Classroom Aquatic Ecosystems and Earth Science Systems: High School Curriculum Applications

By Tyler Brandenburg
CCWI Fortuna Water Quality Project

Abstract This paper will consist of a discussion of how a classroom aquatic ecosystem can serve as an educational tool to enhance the synthesis of Earth Science Systems concepts to benefit a high school curriculum. Including what students can learn from a classroom aquatic ecosystem in terms of wastewater treatment processes, a sample curriculum for a high school science class, and suggestions for future classroom aquatic ecosystem projects for high schools.

Key words: living machines, classroom aquatic ecosystems, earth science systems, biological engineering, and wastewater purification.

Introduction

A classroom aquatic ecosystem contains distinguished but interrelated ecosystems, known as mesocosms, that students create by collecting living organisms from local habitats and other aquatic environments. Students observe and conduct science-based inquiries into how natural systems work and how their communities affect nature. The design of each aquarium or cell becomes a distinct habitat that is home to diverse communities of organisms. Water flows in a re-circulating manner from one cell to another, linking the cells into a biologically diverse ecosystem with its own complex food web (http://www.oceanarks.org/). Ecological and biological engineers use the design of such ecosystems or mesocosms at larger scales and diversity to perform a wide variety of tasks, one of which is wastewater purification.

The wastewater purification technique of living technologies pioneered by the eminent biologist, John Todd, rest upon the design of ecological systems (Todd, 1996).

Todd’s patented method utilizes that of “living machines”. The growing popularity and success of living technologies has revolutionized the wastewater treatment industry.

There are numerous academic components and educational opportunities that can be attained through the study of living machines as a method of wastewater purification at the high school level. The classroom aquatic ecosystem will be the central constituent to which these educational opportunities and scientific methods are exemplified and investigated.

Development and research associated with the design of living technologies rests upon the disciplines of ecology and complex systems. Thus, the application of living machines to an academic context authorizes an earth science interdisciplinary approach that incorporates biology, chemistry, geology, and physics into the study of living machines using an earth science systems (ESS) approach.

Ecological engineering and the systems approach

Ecological engineering is an emerging field capable of addressing a broad range of issues. Many of its practitioners believe it will change the future of waste treatment, environmental restoration and remediation, food production, fuel generation, architecture and the design of human settlements. Ecology is the long-term design framework for the development of new technologies to support the growing populations on Earth (Todd, 1996).

Todd and his colleagues use ecological technology, living technology, ecologically engineered system and natural treatment system interchangeably. Ecological technologies have attributes that separate them from conventional technologies. Mitsch (1993) defined ecologically engineered technologies as being unique in that they apply in their design a wide range of selected life forms, which in new settings have the ability to co-design with the engineer.

He wrote, "Ecological engineers participate in ecosystem design by providing choices of initial species as well as the starting conditions; nature does the rest". This perspective represents a major shift in the way humans view themselves in relation to ecological systems and technology.

The science of designing models of natural systems in laboratory settings has advanced the knowledge of ecological engineering. Adey and Loveland (1991) have been at the forefront of this effort. Their contribution has been to design microcosms and mesocosms, such as mangroves or tidal pools that replicate living systems. To support the intensive care of complex systems housed in small physical spaces they have developed energy intensive ecological support technologies including algal scrubbers. Adapting ecological processes into confined spaces to perform a specific task had led to technological innovation of a high order (Todd, 1996).

Kauffman (1993) has studied how self-organization, ranging in scale from the molecular level to large ecosystems, emerges in nature. He has proposed an explanation of why self-organization and self-design occur in the natural world and why it is possible to use these attributes in technological settings. Further, he has attempted to elucidate what propels a living system towards the edge of chaos or a balanced state. This addresses the question of why a living technology works. The process involves establishing diverse life forms in new combinations of species within artificial settings for specific processes, such as water and soil purification (Todd, 1996).

Thus, in the most technical sense the study of living machines involves the self-organizing properties of ecological systems both natural and engineered. Due to the complexity and diverse disciplines that biological engineering encompasses in regard to wastewater purification an ESS approach proves to be beneficial in teaching the concepts to students.

Benefits of Living Machines to a classroom

Living machines authorizes an earth science interdisciplinary approach that incorporates biology, chemistry, geology, and physics into the study of living machines. The significance of studying ESS at the high school level is believed to be more pertinent for today's youth than it has been in the past.

The National Science Education Standards developed by the National Academy of Sciences/National Research Council identify earth science as a core science curriculum area that integrates chemistry, physics and biology in an applied context at all grade levels (STAT, 2003). Earth science-based courses include astronomy, aquatic science, environmental systems, and the course entitled geology, meteorology and oceanography (GMO). Many teaching associations across the nation strongly support the National Science Standards and believe that the addition of earth science-based courses to the core science curriculum options for high school students will provide students a better understanding of the environmental, energy and water issues that are challenging our state, nation and world (STAT, 2003).

Objective

In developing its Earth/Space System Science high school curriculum Montgomery County Schools in Maryland has drafted four key concepts for earth science systems. It is the objective of the ESS curriculum for the student to understand and apply these key concepts to real world scenarios. It is beyond the scope of this paper to include space systems to a sample curriculum, thus the following will be applied to earth science spheres.

Key Concepts:

I. The Earth system spheres (atmosphere, hydrosphere, geosphere, and biosphere) are distinct but interrelated and governed by physical laws.

II**.** Problems involving Earth systems can be observed and understood through the acquisition, management, and analysis of data gathered from various sources and viewpoints in an environment of team collaboration and individual accountability.

III. Material and energy imbalances within and among Earth systems give rise to events over a variety of time scales, some of which have an impact on human activities.

IV. Earth Science Systems are continually expanding and changing, as are the methods of viewing and measuring the systems.

A classroom aquatic ecosystem can be used to enhance the synthesis of the key concepts of ESS. The objective of ESS at the high school level is two fold. The first objective is to understanding the general themes, components, and function of a system, the second is to increase skills in lab work and identify the role of specific disciplines within the earth science context. Thus, sample lessons will be taken from specific disciplines (i.e. physics, chemistry, geology, and biology) while being applied to the key concepts of systems.

Methods

Classroom aquatic ecosystems are used to facilitate the study of ESS. The classroom aquarium system relies on the processes and scales of macrocosmic, mesocosmic, and microcosmic interactions among organisms and other vital earth science processes and relationships. The structure and composition of various macrocosmic, mesocosmic, and microcosmic relationships are analogous to ESS key concept number one: the Earth system spheres are distinct but interrelated and governed by physical laws. Figure 1 reveals the parallel application of key concept number one to both the classroom aquatic ecosystem and the earth science spheres (*see* appendix). This section outlines the use of such classroom aquariums in facilitating the study of earth science through a systems approach at the high school level.

An instructors experience and expertise will mandate the potential to which a classroom aquarium can be incorporated to every lesson plan. It is evident that some ESS lessons will be more applicable to a classroom aquatic ecosystem unit than others. Though to teach and capture the key concepts of ESS the unit can be considered with significant merit.

For this exercise ESS are organized into four interrelated systems or “spheres”: atmosphere, hydrosphere, geosphere, and biosphere. Matter and energy flow through and among these spheres in ways that are consistent with physical and chemical laws (key concept I.). Earth scientists organize their investigation around research themes, bringing together and synthesizing the content of a wide variety of disciplines, collecting and analyzing data from a number of viewpoints and across a number of time scales. They work collaboratively, manipulate large quantities of data, and look for ways to apply technology to the research task (key concept II.). The flow of matter and energy causes each Earth sphere to change constantly and results in natural events that can be observed and measured (key concept III.). Describing how each sphere is changing over time involves the understanding of past events compared to present conditions. The past and the present are, in turn, used to predict future changes in each sphere and in the Earth system as a whole (key concept IV.).

Curriculum and research themes include local and global climate change, stratospheric ozone depletion, volcanism and earthquakes, circulation of rock in the mantle and core, weathering and erosion of surface materials, severe weather outbreaks, droughts and floods, and the cycling of carbon. The discovery of additional interconnections among spheres and new ways to observe and measure known interconnections lead to the identification of new research themes. Figure 2 organizes the earth science spheres into sample curriculum themes (*see* appendix). The following sample curriculum will highlight how basic themes from each earth science sphere or discipline can be included when studying the systems approach of living technologies to wastewater purification.

One should note that the classroom aquatic ecosystem is a living model of earth science spheres. The model's productivity and health relies on the knowledge base of the instructor and the students, and their ability to co-design with nature to replicate diverse ecosystems that self-organize and optimize in order to process waste within the larger macrocosm. Thus, the classroom aquatic ecosystem is not designed to perform the specific task of wastewater purification, but the processes the govern water purification are inherent in the models productivity.

The Classroom Aquatic Ecosystem

The classroom aquatic ecosystem offers the student access to understanding the dynamic processes of interrelated systems on and inside the Earth and in its surrounding space environment by applying skills in observation and research, utilizing technology and community resources. Figure 1, shows the role of geosphere, hydrosphere, biosphere, and atmosphere sphere as mesocosms within the classroom aquatic ecosystem. Students work in collaborative groups with individual accountability to investigate background materials, participate in scientific experiments, and act as primary researchers. The teacher serves as facilitator or mentor of the research project. The following lists a California Department of Education (CDE) science content standard for each of the earth science spheres. These standards will be related to the classroom aquatic ecosystem.

CDE Science Content Standards:

Geosphere: *Students know* how to explain the properties of rocks based on the physical and chemical conditions in which they formed, including plate tectonic processes.

Atmosphere: *Students know* the different atmospheric gases that absorb the Earth's thermal radiation and the mechanism and significance of the greenhouse effect.

Biosphere: *Students know* biodiversity is the sum total of different kinds of organisms and is affected by alterations of habitats. *Students know* a vital part of an ecosystem is the stability of its producers and decomposers.

Hydrosphere: *Students know* how water, carbon, and nitrogen cycle between abiotic resources and organic matter in the ecosystem and how oxygen cycles through photosynthesis and respiration.

Biosphere Example

In the classroom aquatic ecosystem, design is based on the principles of forest, lake, prairie, and estuary ecosystems working together. These diverse ecosystems contain populations of bacteria, algae, microorganisms, snails, fish, flowers, and trees. Each organism fulfills a niche role in supporting the entire system. Snails graze on algae, slimes, and sludges to clean the tank and lay eggs on the walls and plants, while bacteria living in the “muck” (i.e. biofilm) and on plant roots breakdown wastes and become food for other organisms (http://www.oceanarks.org/).

In this example students must study and optimize the food webs established by the biodiversity of organisms within the classroom aquatic ecosystem. The significance of each organism is closely studied and revealed. Furthermore, as students continue to design and manipulate the populations of organisms or contaminants within the ecosystems they are able to directly experience and observe the effect that habitat alterations have on biodiversity and waste water purification.

Hydrosphere and Atmosphere Example

The primary energy source of a classroom aquatic ecosystem is sunlight driven by hydrological, mineral, and climate cycles. The incoming solar radiation is used in photosynthetic processes allowing plant life to grow. In addition, incoming solar radiation begins a discussion of atmospheric and greenhouse gases.

Since the beginning of the Industrial Revolution about 200 years ago, atmospheric concentrations of greenhouse gases including CO_2, CH_4 and N_2O have risen substantially. These increases are a result of a variety of anthropogenic activities such as the production and use of fossil fuels, as well as other industrial and agricultural activities (http://icp.giss.nasa.gov/research/methane/greenhouse.html).

In studying living machine wastewater purification techniques students learn to distinguish between scientific principles governed by a linear process and those governed by a systems or cylindrical process. The former principles have led to many malignant imbalances within the Earth’s spheres. While the later principles inherent in living machines, respond to the exploitation and depletion of natural resources and seek to heal waters by replicating and accelerating the natural purification processes of rivers, ponds, and wetlands.

The above ESS lesson example is related to key concept number three: material and energy imbalances within and among Earth systems give rise to events over a variety of time scales, some of which have an impact on human activities. This lesson mandates that students first gain knowledge in basic themes associated with atmospheric and greenhouse gases such as sources and sinks of gases and infrared and ultraviolet radiation. However, an ESS perspective allows the student to think critically about how human activities affect other earth spheres outside of the atmosphere. For instance, the Institute for Science and Climate states that a major anthropocentric source of the greenhouse gas, methane, is that of domestic sewage treatment. This exemplifies the inter-related characteristics of the hydrosphere and atmosphere and provides opportunities for the student to distinguish conventional domestic sewage treatment based on linear processes from living machine wastewater purification techniques based on an ESS approach.

Geosphere Example

In studying the processes of living machines one can find ample evidence of the significance of understanding geological processes and its relation to ESS. Brady (1990) argues that the biological richness of the earth is a result of the complexity and diversity of its mineral foundations. In areas of similar climate and weather patterns it is the bedrock that allows for fundamental ecological differences. Biological restoration and resilience is determined, to a large degree, by the rocks and minerals that make up the parent materials of soils. In mineral-rich zones, life can be extraordinarily abundant (Todd, 1996).

Todd's extensive years of research reveals that in designing living technologies mineral diversity should include igneous, metamorphic, and sedimentary rocks. An opulent mineral base will provide for a diverse combination of biological diversity, thus allowing the systems greater capacity to self-design and optimize (Todd, 1996).

By studying the ideal conditions for designing ecologically engineered systems, students can play a direct role in choosing the preliminary mineral base for the classroom aquatic ecosystem. An ESS instructor can facilitate the basic themes of geology that are conventionally taught at the high school level. The health and integrity of a classroom aquatic ecosystem is directly correlated to the extent of which students collect rocks locally and use identification skills to ensure mineral diversity.

In this scenario students are initially acquainted with a basic knowledge of geologic processes. However, removing the mineral mesocosm from the system or manipulating the balance of mineral diversity can reveal several of the key concepts of ESS. Students are able to observe how a disturbance of one earth sphere affects every other sphere within the larger whole system or macrocosm.

Conclusion

Examples such as those described above can serve as pivotal tools by which an instructor leads a larger discussion on geological processes such as those relevant to the major research themes of earth science i.e. local and global climate change, stratospheric ozone depletion, or volcanism and earthquakes. An ESS curriculum facilitates and prepares a student to be able to address the most pertinent issues regarding the environment, energy, and water facing present and future generations.

With the aid of a classroom aquatic ecosystem, an instructor poses several questions that lead students to think critically about a giving topic utilizing a systems approach to answer the question. For example, what other large-scale energy imbalances occur due to human activity? These types of inquiries congeal and encompass the comprehensive objectives of utilizing a classroom aquatic ecosystem at the high school level.

First, students will be able to recognize the specific processes of a discipline such as geology and mineral identification. Second, a student will investigate human activities that cause an imbalance in one Earth sphere such as petroleum exploration and combustion. Furthermore, the student will understand the flow of energy and matter from one sphere to the other, such as fossil fuel combustion and an increase of greenhouse gases and the depletion of atmospheric ozone.

Awareness of earth science concepts is integral to all students' ability to understand the problems and challenges that are of primary importance to today's world. Students who have studied the scientific knowledge and processes of earth science systems will be better prepared to critically analyze the information provided by special interest groups and make informed decisions that are based upon scientific fact (STAT, 1993).

Appendix

Figure 1.

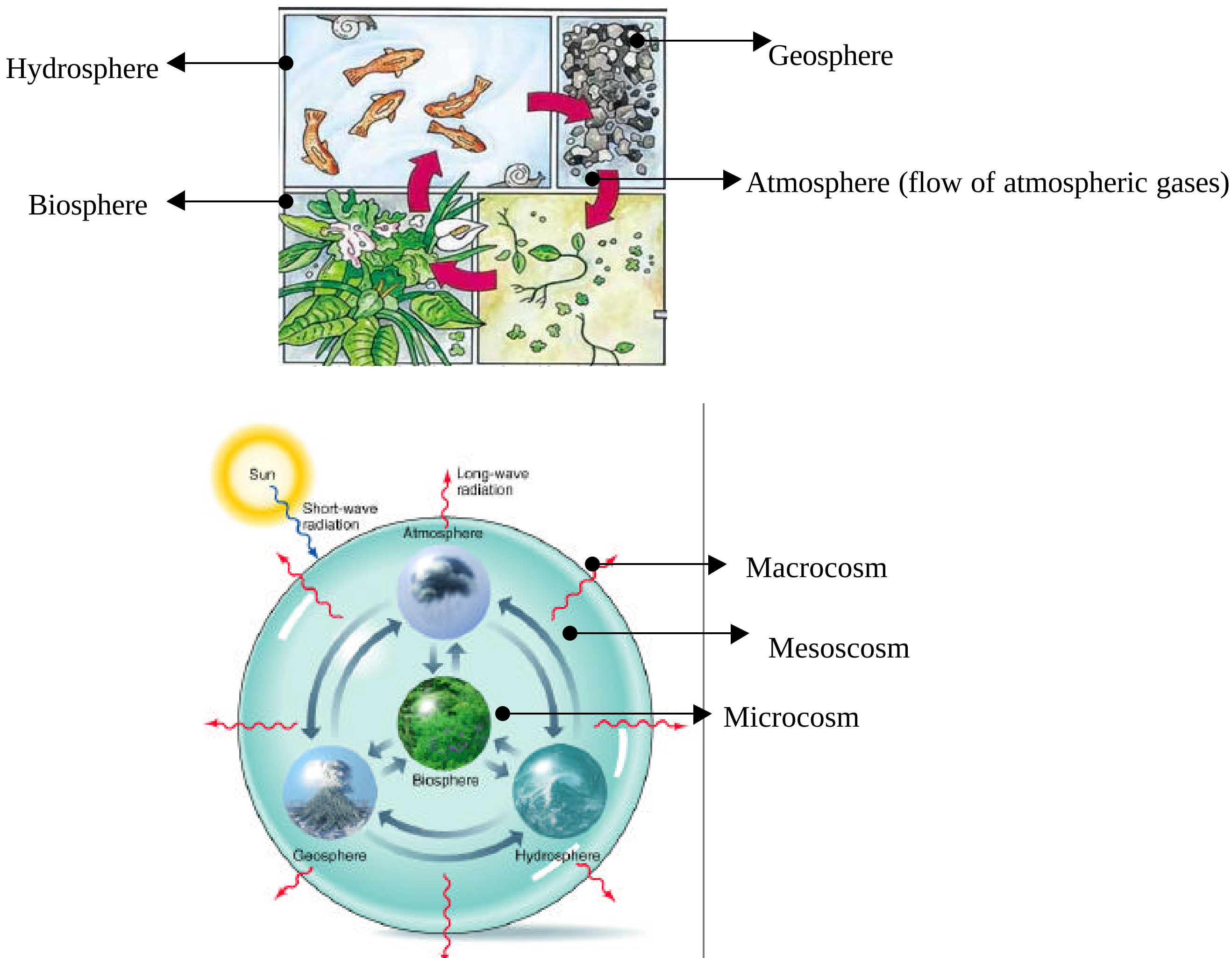

Figure 1. The Earth system spheres are distinct but interrelated and governed by physical laws. Figure 1 reveals the parallel application of key concept number one to both the classroom aquatic ecosystem and the earth science spheres.

Figure 2.

Hydrosphere	**Biosphere**	**Atmosphere**	**Geosphere**
Structure of Hydrosphere	Connect to other Earth Science Systems: carbon cycle, chemical elements, impact of environment on organisms, evolution of life on earth	Matter in the Atmosphere: composition, structure, and molecular interaction (pressure, temperature, and volume)	Rocks and Minerals: identification- hardness, luster, specific gravity, streak, color, cleavage
Global Water Cycle and Cryosphere: latent heat, ice, albedo, sea level	Environmental Impact: greenhouse gases and climate	Energy and Circulation Patterns: Earth's energy budget- heat, radiation, and albedo	Composition: igneous, sedimentary, and metamorphic
Transfer of Energy: vertical currents, weather, and climate	Analysis of a Biosphere sub-system within the Earth Science systems	Investigating Atmospheric Events: greenhouse effect and global warming	Processes: metamorphism, weathering, erosion, deposition, melting, and crystallization

Figure 2. Table of Earth Science systems topics organized by related Earth Science sphere. Source: Montgomery County Public High School. Complied into table by author.

Work Cited

Anne Arundel County Public Schools.2002. *Earth Space Systems Science: Unit 1: Introduction to Systems.* NASA Goddard Education Program.7

Brady, N.C.1990. *The Nature and Property of Soils,* 10th edn. Macmillan, New York, NY.

CDE[California Department of Education].2003. [http://www.cde.ca.gov/standards/science/earth.html]

ICP[Institute on Climate and Planet]. *The Greenhouse Effect, Greenhouse Gases, and Global Warming.* 2003. [http://icp.giss.nasa.gov/research/methane/greenhouse.html].

Kauffman, S.A.1993. *The Origins of Order: Self Organization and Selection in Evolution*. Oxford University Press, New York, NY.

Lovelock, J.1988. *The Ages of GAIA*. W.W. Norton, New York, NY.

Mitsch, W. J.1993. *Ecological engineering*. Environ. Sci. Technol., 27: 438-444.

Mitsch, W.J. and S.E. Jørgensen (Eds.).1989. *Ecological Engineering: An Introduction to Ecotechnology*. John Wiley and Sons, New York, NY.

Montgomery County Public High School.2002. *Draft High School Earth/Space Systems Science Framework 7*.

OAI[Ocean Arks International]. 2003. [http://www.oceanarks.org/]

Science Teachers Association of Texas (STAT).2003. *Position Statement Supporting Earth Science as a Core Science*. Adapted 1.

Todd, John and Beth Josephson.1996. *The Design of Living Technologies for Waste Treatment: Twelve Principles for the Design of Ecologically Engineered Systems Ecological Engineering.* 6 109-136.