchanging but not abandoning self. The gallery might include specific dinoflagellates like *Symbiodinium microadriaticum*, the gyroscopic brown micro-alga which becomes encysted after entering specific cells of many coral animals; Endogonaceae vesicular-arbuscular mycorrhizae that branch into the root cells of temperate grasses and tropical forest plants; ectomycorrhizae which intersperse among root cells of coniferous and deciduous forests; *Rhizobium* bacteria that co-build nodules on the root systems of the vast family of leguminous plants; Hypermastigote protists which metabolize cellulose as they swim in a sea of life within the gut fluid of insects like termites; *Chlorella* green algae within hydra, *Paramecium bursaria*, forams and others living in scattered, oxygen-transferring puddles, ponds, and seas. Our gallery could include the beautiful *Mesodinium rubrum*, a heterotrophic protoctist which harbors cryptomonad-like, photosynthetic symbionts. And would it be remotely complete without the Zen masters of the symbiotic realm, the lichens? Moreover, given the growing knowledge about our own micro-inhabitants, could we not include a human self portrait as well?

We can marvel at this collection, and realize with some astonishment at the array of new structures that exist because of their competitive partnership. From massive, multi-ton skeletons known as "reefs" to a specialized region, "the mycetome," found in aphids and other insects and which harbor a specific array of bacteria; from the obvious slow growing, earth-skin known as "thalli" produced by lichens to entire, complex fermentation vats known as "rumen" in many mammals; from trophosomes in deep sea vent Vestimentifera to the nitrogen-fixing nodules of soy. The products of symbionts, their creations, surround us and impact us practically from moment to moment.

Yet, this living museum of enthralling symbiotic portraits and products has a much larger expression. Indeed, the extension of these numerous characters can perhaps best be appreciated from high above the earth. It is there at this perspective, this distance, that symbiosis ultimately glows in its brightest hues. Or, more pertinent, perhaps it is at this dimension, this higher perch that symbiosis education can finally be realized.

NASA views from space (Stevens and Kelley, 1992) show washboard dunes in Australia held together by patches of shrubs and grasses – growth of which are optimized through symbiotic nutrient conduits, the mycorrhizae. Such dunes were once the benthic strata of vast ancient saline seas commonly made up of living sand symbiotic consortia, the foraminifera and an assortment of micro-algal symbionts.

Appearing as red patches in a satellite view at the meeting point of a river and Guiers Lake in the Senegal, croplands thrive. The human-mediated growing of plant reproductive devices and storage centers that will later be consumed as food sources is what we call "agriculture." For better or worse, it represents a substantial face of the landscape of current earth. Such farmlands are dependent on the cycling of nitrogen, often initiated through symbiotic fixers like *Bradyrhizobium* or in the case of rice paddies, species of *Anabaena* cyanobacteria within folds of the *Azolla* water fern. Moreover, droppings from symbiotic-based factories – sheep, cattle, and goats – enrich certain agricultural areas. These symbiotic disseminators can be seen as a direct and necessary linkage to the nodulated and mycorrhizal domains of the crops.

We can explore the southeast corner of New Mexico and be confronted with symbiosis in all its splendor as we stroll and climb within currently land-bounded reefs, otherwise known as Carlsbad Caverns at the foot of the Guadalupe Mountains. Extending nearly a mile below the surface, much of the limestone construction dates back to Permian times when the massive exoskeleton was growing in the shallow seas of the area (Chronic, 1987). While the stalagmites and stalactites intrigue us in such a spectacular natural cathedral, one is hard-pressed to find tour guides, tapes, or pamphlets that point out to visitors that they are within a coral reef, let alone the fact that much of what they are strolling through is of symbiotic origin. Northern New Mexico shows the dinomastigote-coral creation expressed as a limestone "kiva" by Pueblo Native Americans. These sacred structures could be considered a kind of habitat in which the Pueblos saw themselves as closer to mother earth (Cajete, 1994). We can also appreciate now that these gatherings within such sites were in actuality cultural meetings within reconstructed symbiotic reefs. A view of the central mountain regions in China almost seems like the reef has just lifted out of the sea, while here the perimeters of sea mountain tops in Hawaii evolve fringing and lagoon reefs. We can traverse the countryside of North Isle, New Zealand and touch lichen-covered ancient reefs and coccolithophorid- and foraminiferan-based limestone deposits as they protrude from nearly a sixth of the country. These massive reservoirs of calcium and carbon dominate both undersea and above sea features of the earth. Both the ancient and more modern exoskeletons of hermatypic corals function as luxuriant oases, upon which a mind boggling array of diverse mega- and micro-life depend (Wilson, 1992, p. 179). Indeed, it is right up there with rainforest canopies and our intestines as among the most diverse habitats on the planet, saturated with massive numbers of different eubacteria, archaea, and fungi.

Although recognized as massive deposits which result from the symbiosis of corals and micro-algae many decades ago, the reef in both the popular citizenry and scientific realms is primarily seen as a creation of animal ingenuity. Symbiosis education at this level becomes true myth-bashing! Coral-algal reefs are among the earth's most profound organelles. If the calcium within such reefs were released all in a day or moment, the effect on all life, including many microbes, would be catastrophic (Margulis and Sagan, 1995, pp. 133–134). Ecosystems on earth make sense to us because of the existence of these huge entities. Coral-algal reefs are chaos-breakers. Their existence – due substantially to symbiosis – makes us realize that element flow which drives life on earth is dependent on a series of weigh stations, holding patterns which in effect prevent nutrients from becoming toxic to most life forms.

Blotches of green represent hundreds of kilometers of undisturbed rainforest in Belize and Guatemala. Tropical rainforests are fundamentally defined not only by climate conditions of rain amounts and temperature but by the presence of epiphytes which in large part form the multi-tiered canopy structure of this most diverse of all macro-ecosystems. While more research is needed, there are indications that an essential component in rainforest formation is based upon symbiosis. Common cyanobacterial lichens dominant in rainforests appear to raise the pH which may aid the conversion of bark to humus and their nitrogen-fixation may aid in the following step of plant epiphyte colonization (Y. Gauslaa, personal communication). Moreover, the high water absorption of lichens may prove beneficial to colonizing seedlings. Simultaneously, symbiosis helps structure the rainforest at the soil plant interface through mycorrhizal development, as well as higher in the strata through their obligate infection of orchid seeds (Forsyth and Miyata, 1984, p. 18–19).

Coastal regions around the world show vast amounts of phytoplankton as represented in these red areas around Baja California. Much of this so-called "phytoplankton" are or were once a part of symbioses. Protoctist symbioses in coastal areas, especially among ciliates, radiolarians, and forams is widespread (Anderson, 1983; Lee, 1983).

Not only have we been falsely taught that there are mainly individuals in biology, but we have neglected the emerging notion that the earth's life systems are substantially due to symbiotic processes. And all this with barely a mention of the established symbiotic origin of mitochondria and plastids in most eukarya groups. The realization that fundamental cell organelles of eukarya groups have a different ancestor than the likely archaea domain, nucleated hosts is profound and should be a driving force in re-imagining our view of life systems and their evolution. The symbiotic construction of our cells, combined with the vast amount of microbes interdependent within and on us, suggests that our vast and growing built environment is a kind of symbiotic extension, an excreting reef of sorts, expressed perhaps from satellite as New York City!

All of us at this conference are well convinced of the dynamic nature of symbiotic studies. It is reflected in our research and in our exchange of ideas. But the distance between what we do and realize and the textbooks, references and even scientific journals around us is substantial. This distance is magnified even further when we add the concept of curriculum – whether at 5th grade or 15th grade – to the issue. Despite the fact that all this is known – and little of what I have said today is truly controversial or unaccepted – symbiosis too frequently teeters only on the edge of deep biological thought and earth system understanding. As professionals intimately involved with symbiosis, our responsibility must go yet another step: We must contribute toward a building of symbiosis into school curriculums. Through symbiosis, there is even potential for a more integrated science curriculum, particularly at the high school level. After all, can one find another science discipline that has so many interconnections? Symbiosis understanding frequently involves massive doses of biochemistry, genetics, physiology, biophysics, microbial ecology, geology, and history.

But, how can we make this step beyond today and into mainstream science learning? Here are some reachable proposals:

First, be a risk-taker and forge partnerships whenever possible which link symbiosis themes and innovative pedagogy. We as scientists are finally realizing that the "how" of teaching is as important as the "what." The National Academy of Sciences' recent National Science Education Standards Committee – to which I was a part for three years – produced an accessible vision to improve science education in America (National Research Council, 1996). And, if we examine it closely, we find that the emphasis for change is not in the content sections of the document, but in the re-directing of how students learn. The importance of symbiotic systems in understanding the planet and ourselves might make the greatest in-roads when it is linked to strong pedagogical movements in science education. Even at the undergraduate level, those of us who advocate for greater attention within the science and education communities to Symbiosis, would do well to investigate and even try potentially useful teaching methods such as portfolio-building, reflective journal keeping, small group discussions, ongoing open-ended experiments, problem-solving, and case study analysis. This partnership in thinking and behavior which merges symbiosis and pedagogy may provide a beneficial framework for growth.

Secondly, we can create specific professional alliances with a strong emphasis on working with instructors of life science courses at both pre-college and college levels. Through such ties, can we then advocate for life science course and curriculum changes which begin to include symbiotic studies. For example, if we are primarily involved in symbiosis research, we should carve out some time during the year to invite a biology instructor or professor to see what we are investigating and why we think it is important. If we are involved with teaching, whether pre-college or at college levels, we can reach out to those more knowledgeable and experienced in symbiosis. This growing professional acquaintance can then foster the development of curriculum that not only brings symbiosis into the course of study, but can even be a framework which unifies many sub-themes taught during the whole year or semester.

Thirdly, we must work with science education programs that seek to build important changes in life science curriculum at all levels. One such program which I direct is the international Microcosmos project based at Boston University. Microcosmos shows educators how the microbial world can be a dynamic learning vehicle in classrooms (Travis, 1992; Zook, 1995). Along with building an extensive set of curriculum activities now in use in hundreds of schools nationwide and in some countries overseas, the mostly volunteer-based Microcosmos Team of teachers, science researchers, artists, and students has conducted workshops and reached out to over 4,000 teachers. Given that nearly all symbioses have at least one microorganism in the relationship, symbiosis has become a key part of the Microcosmos effort. Microcosmos proposes to spearhead an effort that will help fill a void in the advocacy and teaching of symbiosis.

We propose building a Symbiosis Education Visual Collection. Our main objective is to collect and make available a collection of 35 mm color slides with accompanying information and descriptions that can be used at pre-college, undergraduate or graduate levels. Eventually they could be transferred to other more advanced media such as laser discs. We have found that no matter what methods and strategies are used in teaching, visual images are always a significant contribution to the learning process. Such a collection for symbiosis teaching – whether as part of a symbiosis course or as a way to help integrate symbiosis into life science courses and curriculum – would be a major step forward. Frequently, we as researchers wonder how we can contribute specifically to science education. Here is a direct way. We are asking that when everyone at this conference returns to their laboratories or other work situations that they select out a slide or a series of slides on their particular research symbiont or symbionts, make a copy of the slide or slides, and forward them with a brief description to us (Microcosmos, Boston University, 605 Commonwealth Avenue, Boston, MA 02215, Attention Dr. D. Zook). The non-profit Microcosmos project will eventually build a marketable collection of symbiosis slides for use. Those who have contributed would be able to receive the slide collection at cost. Of course, all contributors will be fully acknowledged.

Frankly, there is always a very wide gap between science research and what is actually presented in classrooms at any level. This is unfortunate and may never be completely closed by the very nature of the disciplines and the scale of human populations. However, Micrcosomos within the important framework of microbial and symbiotic themes seeks to diminish this gap. This slide collection effort will go a long way to not only making important resources and knowledge from the symbiotic research community available, but will help forge better links between those primarily interested in teaching about symbiosis and those mainly involved with investigating.

We have some important challenges before us. The themes and ideas we find so intriguing and interesting must be allowed to percolate into classrooms. We can all help foster this important step. Indeed, perhaps the day when many students are aware of our sample gallery of symbionts discussed earlier is the day that life science learning will have broadened and become more reflective of how the earth really works.

REFERENCES

Anderson, O.R. 1983. *Radiolaria.* Springer-Verlag, New York.

Cajete, G. 1994. *Look to the Mountain: An Ecology of Indigenous Education.* Kivaki Press, Durango, CO.

Chronic, H. 1987. *Roadside Geology of New Mexico.* Mountain Press, Missoula, Montana.

Drummond, H. 1894. *The Ascent of Man.* James Potts, New York.

Forsyth, A. and Miyata, K. 1984. *Tropical Nature: Life and Death in the Rainforests of Central and South America.* Charles Scribner's Sons, New York.

Gauslaa, Y., August 10, 1997, personal communication.

Lee, J.J. 1983. Perspectives on algal endosymbionts in larger foraminifera. *International Review Cytology Supplement* **14**: 49–77.

Margulis, L. and Sagan, D. 1995. *What is Life?* Weidenfeld and Nicolson, London.

National Research Council 1996. *National Science Education Standards.* National Academy Press, Washington, DC.

Sapp, J. 1995. *Evolution by Association: A History of Symbiosis.* Oxford University Press, New York.

Stevens, P.R. and Kelley, K.W. 1992. *Embracing Earth: New Views of Our Changing Planet.* Chronicle Books, New York.

Travis, J. 1992. Reading, writing, arithmetic ... and microbes? *Science* **258**: 1299–1300.

Wells, H.G., Huxley, J., and Wells, G.P. 1929. *The Science of Life.* The Literary Guild, New York.

Wilson, E.O. 1992. *The Diversity of Life.* WW Norton, New York.

Zook, D.P. 1995. *Inner Space Journeys to Life on Earth: A Standards-based Companion for Science Educators.* Kendall/Hunt Publishers, Dubuque, IA.