THE SCIENCES

AN INTEGRATED APPROACH

THIRD EDITION

James Trefil
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George Mason University

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Preface

Scientific advances touch all our lives every day. We benefit from new materials in the form of cosmetics, appliances, clothing, and sports equipment. We rely on new sources of energy and more efficient ways to use that energy for transportation, communication, heating, and lighting. We call on science to find new ways to treat disease and allow people to lead longer, healthier lives. And science represents our best hope to solve pressing problems related to the growing global population, limited resources, and sometimes fragile environment.

In spite of the central role that science plays in modern life, most Americans are poorly equipped to deal with scientific principles and methods. A 1996 survey by the National Science Foundation found that fewer than half of all Americans know that the Earth orbits the Sun, or that humans evolved from earlier species of animals. At a time when molecular biology is making breakthrough discoveries almost daily, fewer than a quarter of Americans understand the term "DNA," and only about 10% understand the term "molecule." There can be little doubt that we are faced with a generation of students who complete their education without learning even the most basic concepts about science. They lack the critical knowledge to make informed personal and professional decisions regarding health, safety, resources, and the environment.

SCIENCE EDUCATION TODAY

This book attempts to address two problems that pervade the organization and presentation of science at many U.S. colleges and universities. First, many introductory science courses are geared toward science majors. Specialization is vital for these students, who must learn an appropriate vocabulary and develop skills in experimental method and mathematical manipulations to solve problems. Specialization, however, is not well suited for the majority of students—the nonscience majors, for whom experimental technique and mathematical rigor often divorce science from its familiar day-to-day context. Introductory science courses designed for science majors fail to foster scientific understanding among nonscience majors. Ultimately, this needlessly narrow approach to science education alienates most nonmajors, who graduate with the perception that science is difficult, boring, and irrelevant to their everyday interests.

The second problem with most introductory science courses at the college level, even among those science courses specifically designed for nonscientists, is that they rarely integrate physics, astronomy, chemistry, Earth science, and biology. Such departmentally based courses cannot produce graduates who are broadly literate in science. The students who take introductory geology learn nothing about lasers or nuclear reactions, while those who take courses such as "Physics for Poets" remain uninformed about the underlying causes of earthquakes and volcanoes. And neither physics nor geology classes touch on such vital modern fields as genetics, environmental chemistry, space exploration, or materials science. Therefore, students must take courses in at least four departments to gain a basic overview of the sciences.

Perhaps most disturbing, few students—science majors or nonmajors—ever learn how the often arbitrary divisions of specialized knowledge fit into the overall sweep of the sciences. In short, traditional science curricula of most colleges and universities fail to provide the basic science education that is necessary to understand the many scientific and technological issues facing our society.

This situation is slowly changing. Since the preliminary edition of *The Sciences: An Integrated Approach* appeared in 1993, hundreds of colleges and universities have begun the process of instituting new integrated science courses as an option for undergraduates. In the process, we have had the opportunity to interact with hundreds of our colleagues across the country, as well as more than 2000 of our students at George Mason University, and have received invaluable guidance in preparing this extensively revised edition.

THE NEED FOR A NEW SCIENCE EDUCATION

In the coming decades, the 1996 publication of the *National Science Education Standards* by the National Research Council may be seen as a pivotal event in American science education. The *Standards*, which represents the collective effort and consensus of more than 20,000 scientists, educators, administrators, and parents, offers a dramatically new vision of science education for all Americans.

The *National Science Education Standards* calls for reform in both the content and context of science education. The central goal of science education must be to give every student the ability to place important public issues such as the environment, energy, and medical advances in a scientific context.

A central emphasis throughout the *Standards* is development of student understanding of the scientific process, as opposed to accumulation of scientific facts. Emphasis is placed on the role of experiments in probing nature, and the importance of mathematics in describing its behavior. Rather than developing esoteric vocabulary and specialized knowledge, the *Standards* strives to empower students to read and appreciate popular accounts of major discoveries in physics, astronomy, chemistry, geology, and biology, as well as advances in medicine, information technology, and new materials. Students develop an understanding that a few universal laws describe the behavior of our physical surroundings—laws that operate every day, in every action of our lives.

Achieving this kind of scientific proficiency requires a curriculum quite different from the traditional, departmentally based requirements for majors. Most societal issues concerning science and technology draw on a broad range of knowledge. For example, to understand the debate over nuclear waste disposal, one needs to know how nuclei decay to produce radiation (physics), how radioactive atoms interact with their environment (chemistry), how radioactive elements from waste can enter the biosphere (Earth science), and how the radiation will affect living things (biology). These scientific aspects must be weighed with other societal issues—economics, energy demand, perceptions of risk, and demographics, for example. Other public issues, such as global warming, space research, alternative energy sources, and AIDS prevention, also depend on a spectrum of scientific concepts, as well as other social concerns.

THE GOALS OF THIS BOOK

Interdisciplinary courses are not yet widely taught nor have other appropriate textbooks or support materials been available. This text, based on our course "Great Ideas in Science," which has been developed over the past decade at George Mason University, is an attempt to fill those gaps. Our approach recognizes that science forms a seamless web of knowledge about the universe. Our integrated course encompasses physics, chemistry, astronomy, Earth sciences, and biology, and emphasizes general principles and their application to real-world situations rather than esoteric detail.

Many ways exist to achieve this synthesis, but any general treatment should take advantage of the fact that virtually everything in science is based on a few simple overarching principles. By returning to general science courses for all students, we have the means to achieve our goal—to produce college graduates who appreciate that scientific understanding is one of the crowning achievements of the human mind, that the universe is a place of magnificent order, and that science provides the most powerful means to discover knowledge that can help us understand and shape our world.

THE ORGANIZATION OF *THE SCIENCES*

As authors of substantial segments of the *Standards*, we have undertaken this revision of *The Sciences: An Integrated Approach* with the *Standards'* mandate in mind. We have increased the emphasis on the scientific process, reorganized and added text to elucidate the historical significance of key principles, and underscored the integrated nature of scientific knowledge and its application to everyday experience.

The text adopts a distinctive and innovative approach to science education, based on the principle that general science courses are a key to a balanced and effective college-level science education for nonmajors and future elementary and high school teachers, and a broadening experience for science majors. We organize the text around a series of 25 scientific concepts. The most basic principle, the starting point of all science, is the idea that the universe can be studied by observation and experiment (Chapter 1). A surprising number of students—even science majors—have no clear idea how this central concept sets science apart from religion, philosophy, and the arts as a way to understand our place in the cosmos.

Once students understand the nature of science and its practice, they can appreciate some of the basic principles shared by all sciences: Newton's laws governing force and motion (Chapter 2); the laws of thermodynamics that govern energy and entropy (Chapters 3 and 4); the equivalence of electricity and magnetism (Chapters 5 and 6); and the atomic structure of all matter (Chapters 8–11), including an expanded section on observational evidence for atoms in Chapter 8. These concepts apply to everyday life, explaining, for example, the compelling reasons for wearing seat belts, the circulation of the blood, the dynamics of a pot of soup, the regulation of public airwaves, and the rationale for dieting. In one form or another, all of these ideas appear in virtually every elementary science textbook, but often in abstract form. As educators, we must strive to make them part of every student's day-to-day experience. An optional chapter on the theory of relativity (Chapter 7) examines the consequences of a universe in which all observers discern the same laws of nature.

Having established these general principles, we go on to examine specific natural systems such as atoms, the Earth, or living things. The realm of the nucleus (Chapter 12) and subatomic particles (Chapter 13), for example, must follow the basic rules governing all matter and energy.

In sections on astronomy and cosmology (Chapters 14–16), students learn that stars and planets form and move as predicted by Newton's laws, that stars eventually burn up according to the laws of thermodynamics, that nuclear reactions fuel stars by the conversion of mass into energy, and that stars produce light as a consequence of electromagnetism.

Plate tectonics (Chapter 17), and the cycles of rocks, water, and the atmosphere (Chapter 18, substantially revised in this edition), unify the Earth sciences.

The laws of thermodynamics, which decree that no feature on the Earth's surface is permanent, can be used to explain geologic time, gradualism, and the causes of earthquakes and volcanoes. The fact that matter is composed of atoms tells us that individual atoms in the Earth's system—for example, in a grain of sand or a student's most recent breath—have been recycling for billions of years.

Living things (Chapters 19–25) are arguably the most complex systems that scientists attempt to understand. We identify seven basic principles that apply to all living systems: interdependent collections of living things (ecosystems) recycle matter while energy flows through them; living things use many strategies to maintain and reproduce life; all living things obey the laws of chemistry and physics; all living things incorporate a few simple molecular building blocks; all living things are made of cells; all living things use the same genetic code; and all living things evolved by natural selection.

The section covering living things has been extensively revised. Chapter 19 includes new information on ecosystems and their importance to the environment. One chapter (20) covers the organization and characteristics of living things. A revised chapter on biotechnology (24) explores several recent advances in our molecular understanding of life to cure diseases and better the human condition. We end the book with a discussion of evolution (25) that emphasizes observational evidence first. To improve the book's integration in this edition, we have also added more biological coverage to the early chapters on basic scientific principles.

The text has been designed so that four chapters—relativity (7), quantum mechanics (9), particle physics (13), and cosmology (15)—may be skipped without loss of continuity.

SPECIAL FEATURES

In an effort to aid student learning and underscore the integration of the sciences, we have attempted to relate scientific principles to each student's everyday life. To this end, we have incorporated several distinctive features throughout the book.

Great Ideas Each chapter begins with a statement of a great unifying idea or theme in science, so that students immediately grasp the chief concept of that chapter. These statements are not intended to be recited or memorized, but rather to provide a framework for placing everyday experience in a broad context.

Great Ideas Across the Sciences Our theme of integration is reinforced with a tree diagram that appears at the beginning of every chapter. The diagram ties together some of the examples discussed and shows how the Great Idea has been applied in different branches of science and everyday life.

Random Walks Each chapter also begins with "A Random Walk," in which we tie the chapter's main theme to common experiences, such as eating, driving a car, or suntanning. These Random Walks grew out of our idea of the perfect class; during every class period, we would meet outdoors and walk until we saw something that would illustrate that day's topic.

The Random Walk to Chapter 1 was written by a student, Laurie Jewett of Franklin Pierce College, Keene Campus. Her essay was selected by the authors as the winning entry in *The Sciences Scholarship Contest.* Laurie's personal story demonstrates the relevance of the integrated approach and serves as a nice vehicle for introducing this book to other students.

The Science of Life To help show the interdisciplinary nature of the many concepts we introduce, we have included sections on living things in most chapters. Thus, while chapters emphasizing principles specifically related to life are at the end of the book, biological examples appear throughout.

Science in the Making These historical episodes trace the process of scientific discovery and portray the lives of central figures in science. In these episodes we have tried to illustrate the process of science, examine the interplay of science and society, and reveal the role of serendipity in scientific discovery.

The Ongoing Process of Science Science is a never-ending process of asking questions and seeking answers. In these features we examine some of the most exciting questions currently being addressed by scientists.

Stop and Think! At various points in each chapter we ask students to pause and think about the implications of a scientific discovery or principle.

Technology The application of scientific ideas to commerce, industry, and other modern technological concerns is perhaps the most immediate way in which students encounter science. In most chapters we include examples of these technologies, such as petroleum refining, microwave ovens, and nuclear medicine.

Science News Scientific breakthroughs are happening every day. In many chapters we include summaries of recent articles from the weekly periodical *Science News*. These sections are intended to give students a better understanding of new discoveries that were reported in the popular press.

Mathematical Equations and Worked Examples Unlike the content of many science texts, formulas and mathematical derivations play a subsidiary role in our treatment. We rely much more on real-world experience and everyday vocabulary. We believe, however, that every student should understand the role of mathematics in science. Therefore, we have included a few key equations and appropriate worked examples in many chapters. *Whenever an equation is introduced, it is presented in three steps:* first as an English sentence, then as a word equation, and finally in its traditional symbolic form. In this way, students can focus on the meaning rather than the abstraction of the mathematics. We also include an appendix on English and SI units.

Science by the Numbers We also think that students should understand the importance of simple mathematical calculations in making estimates and determining orders of magnitude. Thus we have incorporated many nontraditional calculations of this kind: for example, how much solid waste is generated in the United States, how long it would take to erode a mountain, and how many people were required to build Stonehenge.

Web Links At the end of each chapter you will find a list of relevant web sites. In addition, the www icon appears in the margin throughout the book to highlight links that amplify the text.These links have been well researched and provide additional content on many fascinating topics. You can also visit *The Sciences* home page at *http://www.wiley.com/college/thesciences*, to explore materials developed to support and enhance the study of science.

Thinking More About Each chapter ends with a section that addresses a social or philosophical issue tied to science, such as federal funding of science, nuclear waste disposal, the Human Genome Project, and priorities in medical research.

Key Words Most science texts suffer from too much complex vocabulary, and we have avoided unnecessary jargon. Nevertheless, the scientifically literate student must be familiar with many words and concepts that appear regularly in newspaper articles or other material for general readers. In each chapter a number of these words appear in **boldface** type, and they are listed at the end of the chapters. For example, in Chapter 12 on nuclear physics, key words include proton, neutron, isotope, radioactivity, half-life, radiometric dating, fission, fusion, and nuclear reactor—all terms likely to appear in the newspaper. In the back of the book is a glossary of all the key words.

Many other scientific terms are important, although more specialized; we have highlighted these terms in *italics*. We strongly recommend that students be expected to know the meaning and context of key words but not be expected to memorize these italicized words. We encourage all adopters of this text to provide their own lists of key words and other terms—both ones we have omitted and ones they would eliminate from our list.

Questions We feature four levels of end-of-chapter questions. "Review Questions" test important factual information covered in the text, and are provided to emphasize key points. Many of the Review Questions have been substantially rewritten for this edition. "Discussion Questions" are also based on material in the text, but they examine student comprehension and explore applications and analysis of the scientific concepts. "Problems" are quantitative questions that require students to use mathematical operations, typically those introduced in worked examples or Science by the Numbers. Finally, "Investigations" require additional research outside the classroom. Each instructor should decide which levels of questions are most appropriate for his or her students. We welcome suggestions for additional questions, which will be added to the next edition of this text.

Illustrations Students come to any science class with years of experience dealing with the physical universe. Everyday life provides an invaluable science laboratory—the physics of sports, the chemistry of cooking, and the biology of being alive. This book has thus been extensively illustrated with familiar color images in an effort to amplify the key ideas and principles. All diagrams and graphs have been designed for maximum clarity and impact.

SUPPLEMENTS

The *Study Guide* contains many elements to help foster student success, including a chapter review, learning objectives, key chapter concepts, and key concept charts. Because science depends on the individuals who made important discoveries, also included is an exposition of key individuals linking scientists with their findings. Since many scientific concepts are linked to math, key formulas and equations are also provided. Self-tests and crossword quizzes allow students to test their knowledge.

The *Instructor's Manual* includes teaching suggestions, lecture notes, answers to problems and questions from the textbook, practice questions and problems, and other elements to assist both new and experienced instructors teaching this integrated science course.

The *Instructor's Resource CD-ROM* contains a database of line art and selected photographs from the textbook. This collection of assets can be used with PowerPoint, allowing instructors to create their own electronic slide presentations.

The *Student CD* features an interactive program that links key topics in the text with animations and videos that help illustrate these important concepts further.

The *Web Site* includes web links that relate to topics within the text chapters and on-line quizzing/self-tests for students. Instructors will also have access to WebCT, a powerful web site program that allows professors to set up an on-line course with chat rooms, bulletin boards, quizzing, and student tracking.

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The development of this text has benefited immensely from the help and advice of numerous people.

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Students in our "Great Ideas in Science" course at George Mason University have played a central role in designing this text. Approximately 2000 students, the majority of whom were nonscience majors, have enrolled in the course over the past 10 years. They represent a diverse cross-section of American students: more than half were women, and many minority, foreign-born, and adult learners were enrolled. Their candid assessments of course content and objectives, as well as their constructive suggestions for improvements, have helped shape our text. In preparing the second edition, we also relied on the evaluations of students from Frostburg State University and St. Peter's College.

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