Preface

People feel good about themselves when they exceed self-expectations. School is sometimes a place where we fall below expectations—not only self-expectations, but the expectations of teachers, family, and the overall community. Physics courses have been notorious in this regard.

Too often, physics has the reputation of being the "killer course"—the course that diminishes average-ability students, who may drop out or take an incomplete, and spread the word about how unpleasant it is. Or they hear about it and simply avoid it in the first place. But we physics instructors have a secret: We know that the concepts of physics for the most part are much more comprehensible than the public expects. And when that secret is shared with students in a non-intimidating way, one that prompts them to discover they are learning more than they thought they could, they feel wonderful—about us, about physics, but more important, about *themselves*. Because they are not bogged down with time-consuming mathematical exercises of "the most threatening kind—word problems," they instead get a deeper and wider overview of physics that can be their most enlightened and positive school experience.

This manual describes a conceptual way of teaching. It helps relate physics to the students' personal experience in the everyday world, so they learn to see physics not only as a classroom or laboratory activity, but as a part of everyday living. People with a conceptual understanding of physics are more alive to the world, just as a botanist taking a stroll through a wooded park is more alive than most of us to the trees, plants, flora, and the life that teems in them. The richness of life is not only seeing the world with wide-open eyes, but knowing what to look for. This puts you in a very nice role—being one who points out the relationships of things in the world about us. You are in an excellent position to add meaning to your student's lives.

The appeal of the conceptual approach for nonscience students is obvious. Because conceptual physics has minimum "mathematical road blocks" and little or no prerequisites, it is a rare chance for the nonscience student to learn solid science in a hard-core science course. I say rare chance, because nonscience students do not have the opportunity to study science as science students have to study the humanities. Any student, science or humanities, can take an intermediate course in literature, poetry, or history at any time and in any order. But in no way can a humanities student take an intermediate physics or chemistry course without first having a foundation in elementary physics and mathematics. Science has a *vertical structure*, as noted by the prerequisites. So it is much easier for a science student to become well rounded in the humanities than for a humanities student to become well rounded in science. Hence the importance of this conceptual course.

Too often a physics course begins with a study of measurement, units of measure, and vector notation. I feel this contributes to the unfortunate impression that physics is a dull subject. If you were being instructed on some computer activity, wouldn't you object to being shown everything that might appear much later in your development? Don't we prefer to be shown something when it is needed? The same is true with a physics course. Rather than discuss vectors, wait until you're dealing with how fast an airplane is blown off course by a crosswind. When the vectors help to learn a topic your class is immersed in, they are valued. Likewise with so much else in physics.

It is important to distinguish between physics concepts and the tools of physics. Why spend valuable time teaching a class of nonscience majors the tools needed for physics majors? By minimizing time spent on graphical analysis, units conversions, measurement techniques, mathematical notation, and problem solving techniques, time is provided to teach a broad survey of physics—from Newton's laws to E & M to rainbows to nuclear processes. Too often physics courses spend overtime in kinematics because of its appealing tools, with the result that modern physics is given short thrift. Many people who took a physics course can tell you that the acceleration due to gravity is 9.8 m/s^2, but they have no idea that radioactivity contributes to the molten state of Earth's interior. They didn't get that far in their course, or if they did, they were rushing through the end of the course. Modern physics gets too little attention.

The rest of my remarks here concern science majors. I maintain that science students who use this book in their first physics course are even greater benefactors than nonscience students. Not because it is an "easy" introduction or even because it gets them excited about physics, but because it *nurtures that gut-level conceptual understanding that is the missing essential for so many science and engineering students*—who like their would-be poet counterparts, have mistaken being able to recite poetry for understanding it.

I feel strongly that the ideas of physics should be understood conceptually before they are used as a base for applied mathematics. We are all acquainted with students who can crank out the answers to many problems by virtue of little-understood formulas and a knack for algebraic manipulation—students who even in graduate school are able to do well in written exams (which are most always exercises in problem solving), but who do poorly in oral exams (which are most always conceptual). Is this a surprising outcome for students who have never had a good exposure to the concepts and ideas of physics that weren't at the same time paired with the techniques of mathematical problem solving? To many of these people, physics *is* applied mathematics—so much so, that a physics course without mathematical problem solving seems a contradiction! Conceptual understanding in every physics course they ever encountered took a back seat to problem-solving techniques. The name of the game in every physics course has been PROBLEM SOLVING. Students are solving problems involving the manipulation of twigs and branches when they lack a conceptual understanding of the trunk and base of the tree from which the branches stem.

We all know that the beauty of physics is its elegant mathematical structure. If you want to teach mathematics to your students, a physics course is the way to go. This is because the mathematics is applied to actual things and events. But if you want to teach *physics* to your students, put the niceties of mathematical problem solving in the back seat for a semester and teach physics conceptually. You'll provide your students, especially your mathematical whizzes, a look at physics they may otherwise miss. First having an understanding of concepts on a conceptual level is an essential foundation for any serious further study of physics. Provide your students with a good look at the overall forest before they make measurements of any single tree—place comprehension comfortably *before* calculation.

For an algebra-trig based course that goes beyond the conceptual course, problem solving is central. A blend of conceptual and problem solving is now an option, for Phil Wolf and I have written a supplementary student problems book that we think will be greeted as being as novel as Conceptual Physics was nearly 40 years ago. The book, now in its third edition, is described on the pages that follow. With this supplement, *Conceptual Physics* can be the textbook for courses with a light algebra-trig component.

The challenge is yours. Let's get to work!

Teaching Tips

• ATTITUDE toward students and about science are of utmost importance. Consider yourself not the master in your classroom, but the main resource person, the pacesetter, the guide, the bridge between your student's ignorance and information you've acquired in your study. Guide their study—steer them away from the dead ends you encountered, and keep them on essentials and away from time-draining peripherals. You are there to help them. If they see you so, they'll appreciate your efforts. This is a matter of self-interest. An appreciated teacher has an altogether richer teaching experience than an under-appreciated teacher.

• ENGAGE your students. Recall your own student days with teachers whose engagement was with the subject matter, but seldom with you or your fellow students. Engagement, eye contact for starters, is crucial to your success as a teacher. Be *with* your students.

• Make your course ENJOYABLE. We all enjoy the discovery of learning more than we expected of ourselves. Guide that discovery. When a student's first encounter with physics is delightful, the rigor that comes later will be welcomed.

• Don't be a "know-it-all." When you don't know your material, don't pretend you do. You'll lose more respect faking knowledge, than not knowing it. If you're new to teaching, students will understand you're still pulling it together, and will respect you nonetheless. But if you fake it, and they CAN tell, whatever respect you've earned plummets.

• Be firm, and expect good work of your students. Be fair and get papers graded and returned quickly. Be sure the bell curve of grades reflects a reasonable average. If you have excellent students, some should score 100% or near 100% on exams. This way you to avoid the practice of fudging grades at the end of the term to compensate for off-the-mark low exam scores. The least respected professor in my memory was one who made exams so difficult that the class average was near the noise level, where the highest marks were some 50%.

• Be sure that what knowledge you want from your students is reflected by your test items. The student question, "Will that be on the test?" is a good question. What is important—by definition—is what's on the test. If you consider a topic important, provide an opportunity for students to demonstrate their understanding of that topic. An excellent student should be able to predict what will be on your test. Remember your own frustration in your student days of preparing for a topic only to find it not part of the test. Don't let your students experience the same. Using short questions that fairly span course content is the way to go.

• Consider having students repeat work that you judge to be poor—before it gets a final grade. A note on a paper saying you'd rather not grade it until they've given it another try is the mark of a concerned and caring teacher.

• Do less professing and more questioning. Valuable information should to be the answer to a question. Having frequent "check-your-neighbor" intervals should be an important feature of your class. Beware of the pitfall of too quickly answering your own questions. Use "wait-time," where you allow ample time before giving the next hint.

• Show RESPECT for your students. Although all your students are more ignorant of physics than you are, some are likely more intelligent than you are. Underestimating their intelligence is likely overestimating your own. Respect is a two-way street. Students who know you care, respect you in return.

On Class Lectures

Profess less and question more! Engage your students in lecture by frequently posing questions. Instead of answering your own question, direct your students to come up with an answer, and check their thinking with their neighbor—right then and there. This technique has enlivened my classes for more than 25 years. I call it CHECK YOUR NEIGHBOR. The procedure goes something like this; before moving on to new material, you want to summarize what you've already discussed. So you pose the challenge, "If you understand this—if you really do—then you can answer the following question." Then pose your question slowly and clearly, perhaps in multiple-choice form or one requiring a short answer. Direct your class to make a response—usually written. Tell them to "CHECK YOUR NEIGHBOR"; look at their neighbors' papers, and briefly discuss the answer with them. At the beginning of the course you can add that if their neighbors aren't helpful, to sit somewhere else next time! The check-your-neighbor practice changes *teaching by telling* to *teaching by questioning*—perhaps first admonished by Socrates. Questioning brings your students into an active role, no matter how large the class. It also clears misconceptions before they are carried along into new material. In the suggested lectures of this manual, I call such questions, CHECK QUESTIONS. The check-question procedure may also be used to *introduce* ideas. A discussion of the question, the answer, and some of the misconceptions associated with it, will get more attention than the same idea presented as a statement of fact. And one of the very nice features of asking for neighbor participation is that it gives you pause to reflect on your delivery.

Harvard's Eric Mazur, profiled at the outset of Chapter 9, pioneers the conceptual approach to physics with science and engineering majors. Eric is a strong advocate of what he calls CONVINCE YOUR NEIGHBOR, much akin to Next-Time Questions. Students answer questions with clickers, an extension of whiteboards. This feature is also a central component of the Modeling Workshops that are gaining in popularity. I regret that I didn't employ whiteboards in my classes before I retired in 2000. And electronic clickers are now popular, giving the instructor immediate feedback on questions posed. By whatever method, have your students check their neighbors!

On homework, a note of caution: Please, please, do not overwhelm your students with excessive written homework! (Remember those courses you took as a student where you were so busy with the chapter-end material that you didn't get into the chapter material itself?) The chapter-end exercises are significantly more numerous in this edition only to provide you a wide selection to consider. Depending on your style of teaching, you may find that posing and answering exercises in class is an effective way to develop physics concepts. A successful course may place either very much or very little emphasis on the exercises. Likewise with the problems, which are meant to be assigned after concepts are treated and tested. Please don't let your course end up as a watered-down physics major's problem solving course!

I strongly recommend lecture notes. In all of my teaching years I brought a note or two to every lecture. A list of topics gives you a checklist to glance at when students are going through a check-your-neighbor routine. Such notes insure you don't forget main points, and a mark or two will let you know in your next lecture what you may have missed or where you stopped.

You may find that your students are an excellent source of new analogies and examples to supplement those in the text. A productive class assignment is:

> Choose one (or more) of the concepts presented in the reading assignment and cite any illustrative analogies or examples that *you* can think of.

This exercise not only prompts your students to relate physics to their own experiences, but adds to your future teaching material. I've relied on this procedure to provide me with credible wrong answers for devising multiple-choice exams!

Equations are important in a conceptual course—not as a recipe for plugging in numerical values, but more important, as a guide to thinking. The equation tells the student what variables to consider in treating an idea. How much an object accelerates, for example, depends not only on the net force, but on mass as well. The equation $a = F/m$ reminds one to consider both quantities. Does gravitation depend on an object's speed? Consideration of $F \sim mM/d^2$ shows that it doesn't, and so forth. The problem sets, Think and Solves, at the ends of most chapters involve computations that help to illustrate concepts rather than challenge your students' mathematical abilities. They are relatively few in number to avoid overload. Again, for those who make problem solving a greater part of the course, see the student supplement *Problem Solving in Conceptual Physics* that complements this 12*th Edition*.

Getting students to come to class prepared is a perennial problem. An ineffective way to address this is to preach about the importance of reading assigned material before coming to class. When you do that, you might as well be whistling Dixie. What does work is rewarding the reading directly. What a great idea: If we want students to behave a certain way, we reward them when they do! Start your class with a short quiz on the reading assignment. Suk R. Hwang of the University of Hawaii at Hilo begins each class by handing out a half sheet of paper with one or two questions that highlight the reading assignment. Before lecturing on gravity, for example, the students will take one or two minutes to respond to "State Newton's law of gravity in both words and equation form." Suk collects the sheets and then begins his lecture. The whole process takes less than five minutes. He assigns a grade to the sheets, with brief comments, and returns them. But the grades do not count at all when tallying the final course grade. He is out front with his class when he tells them that the only purpose of the quizzes is to increase the probability of coming to class having first read the assigned reading material. Suk finds that because students abhor returning blank sheets, or dislike not being able to correctly answer the simple questions, they DO the reading assignment. Evidently a well-answered paper, even though it doesn't count to the final grade, is sufficient reward for the student.

More and more instructors are finding that giving daily short quizzes or assigning summary reports gets students to class prepared. Importantly, the instructor needn't be submerged in paperwork. Spot grading or even no grading is sufficient. With a prepared class, instead of presenting material, you can refine and polish, with students that can fully benefit by the questions you pose. Less professing—more questioning!

Make use of the NEXT-TIME QUESTIONS located on your Instructor Resource DVD, which poses intriguing questions accompanied by my cartoons, with and accompanying answer page. These can be photocopied and posted on display boards to capture attention and create discussion. They are also available on the Arbor Scientific website: www.arborsci.com. What I passionately ask is that you heed this advice: Employ "wait time" before displaying the answers. If you put them in printed form, you can display them in a designated space, perhaps a glass case near your office. My policy was to display four or six of them weekly—answers to the ones posted the previous week, with new ones. These can also be projected in your classroom, perhaps via PowerPoint. They will certainly prompt out-of-class discussion. When impatient students want to check their answers with me before posting time I advise them to consult with their friends. When they tell me they have done so and that their friends are also perplexed, I suggest they seek new friends! So post them in a hallway for all to ponder or conclude your lessons with them in class as ties to the next class meeting—hence their name, *Next-Time Questions*. Most all of these first appeared as *Figuring Physics* in *The Physics Teacher*, the must-read magazine of the American Association of Physics Teachers (AAPT).

New with this edition are my Hewitt-Drew-it! PHYSICS screencasts, which are QR coded throughout the textbook. These are quickie tutorials that complement the textbook, often with visual explanations of concepts. Creating these has been my passion for the past two years.

The student ancillary PRACTICING PHYSICS BOOK can serve as a tutor on the side. At CCSF it is carried in the student bookstore as "recommended but not required" and used by about one-third of the students taking the course. Answered practice pages are in the back of the book, reduced in size. I consider the Practicing Physics Book my best pedagogical creation, along with my new screencasts.

The Conceptual Physics package of text and ancillaries lend themselves to teaching by way of the 3-stage LEARNING CYCLE, developed by Robert Karplus some 40 years ago.

EXPLORATION—giving all students a common set of experiences that provide opportunities for student discussion. Activities are both in the *Laboratory Manual* and the chapter-end Think-and-Do's in the textbook.

CONCEPT DEVELOPMENT—lectures, textbook reading, doing practice pages from *Practicing Physics*, viewing *Hewitt-Drew-it! screencasts*, and class discussions.

APPLICATION—doing end-of-chapter exercises and problems, *Next-Time Questions*, experiments from the *Laboratory Manual*, and for your math-savvy students, *Problem Solving in Conceptual Physics*.

The first step of the learning cycle increases the effectiveness of instruction by insuring students have first-hand experience with much of the phenomena to be discussed. For example, before hearing a lecture on torques, have your students pass around a meterstick with a weight dangling from a string (as nicely shown by Mary Beth Monroe in the third chapter-opening photo for Chapter 8 on page 132). Holding the meterstick horizontally with the weight near the end, students feel the greater effort needed to rotate the stick. When the weight is positioned closer to their hand, rotational effort is much less. Aha, now you're ready to discuss the concept of torque, and to distinguish it from weight.

Many of the suggested lectures in this manual will require more than one class period, depending on your pace of instruction and what you choose to add or omit. The lectures of each instructor, of course, must be developed to fit his or her style of teaching. My suggested lectures may or may not be useful to you. If you're new to teaching conceptual physics and your lecture tendency is to lean on chalkboard derivations, you may find them quite useful, and a means of jumping off and developing your own non-computational way of teaching.

DVDs of my classroom lectures are described on page xv.

Please bring to my attention any errors you find in this manual, in the text, in the test bank, or in any of the ancillaries. I welcome correspondence suggesting improvements. E-mail, Pghewitt@aol.com. Good luck in your course!

ANCILLARY PACKAGE FOR THE 12th EDITION

For Instructors

INSTRUCTOR RESOURCE DVD (IR-DVD):
Contains a wealth of goodies, including all textbook illustrations, tables from the text, interactive presentation applets and animations, parts of Hewitt's videoed lectures and demos, in-class clicker questions for use with PRS and HiTT Classroom Response Systems, most of which can be edited and customized for classroom presentations. The main ancillaries are:

> **NEXT-TIME QUESTIONS**:
> These are insightful questions, with answers, to central ideas in physics. Each was formerly published as *Figuring Physics* in the American Association of Physics Teachers (AAPT) magazine, *The Physics Teacher*. Aside from projecting these via PowerPoint or otherwise, consider printing copies and posting for student display. Allow a sufficient 'wait time' before posting solutions. There are Next-Time-Questions for every chapter.
>
> **TEST BANK**:
> Contains more than 2000 multiple-choice questions, categorized by level of difficulty and skill type. The friendly graphical interface enables you to easily view, edit, and add questions, transfer questions to tests, and print tests in a variety of fonts and forms. Search and sort features let you quickly locate questions and arrange them in a preferred order. A built-in question editor gives you power to create graphs, import graphics, insert mathematical symbols and templates, and insert variable numbers or text.

VIDEOS *Conceptual Physics Alive!*:
Features my classroom lectures while teaching Conceptual Physics at the University of Hawaii in 1989-1990. These are available in DVD or rental of individual lessons streamed from Arbor Scientific, (www.arborsci.com) P.O. Box 2750, Ann Arbor, MI 48106-2750.
Additionally, the 12-lecture set of videos taken at CCSF in 1982 have been resurrected by Marshall Ellenstein, and with other "goodies," comprise a 3-disc DVD set "*Conceptual Physics Alive*! *The San Francisco Years.*" The goodies include the 60-minute ***Teaching Conceptual Physics***, which documents how I teach physics conceptually, and the 55-minute ***Lecture Demonstrations in Conceptual Physics***, which is more classroom footage with emphasis on demonstrations (most of which are in the "Suggested Lectures" in this manual). Another goodie is a 45-minute general-interest opening lecture, ***The Fusion Torch and Ripe Tomatoes***. At one-quarter the price of the Hawaii tapes, they are available from Media Solutions, 1128 Irving St., San Francisco, CA 94122 (www.mediasolutions-sf.com/hewitt/sfyorders.pdf).

For Students

PRACTICING PHYSICS BOOK:
This booklet of more than 100 practice pages helps students to learn concepts. This is very different from traditional workbooks that are seen as drudgery by students. These are insightful and interesting activities that prompt your students to engage their minds and DO physics. They play the role of a tutor when you post solutions at appropriate times (like the posting of Next-Time Questions). Practice Book solutions, reduced to one-half size, are included at the end of the book. ***Practicing Physics*** is

low priced and can be offered as a suggested supplement to the textbook in your student bookstore. ISBN: 0805391983.

PROBLEM SOLVING BOOK:
Now in its Third Edition, this is my latest effort to boost the teaching of physics, with co-author Phil Wolf. It is meant for those who wish a stronger problem-solving component in their teaching, and particularly for those wishing to extend *Conceptual Physics* to an algebra-trig course. I feel the novelty of the problems and the simple method employed for solving them will be as important to the way physics is taught as was *Conceptual Physics* when it was introduced some 40 years ago. No longer does the instructor have to plead with students to complete the problem before plugging in numerical values. Instructors no longer have to plead with students to show their work. Why? Because the phrasing of the problems makes these concerns mandatory. Variables are given in letters, not numbers (mass is *m*, velocity is *v*, and so forth). Not until a second part of a problem are numerical values given and a numerical solution asked for. Each chapter set of problems is followed by a second set of *Show-That Problems*, which give the numerical answer and ask the student to show how it comes about. I've been using this method for decades when teaching the algebra-trig and calculus based physics courses. Now it is available to users of *Conceptual Physics*. Solutions to the problems are given on the website in the Instructor's Resource area. At your discretion you can post solutions for your students. ISBN: 0805393773.

LABORATORY MANUAL:
This manual, written by myself and mostly by Dean Baird, is rich with simple activities to precede the coverage of course material, as well as experiments that are a follow through to course material. It also employs the computer in tech labs. New to this 12th edition, the instructor manual for the laboratory manual is separate from this manual.

Flexibility of Material for Various Course Designs

You'll teach more physics in your course if you spend less time on topics that are more math than physics. Topics I suggest you remove from your front seat include units conversions, graphical analysis, measurement techniques, error analysis, overtime on significant figures, and the wonderful and seductive time-consuming toys for kinematics instruction.

Very few one-semester and virtually no one-quarter courses will include all the material presented in the text. The wide variety of chapters provides a selection of course topics to suit the tastes of individual instructors. Most begin their course with mechanics, and treat other topics in the order presented in the text. Some will go immediately from mechanics to relativity. Many will begin with a study of light and treat mechanics later. Others will begin with the atom and properties of matter before treating mechanics, while others will begin with sound, then go to light, and then to electricity and magnetism. Others who wish to emphasize modern physics will skim through Chapters 11, 19, 30 and 31, to then get into Parts 7 and 8. Some will cover many chapters thereby giving students the widest possible exposure of physics, while others will set the plow deeper and treat fewer chapters.

The following breakdown of parts and chapters is intended to assist you in selecting a chapter sequence and course design most suited to your objectives and teaching style. You should find that the chapters of Conceptual Physics are well suited to stand on their own.

PART 1: MECHANICS After the first chapter, About Science, Mechanics begins with forces, rather than kinematics as in earlier editions. Newton's first law kicks off by featuring the concept of mechanical equilibrium. Force vectors are introduced. After this chapter, kinematics is treated, which I urge you to go through quickly. The important concepts of velocity and acceleration are developed in further chapters, which makes prolonged time in Chapter 3 a poor policy. Certainly avoid kinematics problems that are more math than physics, and that many students encounter in their math courses anyway. Chapter 4 goes to Newton's second law, followed by a separate chapter for the third law. There is more treatment of vectors in this 12-th Edition. They use no trig beyond the Pythagorean Theorem. There are no sines, cosines, or tangents, for the parallelogram method is used. (Trig is introduced in the *Problem Solving Book*, however.) Chapters, 2-5, are central to any treatment of mechanics. Only Chapters 2, 4, and 9 have a historical flavor. Note in the text order that momentum conservation follows Newton's 3rd law, and that projectile motion and satellite motion are combined in Chapter 10. My recommendation is that all the chapters of Part I be treated in the order presented. To amplify the treatment of vectors, consider the Practice Book and Appendix D. For an extended treatment of mechanics consider concluding your treatment with Appendix E, *Exponential Growth and Doubling Time*.

PART 2: PROPERTIES OF MATTER The very briefest treatment of matter should be of Chapter 11, atoms, which is background for nearly all the chapters to follow in the text. Much of the historical development of our understanding of atoms is extended in Chapter 32, which could well be coupled to Chapter 11. Chapters 12, 13 and 14 are not prerequisites to chapters that follow. Part 2, with the exception of the brief treatment of kinetic and potential energies in the Bernoulli's principle section of Chapter 14 may be taught before, or without, Part 1. With the exception noted, Part 1 is not prerequisite to Part 2.

PART 3: HEAT Except for the idea of kinetic energy, potential energy, and energy conservation from Part 1, the material in these chapters is not prerequisite to the chapters that follow, nor are Parts 1 and 2 prerequisites to Part 3.

PART 4: SOUND Material from these chapters (forced vibrations, resonance, transverse and standing waves, interference) serves as a useful background for Chapters 26, 29 and 31. Parts 1-3 are not prerequisites to Part 4.

PART 5: ELECTRICITY AND MAGNETISM Part 1 is prerequisite to Part 5. Also helpful are Chapters 11, 14, and 19. The chapters of Part 5 build from electrostatics and magnetism to electromagnetic induction—which serve as a background for the nature of light.

PART 6: LIGHT Parts 4 and 5 provide useful background to Part 6. If you begin your course with light, then be sure to discuss simple waves and demonstrate resonance (which are treated in Part 4). If you haven't covered Part 5, then be sure to discuss and demonstrate electromagnetic induction if you plan to treat the nature of light. The very briefest treatment of light can cover Chapters 26-28. A very brief treatment of lenses is in Chapter 28. A modern treatment of light should include Chapters 30 and 31.

PART 7: ATOMIC AND NUCLEAR PHYSICS Chapter 11 provides a good background for Part 7. Chapter 33 is prerequisite to Chapter 34. Otherwise, Part 7 can stand on its own.

PART 8: RELATIVITY This part can stand on its own and will nicely follow immediately from Part 1, if the ideas of the Doppler effect and wave frequency are treated in lecture. A thorough treatment of only Parts 1 and 8 should make a good quarter-length course.