INFECTION IN THE CLASSROOM:

Parasites as Models To Teach Biology

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In 1998 the American Society of Parasitologists (ASP) established a five-year plan to educate various groups about parasites and parasitology (Education Committee Report to ASP Council, 1998). Targeted groups included K-12 students and teachers, college students and teachers, biologists in other disciplines, the general public, and politicians. A variety of initiatives were undertaken to reach K-12 targets. Plans were made to develop a series of parasitology "kits" or lessons for teachers in the classroom. March 4th, the birthday of the founder of ASP Henry Baldwin Ward, was designated "National Parasite Day." On this day parasitologists were to visit third grade classrooms in their communities to discuss the field of parasitology, talk about their work, and show students parasite specimens. From these activities developed the idea of hosting a symposium and workshop for K-12 teachers

at the annual ASP meeting to inform them about the opportunities and resources available for using parasitology in their classrooms.

On July 2nd, 2001, in Albuquerque, New Mexico, scientists and local public school teachers met in a symposium at the 76th Meeting of the American Society of Parasitologists to discuss why K-12 teachers "need" parasites. Or rather, how they could use parasites and the study of parasitology in their curricula to stimulate their students, teach biological concepts, and meet the requirements of today's K-12 educational environment. In this paper we present ideas and opportunities discussed in the symposium that may be of value in meeting today's challenges. We discuss why biology educators should consider incorporating the study of parasitology into their curricula, provide examples of teachers using such strategies, and describe resources available.

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Why Study Parasites?

Webster's Third International Dictionary defines a parasite as "an organism living in or on another living organism, obtaining from it part or all of its organic nutriment, commonly exhibiting some degree of adaptive structural modification, and causing some degree of real damage to its host." Given this definition, parasitism is arguably the dominant lifestyle on the planet Earth. Price (1980) estimated

that greater than 50% of all plant and animal species are parasitic at some point in their life. Rhode (2000) provides a useful overview with many examples of creatures that exhibit a parasitic way of life. From another perspective, Esch and Fernández (1993) suggested that the important question is not how many parasitic species there are, but how many plants and animals are parasitized? A quick examination of the literature suggests that virtually every organism is parasitized and typically by more than one parasitic species. Janovy and Roberts (2000) note that there are over 100 different species of protozoa, helminths, and arthropods known to infect humans. In addition, one must consider the increasing number of studies reporting parasites having their own parasites (i.e., hyperparasitism). Such considerations lead to the question of how biology can be studied without a careful examination of why and how this is so. To study parasites from a variety of perspectives (historical, molecular, cellular, organismal, ecological, and evolutionary) is to study a large part of biology.

Parasites are a significant public and veterinary health issue. Table 1 presents World Health Organization (2001) estimates of prevalence, morbidity, and mortality for 10 of the most common eucaryotic parasitic diseases. To examine one of these in detail, American trypanosomiasis (also called Chagas disease) is caused by the protozoan parasite *Trypanosoma cruzi*. In some surveys from Brazil, it is reported that 30% of all adults die from Chagas disease transmitted to people via the feces of cone-nosed bugs (Hemiptera: Reduviidae). About 19 million people in Central and South America are infected with *T. cruzi*, another 35 million are exposed to the parasite, and 45,000 people die every year. In fact, some historians have speculated that Charles Darwin may have contracted and died from Chagas disease (Janovy & Roberts, 2000). In the U.S., *T. cruzi* has been found from Maryland to Florida and may be especially prevalent in the southwestern U.S. This emphasizes the importance of another

aspect of parasitology, that is the transmission of parasitic diseases from animals to humans (i.e., zoonotic diseases). Animals that live in close proximity to people, such as dogs, cats, opossums, armadillos, and wood rats, act as important reservoirs for human infection. *Toxoplasma gondii*, a protozoan parasite that normally occurs in felines and rodents, is now known to cause human birth defects when acquired by pregnant women and has become a serious opportunistic disease in AIDS and other immunocompromised patients.

Perhaps of most interest to teachers, however, parasites provide excellent examples and opportunities to explore many biological concepts and, by considering the variety of perspectives from which to investigate parasitology, teaching units can be designed to meet many of the national, state, and local standards and outcomes required today. For example, the National Research Council (NRC) *National Science Education Standards* (1995) lists four standards that pertain directly to biology education:

1. Science as Inquiry Content Standard A—Understanding of and abilities to do scientific inquiry.
2. Life Science Content Standard C—Understanding the cell; molecular basis of heredity; biological evolution; interdependence of organisms; matter,

Table 1.

Estimated total number persons infected, morbidity, and mortality of some of the most common eucaryotic parasitic diseases that infect humans.¹

PARASITE	NUMBER INFECTED	MORBIDITY	ANNUAL MORTALITY
Malaria	200-300 x 10 ⁶	—	1-2 x 10 ⁶
Leishmaniasis	12 x 10 ⁶	—	—
American Trypanosomiasis (Chagas disease)	15-18 x 10 ⁶	—	—
African trypanosomiasis (Sleeping sickness)	3-5 x 10 ⁵	—	25,000+
Ascaris (human roundworm)	1,472 x 10 ⁶	335 x 10 ⁶	60,000
Hookworm	1,298 x 10 ⁶	159 x 10 ⁶	65,000
Trichuris (whipworm)	1,049 x 10 ⁶	200 x 10 ⁶	10,000
Schistosomiasis	200 x 10 ⁶	20 x 10 ⁶	20,000
Onchocerciasis (river blindness)	18 x 10 ⁶	2.7 x 10 ⁵	45,000
Lymphatic filariasis	120 x 10 ⁶	44 x 10 ⁶	—

¹ Derived from Crompton, 1999 and WHO data available at www.who.org.

energy, and organization in living systems; behavior of organisms.

3. Science in Personal and Social Perspectives Content Standard F—Personal and community health; population growth; natural resources; environmental quality; natural and human-induced hazards; science and technology in local, national, and global challenges.
4. History and Nature of Science Content Standard G—Science as a human endeavor; nature of scientific knowledge; historical perspectives.

There are many examples of parasites and the diseases they cause that can be used to develop units of study that meet all the above standards. A unit focusing on malaria, for example, could be designed to meet all of these standards while simultaneously integrating a variety of disciplines. Investigating the biology of the malaria parasite (*Plasmodium* sp.) and the interactions between it and the host provides diverse opportunities to help students understand and practice the scientific method and learn content material to meet Standards A and C. The significance of malaria as a public health problem provides opportunities to investigate science from personal and social perspectives and the components of Standard F. Finally, the effect of malaria on the course of human history and the history of the investigation of the disease provide opportunities to address the history and nature of science and science as a human endeavor (Standard G). Table 2 provides a list that includes not only recommended books and Web sites on malaria, but also recommended readings and Web sites on parasites and parasitology in general for nonspecialists. The latter resources could aid with the development of units focused on other parasite groups

Beyond academic rationales, parasites can be beautiful, fascinating, and sometimes horrifying organisms that can be used to stimulate discussion and excite students about biology and a variety of biological concepts. Consider students who are most interested in the arts and humanities and examine the electron micrographs in

Table 2.

Recommended readings and Web sites with information on parasites and parasitology for nonspecialists.

READINGS

- Desowitz, R.S. (1981). *New Guinea Tapeworms and Jewish Grandmothers: Tales of Parasites and People*. New York: W.W. Norton and Co.
- Desowitz, R.S. (1997). *Who Gave Pinta to the Santa Maria?: Torrid Diseases in a Temperate World*. New York: Harcourt Brace and Company.
- Desowitz, R.S. (1991). *The Malaria Capers: More Tales of Parasites and People, Research and Reality*. New York: W.W. Norton and Co.
- Zimmer, C. (2000). *Parasite Rex: Inside the Bizarre World of Nature's Most Dangerous Creatures*. New York: The Free Press.

WEB SITES

- American Association of Veterinary Parasitologists <http://www.aavp.org/>.
- American Museum of Natural History "Epidemic: the World of Infectious Disease" <http://www.amnh.org/exhibitions/epidemic/index.html>.
- American Society of Parasitologists <http://asp.unl.edu/>.
- Center for Disease Control <http://www.cdc.gov/>.
- Monocystis: Earthworm Parasite <http://www.carolina.com/manuals/index.asp>.
- National Institutes of Health <http://www.nih.gov/>.
- Ohio State University Parasites and Parasitological Resources <http://www.biosci.ohio-state.edu/~parasite/home.html>.
- United State Department of Agriculture Biosystematic and National Parasite Collection Unit <http://www.lpsi.barc.usda.gov/BNPCU.html>.
- World Health Organization <http://www.who.int/home-page/>.
- United Nations Development Programme: World Bank-World Health Organization Special Programme for Research and Training in Tropical Diseases <http://www.who.int/tdr/index.html>.

Figure 1. The detailed pattern of the surface of the structure in Figure 1a is the surface of a segment (proglottid) from a tapeworm (*Tylocephalum* sp.) magnified 10,000X. This illustrates not only the interesting patterns to be found in rather surprising places, but also the biological principle of enhanced efficiency through surface area elaboration. In this case the tapeworm has evolved an exterior surface in contact with the lumen of the intestine and digested food very much like the hosts villi-covered intestine, thus increasing absorptive efficiency. Figure 1b

Figure 1a.

Scanning electron photomicrograph of the surface of a segment (proglottid) of a tapeworm (*Tylocephalum* sp.) Provided by Kirsten Jensen.

Figure 1b.

Cultured bovine fetal fallopian tube epithelial cells and microvilli with two parasitophorous envelopes enclosing intermediate stages (meronts) of the intestinal protozoan parasite *Cryptosporidium parvum* (from Yang et al., 1996, with permission American Society for Microbiology).

might be an interesting scene for a science fiction story, but in fact is a scanning electron photomicrograph of a stage in the development of *Cryptosporidium parvum*, an intestinal protozoan that infects people. What creative student would not be inspired by these interesting images from such unlikely sources?

The details of many parasite life cycles are incredibly fascinating and, consequently, can be effectively used to

interest students in the biology curriculum. Studies of how parasites manipulate host behavior and appearance to enhance transmission to subsequent hosts is one area that students find particularly interesting. For example, Roberts and Janovy (2000) describe the life cycle of the lancet fluke (*Dicrocoelium dendriticum*) that occurs as an adult in the bile ducts within the livers of sheep, cattle, goats, pigs, deer, and rarely, humans. Adult flukes lay eggs that are passed in the feces. Inside the egg a small immature fluke or miracidium develops. Land snails find herbivore droppings a rich source of nutrition, and when feeding, eat the egg; the miracidium hatches out and penetrates the gut wall, transforming into a mother sporocyst in the digestive gland of the snail. The mother sporocyst then multiplies asexually to produce daughter sporocysts that asexually produce many cercariae. These then migrate to and accumulate in the lung or mantle cavity and the body surface of the snail. This irritates the snail, causing it to produce a mucous secretion that encases the juvenile in a “slimeball” that falls off the snail as it crawls along. A slimeball may contain up to 500 cercariae. Drying of the exterior of the slimeball retards drying of the interior and protects the juveniles from lethal desiccation.

It is at this point that the life cycle takes a rather bizarre twist that reads more like the plot of a horror movie. Slimeballs are dietary items for ants, and on eating or feeding them to their larvae, the ants become the second host, infected with the cercariae, which encyst and become infective to the final host—the herbivore. Interestingly, over 100 encysted 4th stages can be present in a single ant with most encysting in the blood cavity of the body. One or two, however, will

migrate and encyst in the subesophageal ganglion or brain of the ant. These are not infective, but they do affect the ant's behavior in a most unusual way. In the evening when the temperature declines, the infected ants, rather than returning to the colony like their uninfected nestmates, climb to the tops of grasses and other vegetation and lock on with their mandibles where they remain until the temperature increases the following

day and they resume their normal behavior. Herbivores most actively feed in the late evening/early morning hours of the day. The infected ants, via their behavior, increase the likelihood of being ingested by the final host, thus completing the parasite's journey from one host to another. Interestingly, this anomalous behavior appears to have been induced by the parasite. In addition, the encysted juveniles that induced the behavior by encysting in the ant brain are not infective.

Discussions of life cycles such as this can lead to wide ranging discussions of concepts such as parasite-host coevolution and life history strategies. Brown and Thompson (1986) describe a series of experiments suitable for advanced high school and undergraduate college students using an acanthocephalan (thorny headed worm) (*Pomphorhynchus laevis*)—freshwater shrimp (*Gammarus pulex*) fish system demonstrating parasite manipulation of host morphology and behavior enhancing transmission.

Of course, parasites and their effects on hosts can also be horrifying. There are few who don't shudder at the sight of an individual whose face is disfigured due to the tragic effects of mucocutaneous leishmaniasis or the grossly swollen limbs or genitals, termed elephantiasis, of one suffering from Bancroftian filariasis. However, as a quick review of the popular media would indicate, there is a certain curiosity in young people about the horrifying and grotesque. Parasites can be used to examine real conditions and issues and learn from this curiosity.

Examples of Parasites & Parasitology in the Curriculum

Although parasites are not widely appreciated, there are teachers who have developed lessons and activities that incorporate parasitological perspectives to teach a number of different biological concepts. In the symposium at Albuquerque, one presentation described how parasitology was used to enhance a problems-based activity investigating organ form and function at a high school in Casper, Wyoming. For this activity, students were introduced to parasitology by considering the meaning of a poem written by Jonathan Swift (*On Poetry*):

*So, Nat'ralist observe, a Flea
Hath smaller Fleas that on him prey,
And these have smaller Fleas to bite'em.
And so proceed ad infinitum.*

Class discussion of this passage led to a consideration of parasitology and parasites and the ubiquity of these types of interactions. In the course of the discussion students learned, from a biological/ecological perspective, that all living organisms could be viewed as habitat, and almost every habitat has been colonized by

some type of organism. Also, organisms must meet certain essential needs to survive: they must acquire food/energy, reproduce, colonize new habitats, and adapt to change. Parasites are no different, and in fact they have developed some rather strange adaptations and behaviors to accomplish this.

For the next part of the activity students, working in small groups, dissected a cow heart, lung, or kidney and were asked to examine organ structure and identify important morphologic features. As they performed the dissection, they were instructed to think about the organ from a parasite's perspective. If you were a parasite living in that organ, what would you eat? How would you reproduce and how would your offspring colonize similar habitats in other hosts? How would you avoid the host's response to your presence? These questions were designed to guide the students to a more complete investigation and understanding of the structure and function of selected organ or habitat. In particular, given the structure and function of the organ:

- What microhabitats are available?
- What resources are available for energy?
- What are the pathways by which the organ could be colonized?
- What kinds of reactions (immune) might be stimulated by your presence?

After completing this exercise students received the problem: Imagine you are a parasite. Write a creative essay describing and explaining your existence. In your essay identify your habitat (host, organ, tissue, and/or cell) and describe and explain how you meet the essential needs for survival listed above. Students were provided with a variety of resources (literature and Internet) to investigate the problem and were asked to read *Do Parasites Rule the World?* (Zimmer, 2000). In addition, an invited parasitologist fielded questions on parasitology and described parasites of particular organs/habitats and their life cycles. Later, using bobcats obtained from a local trapper, the parasitologist demonstrated an animal necropsy and parasitological examination, and students, using dissecting microscopes, examined intestinal scrapings for tapeworms and nematodes. This activity caused quite a bit of excitement, as many students had never observed the internal structure and organization of a mammal, and bobcats and other wild predators are often infected with large numbers of gastrointestinal worms. With these experiences and information, students wrote their essays, imagining they were parasites and describing their existence, which they later read and then explained to classmates and instructors.

A second speaker in the Albuquerque symposium described how thematic units can be developed that use

Table 3.
Types of diseases studied classified by mode of transmission, disease, taxonomic group, and causative agent.

MODE OF TRANSMISSION	DISEASE	TAXON	CAUSATIVE AGENT
Waterborne	Acanthamoeba keratitis	Protozoa	<i>Acanthamoeba</i> spp.
	Amebic meningitis	Protozoa	<i>Naegleria fowleri</i>
	Schistosomiasis	Trematoda	<i>Schistosoma</i> spp.
		fluke	
Foodborne	Trichinosis	Nematoda	<i>Trichinella spiralis</i>
		roundworm	
	Taeniasis	Cestoda	<i>Taenia solium</i>
		tapeworm	<i>Taenia saginata</i>
Vectorborne	Malaria	Protozoa	<i>Plasmodium</i> sp.
	American trypanosomiasis	Protozoa	<i>Trypanosoma cruzi</i>
Fecal/oral	Amebic dysentery	Protozoa	<i>Entamoeba histolytica</i>
	Cryptosporidiosis	Protozoa	<i>Cryptosporidium parvum</i>
	Ascariasis	Nematoda	<i>Ascaris lumbricoides</i>
		roundworm	

parasites as model organisms and also integrate standards from other disciplines. A high school teacher in Albuquerque, New Mexico, described how she developed a unit for her biology course around cell structure and function that incorporated the novelty of parasite and host interactions. Throughout the unit students focused on unicellular parasites to identify key biological concepts. The activities also allowed integration of standards in language arts through narrative writing and career readiness skills through production of a resume. The goals of the unit included the presentation of a narrative with a visual model or slide presentation on the parasite that emphasized specific traits such as transmission types, reproduction, etc. Students also prepared a resume by the parasite, seeking employment in an alternate host.

Another speaker described a program in which graduate students in the School of Public Health at the University of Texas Health Science Center at Houston worked with local high school teachers to develop and implement a parasitology unit. The goals of the project were to have graduate students reinforce their understanding of parasitology by teaching it to others and to provide public health information to community and public school settings.

The program consisted of three phases. In the first phase, high school teachers responsible for an honors

program devoted two weeks of classes to integrating material on several parasitic diseases into a unit on cell structure and function. The types of diseases studied included those that were waterborne, foodborne, vectorborne, and fecal/orally transmitted (Table 3). UT-Houston graduate students taught the teachers about the diseases and produced a variety of materials for teacher use including PowerPoint® lectures, handouts, digital parasite images on compact disk, laboratory activities, exam questions, and Web site directories. In addition, each graduate student was required to present one lecture and lead one laboratory activity in the classroom.

Reactions to Phase 1 by graduate students, teachers, and high school students were positive. On project evaluations, graduate students stated that the activity aided their comprehension of the subject matter, helped them develop an appreciation for presenting public health information to a general audience, and found that the activity was a personally-rewarding experience. The teachers stated that the activities stimulated student interest in the subject, provided guidance and information to facilitate learning in the classroom, and demonstrated that the university valued public educators. The high school students found the activities interesting, involving, and thought-provoking.

The second phase of the program, supported by the National Institute for Health, provided summer

fellowships for teachers to develop curricular units that refined and extended the resources developed in Phase 1. The teachers also worked to align the program with the Texas Essential Knowledge and Skills standards and the district biology curriculum, and construct a program that could be used district-wide. The result of the project was a unit of study on "Infectious Diseases and the Cell" that included lesson plans and materials on parasites and other pathogenic entities including viruses and bacteria.

The third phase involved encouraging the school district to adopt the program developed in the second phase by making this program available to all high schools in the district, and then assessing how the different schools used the unit. In this phase, the unit was modified to fit into the general biology curriculum and to address three different content issues: the effect of protozoan parasites on humans and their environment; the effect of pathogens on the cell and the organism; and the role of pathogens in disrupting homeostasis. The unit was then presented to district teachers in a series of workshops where they received materials including videos, PowerPoint® lectures, case studies, and a printed unit of study. The unit has now been adopted as part of the biology curriculum in the eight high schools of the district. Although the results of these efforts are hard to evaluate, there have been numerous requests for additional supplies and many positive comments about the activities and case studies. Teachers have also contributed new ideas and Web sites to the program developers, and graduate students have continued to generate supplemental materials.

Available Resources for Developing Parasite Units

There are a growing number of materials available to teachers to learn about parasitology and develop activities and units for their classrooms. At the ASP Web site (<http://www-museum.unl.edu/asp/>) teachers can click on the education button to access several resources. For example, the "Wonderwise Parasite Sleuth Kit" is designed for teachers in grades 7-9 and provides information and activities to stimulate student interest in parasites. Another link on the ASP Education site leads to the Educational Outreach page where teachers and students can click on their state/province to find parasitologists willing to serve as resources for parasitological endeavors. Also from the ASP homepage, teachers can access information on the society and careers in parasitology, and the "Parasite Photos" link leads to several Web sites providing digitized images of parasites, their life cycles, and descriptions of the diseases they cause. Table 2 provides additional Web sites and references presenting parasitological information for non-specialists.

Conclusions

Parasites represent one of the most successful life history strategies on the planet Earth. These remarkable creatures cause a variety of significant medical and veterinary problems that, in some instances, have shaped the course of human history. The biology of these organisms is illustrative of a wide diversity of biological phenomena ranging from the molecular to the ecological and evolutionary, and can be used to meet a number of the educational standards adopted at the local, state, and national levels. But beyond the biological justifications for study, parasites are fascinating, sometimes beautiful, and sometimes horrifying creatures, that can stimulate interest in a variety of biological phenomena and issues. We have presented information in this paper to encourage science teachers and students to use parasites as models to study biological processes and to use parasitology to illustrate the scientific process and the interactions of science and society.

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