SCIENCE IN BIOLOGY
AN INTRODUCTION

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PREFACE

Introductory biology textbooks are huge and have been described by some as "tediously compendious", "dully thorough and thoroughly dull." Introductory biology textbooks average 738 pages long and present over 3500 new terms, which is around 45-50% more new words than are presented in a semester of foreign language! Comprehensive introductory textbooks either completely lack an overall conceptual framework, or if the scientific process is explained, it is treated as a discussion topic, not as an organizing theme, or if present, the concepts are buried in an avalanche of biological terms and facts. There are so many terminological trees that students fail to see the conceptual forest.

This textbook is an attempt to find a better way to present biology to non-majors. Our solution to the problem has been to focus consistently upon concepts and testing of hypotheses. Our hope is that by so concentrating our emphasis, students will gain a solid appreciation of the process of science. While they may not know all of the trees that exist, perhaps they can appreciate the beauty of the forest. Since well developed explanations will be retained longer than an array of terms and definitions, and since concepts may be easily applied to new situations and problems, our approach may help address the problem of declining scientific literacy. We also hope that this approach has produced a textbook that is more easily read and more interesting to read.

The names of many biologists and other scientists are mentioned throughout the text, not as a memory challenge or because we assume you will recognize any of the names, but to emphasize that people conduct the business of science.

We have attempted to use an organismally diverse array of examples to show that life is diverse, but unified. In particular, we have reduced the emphasis on vertebrates that is so prevalent in many textbooks, although we have included enough information on humans to show that our species is part of biology, and we have given plants equal status with animals. We have purposely avoided the slick graphics and photographic illustrations that can distract students from the conceptual content.

We thank our colleagues James Seago, Marshall Sundberg, Steve Juliano, Scott Sakaluk, and Lori Munneke for attempting to help us make sense out of various earlier drafts of the text. The text is richly complemented by the original artwork of Douglas DeWitt. The College of Arts and Sciences, Illinois State University provided support for the development phase of this manuscript. We are grateful to Neil Rowe for his patience and support. A special thanks must be included for our lovely wives, Nan and Nancy, who helped greatly with the task of proofreading. In spite of the help and encouragement of these many individuals, any remaining mistakes are ours.

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INTRODUCTION

Why should a non-science major be required to take a science course? The answer to this question is both complex and compelling. Science is an area of human endeavor and achievement, as are art, music, and literature. Indeed, science has been the cornerstone of the material success of our society. While art, music, and literature suit our aesthetic needs, science and technology generate the means to satisfy our material needs. An educated person should understand the nature of science and its role in the development of our society.

Science and scientific issues surround you. The news media often report about the findings of science, but the reporting is often inaccurate and superficial. Sales pitches and advertisements tell us the results of what are held to be scientific studies testing new, improved products. "Scientifically conducted" surveys and polls are used to predict political elections. Legislation drafted by our elected representatives is often based on, or sometimes completely ignores, the findings of scientific studies. Your tax dollars are used to support many types of basic and applied scientific research.

This is a scientific age, a situation that does not please everyone. Like it or not, science, and its close cousin technology, affect your everyday lives. Your way of life, your health, your standard of living, and that of your children and grandchildren, will be affected by many aspects of science and technology. Our use and misuse of the

Earth's natural resources, the tremendous impact of human activities on our environment, and the continued increase of the human population will certainly change the way you live your lives. This textbook is not intended to be issue oriented, but understanding science and how it works is essential for you to understand the many specific problems and issues facing our society. We are not attempting to make value judgements, but to provide you the intellectual tools to evaluate the science that surrounds you.

WHY WRITE ANOTHER BIOLOGY TEXBOOK?

The motivation for writing this text grew out of discussions of what to teach non-science majors in what may be their only college-level biology course. Every biologist had a different opinion about what important subjects **must** be covered in a one semester course. To please everyone, the composite subject outline would be the entire undergraduate curriculum for biology majors. Obviously a great deal of the traditional knowledge of biology must be omitted in a single semester course. How did we choose what to leave out?

A number of studies have addressed the problem of decreasing scientific literacy in our country. A major contributor to the problem is an emphasis on rote memorization of factual information. Science has been taught as factual information without providing students with any knowledge of the process by which the information was acquired or of the conceptual framework that makes sense out of it. The correct question was not **what** to teach, but **how** to teach it.

This textbook attempts to correct these problems by emphasizing the conceptual framework, the theories, the explanations that make biological science a coherent, organized body of knowledge. It does not attempt to present a comprehensive body of factual information. Factual information is presented primarily to illustrate or test predictions. In all cases there are many other examples that could have been used.

Learning concepts is a more efficient means of education than just memorizing facts. You can memorize and recite a 100 word poem much more easily than you could memorize a list of 100 unrelated words, simply because the interrelated meanings of the words in a poem make logical connections. We remember interconnected pieces of information much longer and much more easily than a similar number of isolated items. By concentrating on the concepts that interconnect and explain biological facts, we hope to present knowledge that will be retained longer, and that can be applied in the future to new and different situations.

SCIENCE

What is science? What makes biology, chemistry, geology or physics different from history, or literature, or psychology? Most dictionaries will say that "science is a body of facts or truths systematically arranged and showing the operation of general laws." This definition probably reflects generally held perceptions of science, but it is inadequate. Nowhere in the dictionary definition is there any suggestion that science is a process. It is the application of this process in biology, chemistry, geology and physics that makes them science. Such a fundamental misunderstanding about science has led to very poor decisions about how to teach science.

Science is composed of two types of facts, which for convenience can be called Type I Facts and Type II Facts. A Type I Fact is an observed phenomenon or datum. These are absolutely true unless the observer made a mistake. Type I Facts have the potential to be repeated or made independently by different individuals. In this way Type I Facts are self-correcting. Observing tiny fairies dancing every time you look through a microscope is not a Type I Fact unless every other competent observer who looks through the same microscope at the same specimen sees the same thing. Well-verified Type I Facts come as close to truth or certainty as anything can come.

Type II Facts are the explanatory concepts used to organize and explain Type I Facts. They are accepted as true because they have been extensively tested and not found to be false. If the discovery of Type I Facts is compared to making bricks, then Type II Facts can be compared to constructing a building from the bricks. You need bricks to make a building, but a building is much more useful than a disorganized pile of bricks.

You may not think it sounds very "scientific", but as shall be explained below, Type II Facts cannot be proven to be absolutely true. As a result, Type II Facts are considered conditionally true. Better explanations may be found and further scientific work may result in their modification. However, Type II Facts can be proven to be absolutely false, and consequently they may be wholly rejected. All Type II Facts that are accepted as true have survived numerous attempts to falsify them. The commonly held view that scientists attempt to prove that theories are true, actually is incorrect. As you shall see, only in falsification is there certainty.

In science a THEORY represents both a body of knowledge, the Type I Facts, and the explanatory concepts constructed to make sense out of them, the Type II Facts. In this text we will examine three major theories, the Cell

Theory, the Theory of Heredity, and the Theory of Evolution. Are theories facts? Yes, in every operational way they are. However, these are conditional facts or truths since we expect new ideas and new findings to be incorporated into the intellectual framework of our explanatory concepts. While major scientific theories are only considered conditional truths, they have been well verified and for this reason biologists and biology students may have a great deal of confidence that major theories will not be falsified completely.

How do scientists define or describe science? The following excerpts are typical of the working view of science as held by its practioners.

> "...facts and theories are different things....Facts are the world's data. Theories are structures of ideas that explain and interpret facts. Facts do not go away when scientists debate rival theories to explain them...
>
> Moreover, 'fact' does not mean 'absolute certainty'...In science, 'fact' can only mean 'confirmed to such a degree that it would be perverse to withhold assent.'
>
> ...Philosopher Karl Popper has argued for decades that the primary criterion of science is the falsifiability of its theories. We can never prove absolutely, but we can falsify. A set of ideas that cannot, in principle, be falsified is not science." (Stephen Jay Gould, 1981).

> "...scientific theories can never be proven absolutely...Science is not, therefore, truth--at best it is the unending **search** for truth. The conclusions reached by science are only **contingent** truths--truths contingent upon man's limited knowledge of himself and the world around him.
>
> Now, one may ask what good is a theory if it is not true? A theory is good because it is **useful** and it is

fruitful of new knowledge. Scientific methods have explained more of the empirical world than any alternative approaches, including religion. Science allows man to **work** in the universe as no other system of knowledge does...

Man's ability to act usefully from the predictions of a theory, however, depend upon his ability to test the predictions made by the theory. The process of testing...is more important than the theory itself...Thus, right or wrong, a testable theory always yields new information about the problem it claims to resolve....All good scientific theories work this way. Thus, although scientific truths are always contingent ones, the method by which they are advanced and tested ensures their improvement.

In short, the power of scientific theories results from the fact that they are correctable. They may be tested. Whether the theory is right or wrong, these tests yield new information about the world. And, if the theory is wrong, then this new information can be used to invent a new and better theory. Thus, while scientific theories are never perfect, they become better and better with time." (Robert Root-Berstein & Donald McEachron, 1982).

"Science is the human search for a natural explanation of what the universe is: How it is constructed, how it came to be. The only rule of the scientific method is that we must discard any scientific statement if the evidence of our senses shows it is wrong.

If there is one rule, one criterion that makes an idea scientific, it is that it **must** invoke naturalistic explanations for phenomena, and those explanations must be testable solely by the criteria of our five senses." (Niles Eldredge, 1982).

A better definition of science than that usually found in dictionaries is **"a human process whose objective is to gain an understanding of the Universe through the use of the hypothetic-deductive method** (described below)."

Limitations of Science

Science ultimately is based upon unproven and unprovable assumptions about the nature of the Universe. (1) The Universe is real, and its nature can be perceived and understood by the human mind. (2) All observable phenomena are the effects of potentially knowable causes. (3) Nature is unified, and the whole Universe operates under one set of rules. When something is discovered about an atom or an apple, something has been discovered about the whole Universe. These assumptions limit the scope of science, and thus science only deals with the known natural Universe. There are no assumptions made about the supernatural. Science does not deny the existence of the supernatural, but science has no means of understanding anything supernatural. Some people feel that the Universe can be satisfactorily explained without assuming anything supernatural exists. Many people feel that science does not offer a complete view of existence, which they compliment with various religious beliefs.

Progress in Science

The cyclical nature of the scientific process, the testing and rejecting of hypotheses, and the replacing of older hypotheses with better explanations allows our scientific knowledge and understanding to accumulate and improve. In other words, science makes progress. The research of scientists becomes incorporated into the hypotheses and theories of the entire scientific community. Thus, science is a human community endeavor that progresses toward an understanding of our Universe.

Real science bears little resemblance to the brilliant, but warped, experiments of mad scientists in the movies. Unusual ideas or inspirations of individuals do not attract