2006-644: A COMPREHENSIVE COURSE IN ENVIRONMENTAL BIOLOGY

David Vaccari, Stevens Institute of Technology

A COMPREHENSIVE COURSE IN ENVIRONMENTAL BIOLOGY

Introduction

A new course was developed to introduce environmental engineers and scientists to biology. The primary novelty of this course was its division of the subject into three core areas of relevance to environmental professionals: microbiology, ecology, and toxicology.

This paper will further describe the need that exists for this course, and will introduce a textbook and other materials that were developed for the course. A somewhat novel approach to the use of computer presentation materials has also been developed for this course, and this is also described here.

The Need for the Course

The course was originally developed for an environmental engineering program. Those coming from a science background might be surprised to discover that engineers typically do not have a single biology course in their bachelor's degree programs. Environmental engineering students often receive only a brief exposure to sanitary microbiology, completely neglecting a vast range of biological issues and concerns. However, the growth of the environmental sciences has greatly expanded the scope of biological disciplines with which engineers need to deal. With the possible exceptions of biomedical and biochemical engineering, environmental engineering is the engineering discipline that has the closest connection with biology. Certainly, it is the only engineering discipline that connects with such a wide range of biological fields.

Table 1 shows the results of a pre-test administered to a class of 9 graduate and undergraduate environmental engineering students. The results show a very low familiarity with basic ideas from general biology.

Table 1. Percent of students who showed familiarity with biological concepts

Evolution	33%
Eukaryotes	11%
Carbohydrates	33%
Lipids	67%
Amino acids	56%
Org chem structure	22%
Enzymes	56%
Bacterial cell walls	33%
Mitosis vs. meiosis	0%
Osmosis	44%
ATP	33%
1st order reactions	11%
Chemistry of genes	11%
Cross-breeding	33%
Transcription	22%

The need to make engineers literate in biological concepts and terminology resulted in the development of a new graduate-level course designed to familiarize engineers with the concepts and terminology of a broad range of biological disciplines relevant to environmental engineering. The course is also offered to upper-level undergraduates.

The course has been taught to both graduate and undergraduate environmental engineering students for twenty years. However, no textbook was found that focused on the three areas mentioned above. General college biology textbooks included microbiology and ecology, but excluded toxicology. Furthermore, they lacked the depth needed for this specialized field. Some introductory environmental engineering or science textbooks covered all the required areas, but also not in sufficient depth. Nevertheless, general biology textbooks were initially used for the course, supplemented with additional materials.

Eventually, a textbook was developed based on the course. The textbook was designed for a target market broader than environmental engineers, to also include other environmental professionals. As a result the course, itself, is appropriate for providing a basis in biology for chemists, geologists, and others who apply their fields for protection of the environment.

The Course

The pretest results show the need to teach basic concepts in an environmental biology course, as well as the specialized topics mentioned above. The syllabus that has been developed over the years that the course has been offered is shown in Table 2.

Table 2. Syllabus for Environmental Biology

1. Why study biology? Engineering vs. Science. Studying. Complexity. Ethics. Hierarchy, evolution, taxonomy, interactions.
2. **Biochemistry -** Basic organic structures, carbohydrates, proteins, lipids
3. **The Cell** - structure and function, mitosis, meiosis
   Metabolism - enzyme kinetics, glycolysis, fermentation, respiration, photosynthesis.
4. **Genetics** - Heredity, Mendel, DNA replication, protein synthesis, mutations, DNA repair, Polymerase Chain Reaction
5. **Plant and Animal Taxonomy** - including the fungi
   Human Physiology - 11 systems and reproduction and development
6. **Microbiology** - Stoichiometry, metabolism and classification, pathogenesis
7. Microbial growth kinetics, biogeochemical cycles
8. **Ecology** - Energy pyramid, food web, biogeochemical cycles
9. Population dynamics, diversity
10. Soil, aquatic, and wetlands ecosystems
11. Pollution control microbiology, biological treatment processes
12. **Toxicology** - mechanisms, effects, carcinogens, organ effects
13. Uptake, absorption, distribution, biotransformation, excretion
14. Dose-response, extrapolation, interactions, toxicity testing, epidemiology
15. Toxicity of specific substances, risk assessment

Each numbered item shown in Table 2 (which may contain more than one topic) is covered in approximately one week for a three-semester-credit course. Two features of this syllabus deserve mention. First, general biology topics require occupy almost half of the course. This is necessitated both by the results of the pretest, and by the requirement to provide fundamentals for the specialized subject matter. For example, an understanding of genotoxicity requires an understanding of basic molecular genetics. Numerous topics in microbiology and toxicology require an understanding of metabolism.

Secondly, it is clear that this course contains a large volume of material. As a result, the course is necessarily a survey course. This is consistent with the course goal of forming a foundation for the study of environmental biology, which can be pursued further by additional coursework or independent study.

The Textbook

A new textbook[1,2] and other teaching materials have been developed to cover the three core areas of microbiology, ecology and toxicology, as well as a survey of basic biology as a reference for students who either haven't had a general biology course or who had it long ago. The textbook (and the course) has a prerequisite only of general chemistry. Although some mathematical passages may require calculus, these sections may be made optional.

A decision was made that the book should be comprehensive enough so that an instructor would have the ability of selecting portions to emphasize. I.e., it contains more material than could be covered in a one-semester course. This also enabled it to be designed to have value as a reference. The textbook consists of 909 pages, including 339 figures, 151 tables, and eight appendices. The index contains 6300 entries.

The first nine chapters cover general biology in 225 pages (25% of the book). One early chapter describes "holistic" aspects of biology that cut across the specific "reductionist" chapters forming the rest of the book. Holistic topics include evolution, origins of life, and taxonomy. Other chapters in this section focus on biochemistry, metabolism, the cell, genetics, and separate chapters on plants, animals, and human physiology. Connections to environmental science are emphasized wherever possible. For example, the importance to toxicological pharmacokinetics is foreshadowed in the human physiology chapter.

Microbiology is covered in three chapters (10 to 13) occupying 229 pages. The topics here include taxonomy, metabolic characteristics, quantification, growth kinetics, disease, and the microbial role in elemental cycles. One may include in this count Chapter 16 (128 pages), which is on treatment processes, although this topic includes processes that are not solely microbial-based, such as phytoremediation and even vermiculture. Combining these chapters would constitute a traditional approach to environmental microbiology, and indeed these topics occupy almost 40% of the pages in the book. Chapter 16 is placed after ecology so that treatment processes could be discussed as ecosystems, especially with reference to biogeochemical cycling.

Ecology is covered in Chapters 14 and 15, with 137 pages (15%). The first of these chapters covers energy and material balances, population dynamics, and ecological interactions. The second focuses on individual ecosystems including terrestrial, aquatic, marine, and wetlands. Toxicology is covered in Chapters 17 to 22, for a total of 190 pages (20%). These chapters cover toxic mechanisms, effects, pharmacokinetic fate and transport, modeling of dose-response relationships, toxicity of specific classes of substances, and applications to risk assessment and toxicity reduction evaluation.

Because of the large number of terms in the book, inclusion of a glossary would add too many pages to the book. Therefore, the approach was taken to indicate by boldface in the text when a new term was being introduced, to include a clear stand-alone definition at that point, and to boldface the corresponding entry in the index so that definitions could be easily found. Numerous original figures were created for the book. Most of these were created using Microsoft Office© drawing tools. Figures 1 and 2 show examples of some of the complexity that can be achieved with these tools.

Figure 1. The structure of the eukaryotic chromosome (Based on Postlewait and Hopson[3]).

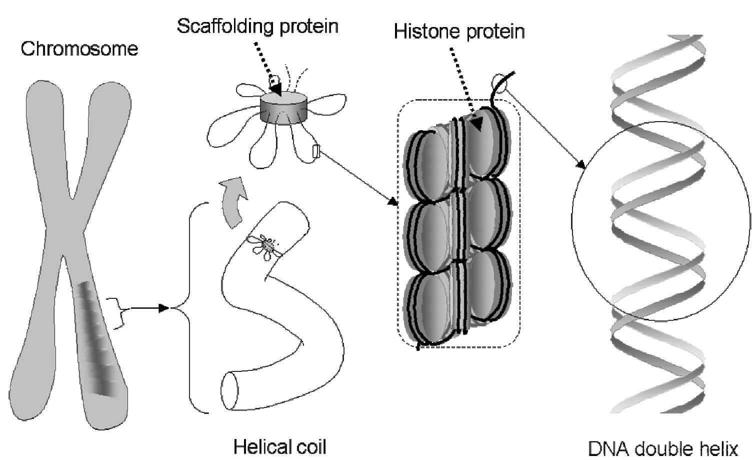
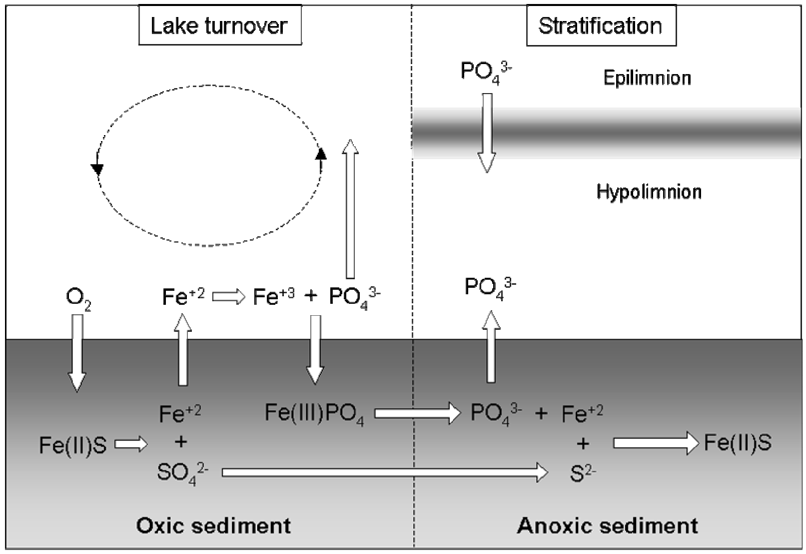


Figure 2. Phosphorus interaction with sulfur and iron in lakes (Based on Horne and Goldman[4]).



As the original conception of the course and textbook was oriented to environmental engineering students, the text was written with a strong quantitative approach. However, this is also a strength for non-engineers. All fields of biology are becoming increasingly quantitative. Environmental scientists will benefit from this approach. It can be said that this isn't really new in biology. Gregor Mendel's development of the laws of heredity constitutes one of the earliest uses of statistics in science.

Some of the topics approached by mathematical modeling include:

- Chemical thermodynamics and equilibrium
- Enzyme kinetics
- Oxygen demand and oxidation number
- Microbial growth kinetics
- Ecological population dynamics (logistic equation, life tables, predator-prey modeling)
- Stochastic extinction
- Diversity indices
- Mass balance in chemical reactions
- Systems mass balances in biogeochemical cycles
- Sensitivity and interactions in phosphorus vs. chlorophyll
- Dissolved oxygen in rivers (Streeter-Phelps equations)
- Microbial growth kinetics and treatment process design
- Epidemiology and relative risk
- Dose-response relations, mechanistic and empirical
- Pharmacokinetics, including membrane mass transfer
- Toxic interactions
- Risk assessment
- Radioactive dose and exposure

In addition, many other topics are described quantitatively, such as

- Plant, animal, and microbial nutrition
- Physicochemical parameters
- Primary productivity
- Effect of hardness on metals toxicity
- Mean lethal dose of toxins

Although the course and text are designed to provide essentials of biology relevant to environmental professionals, they go beyond "need to know" information. A further goal of the course and the textbook is to stimulate an interest in the subject, and to raise the general biological literacy of students and readers to improve their ability to understand issues in society that require an understanding of biology.

Computer Presentation Materials and Approach

A variety of materials have been developed for the course. These have been made available for download by the publisher of the textbook[3]. Presentation materials provided include:

- Microsoft Powerpoint files containing most of the figures from the book
- Microsoft Word files containing detailed lecture notes, arranged in five files :
    - General Biology (Chapters 1 to 9)
    - Microbiology (Chapters 10 to 13)
    - Ecology (Chapters 14 and 15)
    - Control Applications (Chapter 16)
    - Ecotoxicology (Chapters 17 to 21)
- Two additional Microsoft Word files containing selected Tables from Chapter 9 (The Animals) and from Chapters 10 to 13 (Microbiology)
- A solution manual for end-of-chapter problems
- A test bank containing several hundred short-answer questions for use in exams

The files can be edited to select topics that the instructor wishes to include and to exclude the others. For example, in Chapter 16 (which includes treatment processes), an instructor may decide to focus on activated sludge and anaerobic digestion, with only a brief mention of the other processes, whereas another instructor might want an even treatment of all the processes, with less depth in each. Alternatively, an instructor may decide to use this textbook for a conventional course in environmental microbiology, and concentrate almost completely on the three microbiology chapters (10 to 13) and the chapter on treatment (16). The lecture notes files can be further edited to leave only headings and topics, to use as a class handout to guide the student in note-taking. Removing most of the information from handouts encourages active learning on the part of the student.

The novel presentation approach alluded to above is enabled by a division of the lecture notes separate from the Powerpoint presentations, instead of merging them into a single presentation file. In this approach the instructor opens both the Word notes file and the Powerpoint presentation of the Figures on the computer. Both are placed in a full-screen mode. The instructor can then switch between the two documents using the control-tab feature of Microsoft Windows. The notes and the Powerpoint presentation can be scrolled independently. This allows the instructor more control of the presentation. In the case of the chapters on animal and microbial taxonomy, where it is fruitful to switch back-and-forth between notes and the large taxonomy tables, separate files containing the tables are also provided. The notes files contain notices to cue the instructor when to switch to the Figures or Tables.

The supplementary materials also include solutions to most of the end-of-chapter problems, plus a test bank of 286 quiz questions. The test bank contains questions arranged by chapters or groups of chapters. These questions are all short-answer questions. The end-of-chapter questions and problems in the textbook tend to be more complex or open-ended. These, or variations on them, may be suitable for use in an exam, although they may be more suited for use as homework assignments. For example, an end-of-chapter problem on biogeochemical cycles is:

> It can be hard to visualize the huge quantities in global biogeochemical cycles. The earth has a land area of 148,429,000 sq km, and water area 361,637,000 sq km. Normalize the fluxes and reservoirs in the carbon cycle as shown in Figure on a per square meter basis. Separate the atmosphere into the portions over land (29.1%) and over water (70.9%). How does productivity on land compare to that on water?

An example of a question on the same material from the test bank is:

> Name the three largest reservoirs for carbon.

Conclusions

The environmental profession is, paradoxically, a diverse specialty. Specialists in every field have learned not to expect their colleagues trained in other areas to have certain basic knowledge in their own area. This course aims to break one of these barriers of overspecialization. The objectives of this course will have been met if an engineer, chemist, or geologist who studied it is meeting with a biologist to discuss a situation of environmental concern, and the biologist at some point turns and says: "How'd you know that?" It should not be a surprise that any well educated person possesses some specialized knowledge outside his or her own profession.

This course also offers a challenge to instructors in environmental programs. It covers a far wider range of biology than has historically been taught to environmental engineers and scientists. The intent in doing so is to strike off in a new direction with the approach to be used for training environmental professionals in the future.

References

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