The most remarkable discovery made by scientists is science itself.

JACOB BRONOWSKI

Preface

Our knowledge and understanding of the biological world is based on the scientific enterprise of asking questions and formulating and testing hypotheses. Scientists gather data, then evaluate and interpret their results, communicating their findings through papers and presentations. An important aspect of learning biology is participating in the process of science and developing creative and critical reasoning skills. Our goal in writing this laboratory manual is to present a laboratory program that engages students in the scientific process and encourages scientific thinking. We want students to experience the excitement of discovery and the satisfaction of solving problems and connecting concepts. For us, investigating biology is more than just doing experiments; it is an approach to teaching and learning that promotes inquiry.

The laboratory exercises are designed to encourage students to ask questions, to pose hypotheses, and to make predictions before they initiate laboratory work. Students are asked to synthesize results from their observations and experiments, then draw conclusions based on evidence. Whenever possible, students apply their results to new problems and case studies. *Investigating Biology* provides students with many opportunities to design their own open-inquiry investigations as part of the laboratory. In addition, students can pursue independent investigations using the suggestions and extensions provided at the end of lab topics. Scientific writing and communication are emphasized throughout the laboratory manual and supported by an appendix that includes instructions for writing each section of a scientific paper, obtaining information from primary sources, and preparing oral and poster presentations. Instructors are given suggestions for organizing a laboratory writing program.

Investigating Biology uses a stepwise approach to developing scientific knowledge and skills, as students in early lab topics practice asking questions, developing hypotheses, and designing experiments. Early laboratory experiences build on knowledge (e.g., how cells and enzymes function, genetics, and then biodiversity as an expression of variation and evolution). At the same time, students are developing laboratory and thinking skills, such as pipetting, using instruments, analyzing results, organizing and managing collaborative teams, and developing systematic approaches to experimental design and problem solving. Lab topics are a mixture of directed-inquiry and open-inquiry, with more directed investigations in the initial lab topics and increasing opportunities for open-inquiry in subsequent lab topics. In the open-inquiry investigations, students are presented with a topic and preliminary experiment, then encouraged to develop their own questions, design their investigations, and write their proposals before implementing their own investigations. They must then collect and interpret their data. We use a similar approach for scientific writing. Students write individual sections of a scientific paper for initial lab topics, receiving feedback and the opportunity to revise. Then, for

open-inquiry investigations, they are prepared to use their writing expertise to write a complete scientific paper. This incremental approach to knowledge, skills, and disciplined ways of thinking is a hallmark of our approach throughout the lab manual and is adaptable to programs with large laboratory sections or small groups of students. *Investigating Biology* provides a comprehensive introduction to the diverse topics and subdisciplines in the biological sciences, always with an emphasis on scientific investigation.

We are convinced that involving students in the process of science through investigating biological phenomena is the best way to teach. The organization of this laboratory manual with a mix of directed-inquiry and open-inquiry investigations complements this approach to teaching and learning.

New in the Ninth Edition

The ninth edition of *Investigating Biology* offers expanded opportunities for students to participate in science. Adopters of the ninth edition will notice a continued emphasis on recurring themes in biology, including structure and function, unity and diversity, transmission of genetic information, energy transformations, and the overarching theme of evolution. These themes are developed across hierarchical levels from cells to organisms to ecosystems.

Scientists and students in the biological sciences strive to understand complex systems, structures, and processes that range from the molecular to the landscape. Often their inquiries are enhanced by visualization through images, models, and digital media. Building on the addition of full color in the eighth edition of the manual, in this edition we have revised selected pieces of art and added new photos to accompany art in many lab topics, including enhancing dissections, investigating biological diversity and phylogenetic relationships, and illustrating procedures and experimental design. We continue to update and expand media options in the resources sections at the end of each lab topic, including new videos from Biointeractive (HHMI).

We have revised procedures and added tables to clarify methodology. In Lab Topic 10, we have incorporated a new system to visualize gels using SYBR® Safe and blue light illumination because of the high quality results, ease of use, safety, and reduced waste. In Appendix C, we have updated instructions for the two most widely used spectrophotometers and for vernier calipers.

In this edition you will find expanded coverage of vertebrate anatomy with photographs to accompany drawings and, in response to current interests in brain function and suggestions by reviewers, a new investigation of the sheep brain in Lab Topic 24. The fungi lab topic introduced in the eighth edition has been expanded to include additional life cycles and investigations. We continue updating the phylogeny of the protists and invertebrate phyla to emphasize the latest published hypotheses for phylogenetic relationships based on the explosion of molecular research in this area.

In all of the lab topics, we include connections with advances in current research. In the lab topics with opportunities for open-inquiry, we include suggestions to prompt student questions that will lead to independent investigations and to collaborative team research. The opportunities to extend research in the laboratory and through the scientific literature have been enriched with new suggestions for Investigative Extensions and Applying Your Knowledge

questions. Additional support for investigations is provided in the *Preparation Guide for Investigating Biology* available to instructors.

Writing and scientific communication continue to be a strong component of the laboratory program. In the ninth edition, we revised Appendix A Scientific Writing and Communication to provide resources on how to read and summarize scientific literature and to reduce plagiarism. We provide tips for preparing and presenting oral papers and posters and extended resources and websites that provide instructions, checklists, and examples. The writing program is supported by materials in the Preparation Guide, including new templates for proposal writing to coordinate with open-inquiry investigations.

For instructors, we have modified the AIE Teaching Plans to provide clear objectives and support for teaching using inquiry-driven approaches. We include recommendations for organization, student development, and evaluation. No other laboratory manual is supported by a comprehensive laboratory Preparation Guide that includes detailed information on planning, ordering, materials preparation, organization, and care and culture of organisms. The catalog numbers have been updated for all lab topics, and new vendors and sources are included.

In all of these changes and modifications, our objective has been to provide laboratory experiences that are challenging to students and allow them to participate in scientific investigations. We are keenly aware of the constraints on laboratory programs, including number of students and sections, preparation of laboratories and instructors, and the expense and mentoring that are required to teach inquiring young scientists. Our objective is to provide the options and resources that will assist you in meeting the goals for your laboratory program.

Laboratory Topics

The laboratory topics build on information and techniques in previous exercises. Various laboratory exercises incorporate a combination of directed and open-ended procedures. There are basically three types of lab topics included in the manual:

1. *Directed-Inquiry Investigations,* in which exercises have been constructed to involve students in the process of science. We have organized these lab topics to include introductory information from which students develop hypotheses and then predict the results of their experiments. They collect their data and summarize the data in tables and figures of their own construction. The students must then accept or reject their hypotheses, based on their results. Examples of these directed-inquiry investigations include Lab Topic 3 Diffusion and Osmosis, Lab Topic 4 Enzymes, and Lab Topic 6 Photosynthesis.
2. *Key Theme Investigations,* in which laboratory exercises have been designed and reorganized with a focus on key themes of biology, for example, the unity and diversity of life. In these thematic exercises, students summarize and synthesize their results and observations connecting to the key themes. They use their observations as evidence in support of these major concepts and apply their understanding to new problems. Examples of these laboratories (and their underlying themes) include Lab Topic 2 Microscopes and Cells (unity and diversity of life); Lab Topics 14 and 15

Plant Diversity I and II (adaptation to the land environment); and Lab Topics 22 to 24 Vertebrate Anatomy I, II, and III (structure and function).

3. *Open-Inquiry Investigations,* in which students generate their own hypotheses and design their own experiments. These exercises begin with an introduction and a simple experiment that demonstrates procedures. Then students are given suggestions and encouraged to develop their own questions and methodologies for further investigation. Examples of these open-inquiry investigations include Lab Topic 5 Cellular Respiration and Fermentation, Lab Topic 11 Population Genetics, Lab Topic 13 Protists, Lab Topic 17 The Kingdom Fungi, Lab Topic 21 Plant Growth, Lab Topic 26 Animal Behavior, and Lab Topic 28 Ecology II.

Lab topics are designated as *Directed-Inquiry, Key Theme, or Open-Inquiry Investigations* in the table of contents.

Scientific Communication: Writing and Presenting

Scientists communicate their results in writing and in presentations to research groups and at meetings. Undergraduates need instruction in writing and an opportunity to practice these skills; however, instructors do not have the time to critique hundreds of student research reports for each exercise. Throughout this lab manual, teams of students work together on improving their skills. They are asked to organize and present their results to their peers during the discussion and summary sessions in the laboratory. Students are also required to write as part of each laboratory. They summarize and discuss their results and then apply information to new problems in the questions at the end of the laboratory.

We have also incorporated a scientific writing program into our lab manual in a stepwise fashion. Students must answer questions and summarize results within the context of the laboratory exercises. For directed-inquiry investigations, students are required to submit one section of a scientific paper. For example, they might submit the Results section for one experiment in Lab Topic 3, and the Discussion section for one experiment in Lab Topic 4. Once students have experience writing each section, they write at least one complete scientific paper for an open-inquiry investigation, for example, Lab Topics 13, 17, 21, and 26. Instructions for writing a scientific paper, developing an oral presentation, and creating a poster are included in Appendix A, which also contains suggestions for developing a systematic writing program. Instructors may choose to organize a session similar to scientific meetings for oral or poster presentations.

See Appendix A and the Teaching Plans in the Annotated Instructor's Edition for additional information on scientific writing and presentations.

Special Features

Reviewing Your Knowledge: Students recall terminology and content by describing and explaining fundamental concepts. Students examine their results and then use evidence as they evaluate their understanding and knowledge.

Applying Your Knowledge: As instructors, we want our students to be challenged to think and to develop critical thinking skills. Throughout this manual, students are asked to work logically through problems, critique results, and modify hypotheses. To emphasize these skills further, we have developed a section in each laboratory topic called Applying Your Knowledge, in which students are asked to apply their knowledge to new problems and to make connections between topics. The questions encourage students to use their knowledge as they solve problems developed from current research as well as issues in science, medicine, and society.

Excel Tables: All data tables used for recording and analyzing results are available in Excel format for modification and use in the laboratory. These tables are designated in the table title and can be downloaded to laboratory computers for student use at www.masteringbiology.com in the Study Area.

Images and Data: Full-color images and figures are integrated throughout the lab manual. Lab Topic 16 Bioinformatics: Molecular Phylogeny of Plants is supported by images in the text as well as the masteringbiology.com website. Folders found under the Study Area contain images of the plants used in the investigation along with the edited and ready-to-use nucleotide sequences for each species. These can be downloaded to laptops or accessed on the website.

Investigative Extensions and Case Studies: Students and instructors have expressed interest in extending laboratory topics to open-inquiry investigations or simply to pursue additional questions that connect the topic to current research and issues. At the end of most lab topics, we have provided questions to prompt student-designed investigations. For a few, we provide case studies that build on the lab topic and require additional reading and research.

Student Media and Web Resources: Providing media and Web resources can enhance teaching and learning in the laboratory. For students, we have included references to videos that connect to their laboratory activities. These are designated in the text with a media icon. Also, at the end of each lab topic, we have included the section **Student Media: BioFlix, Activities, Investigations, Videos, and Data Tables**, which directs students to the website for **activities** and **investigations** that can be used to prepare for the laboratory or review and practice after the laboratory. These media resources are available at www.masteringbiology.com in the Study Area.

Safety Considerations: Safety concerns are noted in the text by the use of icons for general safety and for biohazards. Laboratory safety is also addressed in the Teaching Plan at the end of each lab topic in the Instructor's Edition. Note the **Laboratory Safety Guidelines** printed on the inside front cover.

Notes to Students: To assure student success, cautionary reminders and notes of special interest are also highlighted in the text.

Appendixes: Information needed in several laboratory topics is included in the appendixes: scientific writing and communication, the metric system, instrumentation and techniques, using chi-square analysis, and dissection terminology and techniques.

Instructional Support

The Preparation Guide and the Teaching Plans in the Annotated Instructor's Edition provide valuable suggestions and essential information for the successful implementation of the laboratory topics.

Preparation Guide: A detailed *Preparation Guide for Investigating Biology* accompanies the laboratory manual. It contains materials lists, suggested vendors, instructions for preparing solutions and constructing materials, schedules for planning advance preparation, and suggestions for organizing materials in the lab. The Preparation Guide is essential for successfully preparing and teaching these investigative laboratories. It is now available in hard copy and electronically at masteringbiology.com in Instructor Resources, Instructor Guides for Supplements. Instructors can download preparation and ordering lists as needed and customize these for their program.

Annotated Instructor's Edition: Teaching biology using an investigative approach requires that instructors guide students in posing questions and hypotheses from which they can predict the results of their experiments. We have included additional support for the instructor in the form of instructor's annotations in each lab topic. These annotations are intended to guide the instructor in responding to students, not to provide the right answers to every student question. We encourage instructors to become the guide to discovery rather than the repository of correct answers. Features of the Annotated Instructor's Edition include:

- **Margin notes** with simple suggestions, such as accepting hypotheses as long as they are testable, hints for success, and additional explanations appropriate for the instructor.
- **Suggested answers** to student questions.
- **Typical results**
- **Explanatory figures**
- **Teaching Plans**

Teaching Plans: The teaching plans are the instructor's guide to organizing and teaching each laboratory, and they reflect our objective to systematically develop more effective ways to engage students in the study of biology. The teaching plans have been particularly useful for instructors initiating investigative approaches to lab programs. Instructors should feel free to modify these plans to meet their specific needs. The Teaching Plan for each lab topic includes:

- **Detailed objectives** both for content and for development of skills in problem solving and scientific methodology.
- **Suggested order of the lab.**
- **Estimated time requirements** for each portion of the lab.
- **Suggested options for organizing the activities for a 2-hour lab period.**
- **Hints on how to manage groups of students** and involve them in investigations that might otherwise become passive learning experiences.
- Information about **lab safety precautions.**

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