A. Introduction

Understanding Physics is a completely revised, updated, and expanded edition of the *Project Physics Course*. It is an integrated introductory physics course, developed with funding from the Carnegie Corporation and the Sloan Foundation and with the close cooperation of Springer-Verlag, New York.

In approach and content, *Understanding Physics* is similar to the *Project Physics Course*, but it updates the content of that course to include more recent developments in physics, and it places a stronger emphasis on the relationships among physics, technology, and society. We have sought especially to incorporate the salient lessons of recent physics education research as well as practical experience gained in the classroom.

While many high-school students can benefit from the course, *Understanding Physics* is written primarily for undergraduate college students not intending (at least initially) to enter careers in science or engineering. These may include liberal-arts students, business majors, prelegal, and prospective architecture students. We have found that when the course is taken with laboratory work it has been deemed suitable by medical schools for premedical students.

One especially important goal of this course is to prepare those who plan to teach, or are already teaching, in K–12 classrooms. As has been widely discussed, there is a special need for improvement in the science education of current and future teachers as an important step toward achieving greater scientific literacy in general. Many States have recently incorporated the contextual approach pioneered by *Project Physics* and continued in *Understanding Physics* into State science education criteria. It is in part to meet the challenge of teacher education that this course was developed. However, this course is not intended to provide pedagogical training in K–12 science education. Such training is better provided in professional education courses, for which these materials might serve as resources.

Moreover, it is now widely acknowledged that familiarity with the basic concepts, as well as the developmental processes of physical science, is essential for achieving "scientific literacy" for every educated citizen in the new century. One definition of scientific literacy is found in the National

Research Council's *National Science Education Standards* (Washington, DC: National Academy Press, 1996):

> Scientific literacy is the possession of the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity. It also includes certain types of [scientific] abilities. (p. 22.)

For the above reasons our text, *Understanding Physics*, contains—along with some of the exciting contemporary developments in physics—the more traditional topics of mechanics, astronomy, heat, and electricity and magnetism, as well as atomic theory and the conservation of energy. These topics are of course essential for appreciating contemporary developments. Moreover, they appear in all of the state science teaching standards, and many states now include such material on teacher certification examinations.

PROJECT PHYSICS AND BEYOND

To a large degree, *Understanding Physics* follows the trail blazed earlier by the thoroughly tested *Project Physics Course*. That course, was especially known for its success in placing the fundamental concepts of physics within the broader humanistic and historical contexts in which they arose, but without handicapping students in tests that compared their performance with students who had taken the more conventional physics courses. On the contrary, these tests showed that Project Physics students had gained a much deeper understanding of both the content and the processes of scientific research than otherwise attained, as well as an appreciation not only of what we know, but also of how and why we think we know it.

Because of its success, the Project Physics approach has been reiterated recently at the national level in the recommendations offered both in the National Research Council's *National Science Education Standards* and in Project 2061's *Benchmarks for Science Literacy*. Both of these initiatives have been influential on recent revisions of State requirements in science education and teacher training. In turn, *Understanding Physics* is compatible with both of these national initiatives. The subject matter meets, and in most cases exceeds, the recommendations for a model introductory physics course.

As to the usefulness of the history of science in the context of science courses, the National Research Council document states:

> In learning science, students need to understand that science reflects its history and is an ongoing, changing enterprise. The standards for the history and nature of science recommend the use of history in school science programs to clarify different aspects of scientific inquiry, the human aspects of science, and the role that science has played in the development of various cultures.*

In this text we have taken great care to derive all necessary equations very patiently, but whenever possible we have used narrative instead of equations to convey the meanings of laws and concepts. While the text of *Understanding Physics* uses the story of historical developments as teaching tools in this sense, and shows that science is an evolutionary process involving real people, we hasten to add that this is, above all, a physics course, not a course in the history of science and culture. Moreover, research in physics education has revealed a tremendous amount in recent years about how students at all levels learn—or fail to learn—physics. Thus, in preparing this work, we have especially attempted to incorporate recent research and innovations in introductory physics education, to pursue various strategies for promoting much more active engagement with the material by the students, and to offer as much flexibility as possible to instructors in adapting the course to the needs of their students and to their own needs and expertise. Materials are provided in the discussions, chapter questions, and laboratory explorations for students potentially representing a range of prior experience in science and mathematics.

We have also benefitted greatly from the publications of Arnold B. Arons, Lillian C. McDermott, Clifford E. Swartz, Shiela Tobias, and many others. The result, we believe, enables students to gain an even fuller appreciation of physics as both a discipline and a developing body of knowledge than previously achieved: a real sense of the nature of scientific thinking, the way, historically, intuitions about science had to be, often painfully, acquired by scientists, what our current concepts really mean, where they came from, and why we think we know what we know.

ORGANIZATION AND OVERVIEW

Understanding Physics is an integrated curriculum of reading, discussion, observation, and hands-on inquiry. It is designed with the aims of engaging all of the students' learning faculties in the wonder of the physical world

* National Research Council, *National Science Education Standards* (Washington, DC: National Academy Press, 1996), p. 107.

around them and providing them with a variety of mutually supporting avenues for exploring and learning how that world operates. The course materials consist of three components: the *Textbook*; the *Student Guide*, containing inquiry-based laboratory investigations and additional materials; and this *Instructor Guide*, which contains suggested educational strategies, examination questions, resource references, and other helpful information.

As noted earlier, we have designed this course with *maximum flexibility* in mind—both for the instructors and for the students. These materials may be used in a variety of settings, by a variety of students with different backgrounds and career goals, and by a variety of instructors with different interests, expertise, and educational preferences. The textbook and related materials are adaptable either to the traditional lecture–recitation format or to nontraditional, collaborative, and active-learning approaches. Further, we have designed all of the course components to work together in providing nonscience students with a total educational experience in physics that can be initiated from any starting point: class discussion, laboratory exploration, textbook inquiry, or individual initiative.

The materials are designed primarily for a two-semester course, but they are organized in such a way that either part can be used by itself in a one-semester course—and even in reverse order, if necessary. However, we have found that if one adheres to the strategy "Less is More," then, depending upon the prior experience of the students, it is often not possible to cover all of the material presented in either half of the course within one semester. In such a case, it is better for students to understand a smaller range of material well than to "cover" a large range of material that is only poorly understood. Again, *Understanding Physics* offers instructors the flexibility to adapt the course by choosing an appropriate subset of topics that will best meet the students' needs and the instructor's aims.

Some suggested semester syallbi for whole or partial coverage of each Part are presented elsewhere in this *Instructor Guide*, along with a suggested arrangement for trimester usage.

In general terms, the topics of the course are arranged in such a way that each half contains one or more components of "classical physics" as well as one of the major components of nonclassical physics, either relativity theory or quantum mechanics. The emphasis in the first half of the text (Part One) is on motion, force, energy, and the Newtonian world view, in which motion in the solar system is an important aspect, as is the nature of research in physics. The theme of motion is also carried forward into studies of the physics of heat, the kinetic theory of matter, waves, and light. These lead naturally into a discussion of relative motion and the special theory of relativity.

The emphasis in the second half of the course materials (Part Two) is on an inward journey, starting from electricity, magnetism, and electromagnetic waves into atomic structure and the nature of quantum mechanics. This is followed by the related fields of condensed matter and nuclear research. Technological and economic applications of these fields are discussed throughout the second half. "Technology inserts" dispersed throughout the text enable students to learn more about the practical, economic, and cultural significance of research in physical science.

The total number of chapters in both Parts is limited to 18 so that students can spend more time with each topic, have the opportunity to perform directly related hands-on activities, and to achieve a more thorough understanding of the material. Suggested "Mini-Laboratory Explorations" are provided as brief observations or demonstrations of material in the text. The "Major Laboratory Explorations" are designed for more extensive inquiry and exploration. Alternatively, the components of the major laboratories may be utilized as individual mini-laboratories. The number of suggested major laboratories is not large, in order to allow sufficient time for students to gain maximum familiarity with the phenomena, and to explore on their own the related physical laws and concepts. Of course, the suggested explorations and "mini-laboratories" may be modified, replaced, adapted, or augmented by other explorations and exercises, depending upon the instructor's preferences and available equipment. (See "Discussion of Laboratory Explorations" later in this *Instructor Guide*.)

Those classes that are able to complete the material in one of the Parts in less than a semester might use the remaining time to cover selected topics in greater depth or to go on to related topics. In any case, there is enough leeway for the instructor to insert into the course his or her own favorite topics, demonstrations, examples, etc., including those from other textbooks. [One text that instructors may find especially useful for this purpose is a text intimately related to *Understanding Physics*, namely G. Holton and S.G. Brush, *Physics, The Human Adventure: From Copernicus to Einstein and Beyond* (Piscataway, NJ: Rutgers University Press, 2001).]

THE TEXTBOOK

As we inform the students in the *Student Guide*, we utilize three main "avenues of learning" in this course:

- Direct, hands-on experienced with the phenomena in the laboratory.
- Oral presentations, explanations, and discussions in class, as feasible.
- Written presentations in the textbook.

All three of these are designed to work together to help students to understand the concepts of physics and the processes of scientific research. No one way alone will suffice.

Of these three avenues, many students (and instructors) find, in general, that the use of a textbook is problematic. We have been aware from the start that many students today do not willingly immerse themselves at length in the reading of textbooks, especially a science textbook that also encompasses the cultural context of science. Nor are some students deeply engaged in the educational process, especially in a course that they may be attending only because it is part of their general education or core requirement. With the continued absorption in "multimedia," opportunities for Web surfing, and Internet information overload, the trends toward passivity, short attention spans, and the aversion to major reading assignments are problems to be faced. Indeed, many students are entering college without having learned *how* to read a textbook productively in any subject.

Among the solutions advocated, one has been to abandon textbooks altogether and to rely solely on hands-on activities. We have concluded that there is much more to be said for retaining the text—but in a form that more firmly engages students' active participation in the learning process, that enables them to learn how to obtain information from the written word, and that provides them with direct connections between the text material and their own life experiences and laboratory activities.*

In order to encourage thoughtful reflection on "the real world," the *Student Guide* urges students to keep a personal journal of notes on all of their readings, activities, questions, and thoughts connected with the physics study throughout this course. Many of the questions at the end of each chapter are designed to be answered in conjunction with such on-going journal records.

The chapter discussing elsewhere in this *Instructor Guide* provide background on the aims and objectives of each chapter, as well as pedagogical inspiration and sources. Further content and pedagogical resources are given there also.

Study Guide Questions

Two types of questions appear at the end of each text chapter: "Study Guide" Questions and "Discovery" Questions. The study guide questions are designed as a guide for the study of each chapter. They can be used quite

* This issue has been further addressed by C.E. Swartz and T. Miner, *Teaching Introductory Physics: A Sourcebook* (Woodbury, NY: AIP Press, 1997), pp. 1–5; and What's the use of high-school physics texts? *Phys. Teach.*, **37** (1999), 306–308.

profitably either for individual study or as the basis for group discussion during or outside of class, as feasible.

Although the study guide questions do involve a degree of "regurgitation" of text information, we have found such questions essential in helping students, especially beginning students, to grasp the essentials presented in the text. One of the greatest difficulties for introductory students is discerning what is "important" and what is "not important." The study guide questions first ask the students to outline the major points in the chapter and in each section, and then to answer a series of (largely qualitative) questions that focuses their attention on these points. All of the answers to these questions may be found in the respective section of the chapter. Assuming that students performing the outlines will soon become familiar with this method of study, references to the outline are lessened after the first few chapters.

During the early weeks of each semester, instructors might wish to monitor students' answers to the study guide questions, whether answered individually or in groups, in order to ensure that the students are learning how to benefit from the text. Altogether there are only a relatively few questions per chapter and section, so that the students will be able to answer each in some depth. Most of the questions are designed to elicit declarative responses so that students will learn to express these new and sometimes abstract concepts in their own words, in writing and/or verbally to the group or class, as feasible, an important task that many students also find initially to be difficult. As an inducement to the reluctant, you might resort to collecting and briefly reviewing their notes during the first weeks, as needed.

Students should also be encouraged to record any questions they have about the material and to indicate passages that they do not understand, and to bring these up in class. We have found that instructors need to remind students frequently of the purpose of the study guide questions and the advantages to them in taking the time to answer them carefully. The advantages may become even more immediate if students are notified in advance that some of these same questions, or versions thereof, may well appear on the next examination. This helps them to know what to study, it indicates by example what is "important" enough that it appears in an examination, and it gives them confidence that they can succeed in physics.

However you choose to handle these questions and any other facets of the course, the students should perceive the instructor as someone who is in partnership with each of them as they confront this material, rather than representing to them an obstacle to be overcome in "getting through the course."

Given the likely wide variation of expertise in mathematical problem solving among students in a course such as this, quantitative problem solving is less emphasized than is conceptual comprehension. (Of course, depending on the class's ability or the abilities of individual students, instructors might wish to place more emphasis on problem solving, and to add further exercises along these lines. In fact, on discovering a highly talented student, an instructor must pay special attention to providing any additional materials, exercises, or reading so as to widen the boundaries and add to the excitement of discovering science.) Nevertheless, the course materials do involve the use of mathematical symbols and equations, for which students will also have practice in the laboratory. Although some of the study guide questions do involve mathematics, they generally encourage students to work through the examples in the text for comprehension. In so doing, students gain further confidence in their own ability at mathematical manipulation, a confidence that they may not have acquired previously.

The study guide questions are also intended to be conducive to group collaboration. In those settings where it is feasible for students to work together in groups in or out of class, finding the answers together and explaining the results orally to one another has been shown to have considerable benefits. If group work is encouraged during class, the time lost to lecturing is usually more than compensated for by the gain in comprehension. As every teacher knows, the best way to learn a subject fully is to have to explain it to others.

Discovery Questions

The "Discovery" questions are designed to encourage students to "discover" and to inquire further on their own, or in groups, about the ideas in the text. Some of the questions involve outside projects, Internet references, and brief individual or group inquiries.

Some of the questions entail quantitative work that is similar to examples in the text but may require some prior experience in manipulating algebraic equations. As in conventional physics texts, problem solving helps students to gain a greater familiarity with the conceptual meaning of the fundamental equations. However, as noted above, because of the wide diversity in the mathematical preparation of nonscience students and in their ability to relate mathematical symbols and equations to physical concepts, not all students are able to attempt such problems. The investment of time required to bring the entire class up to the level of minimal proficiency in problem solving is perhaps better spent in attempting to achieve the more immediate goals of the course in the qualitative comprehension of the content and processes of physics. But where such questions may be beneficial, they should be attempted.

Several of the early discovery questions in each chapter may be indicated by an asterisk. These questions, which sometimes involve small projects, are designed to help awaken students' interest in the material of the chapter and to help them to begin making connections between the course material and their own experiences and observations of the world around them. It is suggested that these questions be answered even before the students begin reading the chapter. Students can return to them again after they have read the chapter, and revise any conclusions and thoughts they had earlier. Again, a journal of their work may be helpful in such an exercise.

LABORATORY EXPLORATIONS

A course such as this cannot succeed without direct, hands-on laboratory experience. As we state in the *Student Guide*, the best way to learn physics is by *doing* physics. Laboratory work enables students to experience at first hand some of the processes of scientific research, scientific "habits of mind" that include truthfulness in reporting and careful attention to measurements, and the concepts that emerge from direct experience with the phenomena. Many of the concepts discussed in the text may be, for some students, too abstract to be comprehended by reading or oral description alone. In fact, the more laboratory experience the better. If the activities are well designed, students enjoy working in the laboratory, they gain further confidence in their abilities, and instructors appreciate the positive results that their efforts are achieving.

It is generally accepted that the old "cookbook" style of laboratory "exercise" is no longer adequate—if it ever was. A great deal of research and creative effort have been devoted in recent years to the development of truly beneficial laboratory activities for nonscience undergraduates and future teachers. These endeavors have inspired much of the approach represented in our suggested laboratory work.

Students should be aware that the purposes of the laboratory are to allow them: (a) to gain familiarity with the phenomena and concepts in the course; and (b) to "do science themselves"—to engage in the various types and aspects of research analogous to that found in actual laboratory research. These include the opportunity to explore the unknown, to test hypotheses and predictions, to measure unknown quantities, to analyze data and draw conclusions, to gain familiarity with new instruments, to present their findings to others, and, especially, to gain a first-hand understanding of the basic concepts and laws of physics.

At the same time, students should also be assured that it is *not* the purpose of the laboratory "to get the previously established right answer." The grade should depend to a large degree upon the student's thoughtfulness, care, and honesty in observing and recording the phenomena, designing alternative explorations, interpreting the results and drawing conclusions, critically assessing their results, and reporting them to others. By the end of the semester, students should be able to frame the question to be investigated within the context of a given exercise; to design an alternative experiment; to choose the proper apparatus; to collect, organize, and interpret the data; and to present their results to others for review. After all, this is the way actual research is carried out.

All of the suggested laboratory activities involve somewhat open-ended and fully hands-on explorations of apparatus and observations that are directly related to the material in the text. The related sections in the text are indicated in each exploration, as appropriate. Since most nonscience students require considerable preparation for laboratory work, we have found that it is often necessary to begin each exploration in the form of a guided inquiry, leading gradually into independent work. In many cases, students are asked to predict what will happen, then to test their prediction, often with surprising results, and to analyze the agreement or disagreement with their expectations. In order to encourage a clearer understanding of their data, students are asked to organize and present the data in tables of their own design.

All of the suggested apparatus, data acquisition, and data analysis are deliberately intended to be as "low tech" as possible in order to afford students maximum opportunity for hands-on experience with the phenomena and the analysis—and to afford instructors the flexibility of adapting the exploration to their own equipment, whether of higher technology or not. Unfortunately, many students have never had an opportunity to observe nature directly during their prior education. The apparatus suggested here is inexpensive and common to most instructional laboratories (though, of course, the suggested equipment may be supplemented by the instructor). Suggested sources of equipment are provided in the discussions below. Where appropriate, some of the explorations provide opportunities for students to learn the methods of data handling and analysis offered by spreadsheets and computer graphing.

Research has not yet reached a consensus on the most beneficial utilization of computer simulations of phenomena in the laboratory and classroom. So far we have found that simulations can be helpful *after* students have had first-hand experience with the actual phenomena. Simulations can be used as a type of modeling technique, which will be increasingly common in many professions. They can also help students to see the potential impact of changes in certain variables ("What if . . . ?" types of questions) which they might then also try out in the laboratory. And simulations might help students to observe situations and phenomena that cannot be duplicated in their laboratory. Some suggested programs and interactive Web sites are given in the references section elsewhere in this *Instructor Guide*.

Explorations

The *Student Guide* contains two types of suggested laboratory explorations: "mini-laboratory explorations" and "major laboratory explorations." Instructors might utilize these explorations separately or in combination, depending upon the needs of the class. There are also a series of "Activities" that students may pursue.

The mini-laboratories are brief hands-on exercises related to specific material in the text. They can be performed during the class or lecture as a demonstration or a brief laboratory activity, after class as a self-guided exploration, or in sequence during a laboratory period. In addition, two or more mini-laboratories might be combined or enhanced to form a major laboratory.

The "major laboratory explorations" are designed for extended work in the laboratory. As noted earlier, we suggest only a handful of such explorations per semester in order to provide enough time for a complete encounter with each exploration. Each exploration is broken down into sections, enabling the exploration to be utilized in a variety of ways depending upon the needs of the class and the instructor. For instance, the exploration might be followed over several weeks; or each section might be "subcontracted" to individual groups, after which the entire class gets together to discuss the overall results; or one or more sections might be treated as a mini-laboratory.

Good Reading and Writing

One of the secondary aims of this course is to encourage good writing and good verbal skills, in addition to good reading habits—areas in which many students today are deficient. The laboratory is another venue in which such skills can be encouraged. In answering the questions as they work through each laboratory exercise, students may want to make rough notes in their journals, but at some point—when they turn in their work, or before then—they should be required to write their answers in clear, complete sentences and in proper grammatical form. Each major laboratory ends with an "evaluation" section that is intended to help students to attain an overview of what they have accomplished and to evaluate their experience and results. It also affords them the opportunity to articulate their results in writing, and perhaps also verbally to others.

STUDENT EVALUATION AND TESTING

We leave this topic, of course, to the discretion of the instructors, but we do have several suggestions, based upon prior experiences with *Project Physics* and current experiences with nonscience undergraduates. First, we would suggest that grading only "on the curve" be minimized or avoided entirely. The reason is that it tends to introduce an unnecessary competition that may undermine students' self-confidence and defeat the cooperative nature of any group activities used in the course. On the other hand, an absolute scale can be equally threatening and even unfair for students entering the course with different levels of preparation. Both of these methods are perhaps more appropriate for more homogeneous classes of majors in physics, in which all of the students enter the course at roughly the same level of preparation.

Ideally, grades should be based on an evaluation of the *growth* of each student during the course, as determined by comparing his or her level of comprehension at the end of the course with his or her level of comprehension at the beginning. This is particularly true in a course such as this, in which the comprehension of the meanings of the equations and laws and the reasons why we accept them is at least as important as the solution of quantitative problems or the recitation of various laws of nature. In addition, not only may student preparation differ greatly among different students, but also the course deliberately encourages student initiatives and provides opportunities for individualized learning. And it permits different students to pursue different interests and to shape for themselves somewhat different experiences. It follows that each student ought to have opportunities to demonstrate his or her individual progress in the course objectives as the basis for grading. But such an approach is impractical for large classes and impossible to achieve completely even in small classes.

So, in the end, we have settled on recommending a hybrid approach in which the "curve" is used as a "first approximation." But the approximation must be enhanced by factoring in what we know about the student's progress and effort as evidenced, for example, by his or her participation in class discussions, laboratory inquiries, outside projects, and performance on graded work throughout the semester, including examinations. In this way students feel that they are being treated fairly as individuals, while at the same time they understand that they must keep up with others in the class. In no case, however, should a student's examination scores be taken as the sole basis on which each student's achievement is assessed and graded.

Some suggested examination questions are provided elsewhere in this *Instructor Guide*. A few caveats are in order. The first is that, while multiple-choice questions are less time-consuming to grade and are almost essential in a large lecture class, it is well known that they do not necessarily correlate completely with the students' actual comprehension of the material. Questions in which students must write their own answers in their own words often reveal more clearly what a student actually understands or does not understand about a concept or a development. Although such questions require much more time and effort to grade, we do suggest the inclusion of as many short-answer questions as possible. As indicated earlier, some of these might be based on the "discovery questions." This practice will reinforce the most important material for the students and provide them with the confidence, especially in an early examination, that they can succeed if they try.

We provide a series of multiple-choice questions for each chapter, along with other questions, elsewhere in this *Instructor Guide*. Eventually these will also be available for download on the course Web site at: http://www.springer-ny.com/up.

As the suggested syllabi indicate elsewhere in this *Instructor Guide*, we suggest two examinations and a final examination per semester, each examination covering roughly three chapters of material, two related major laboratories, and one or more mini-laboratories. Most of the chapters cover so much material that some students may find it overwhelming to prepare for more than this amount of material for one examination.