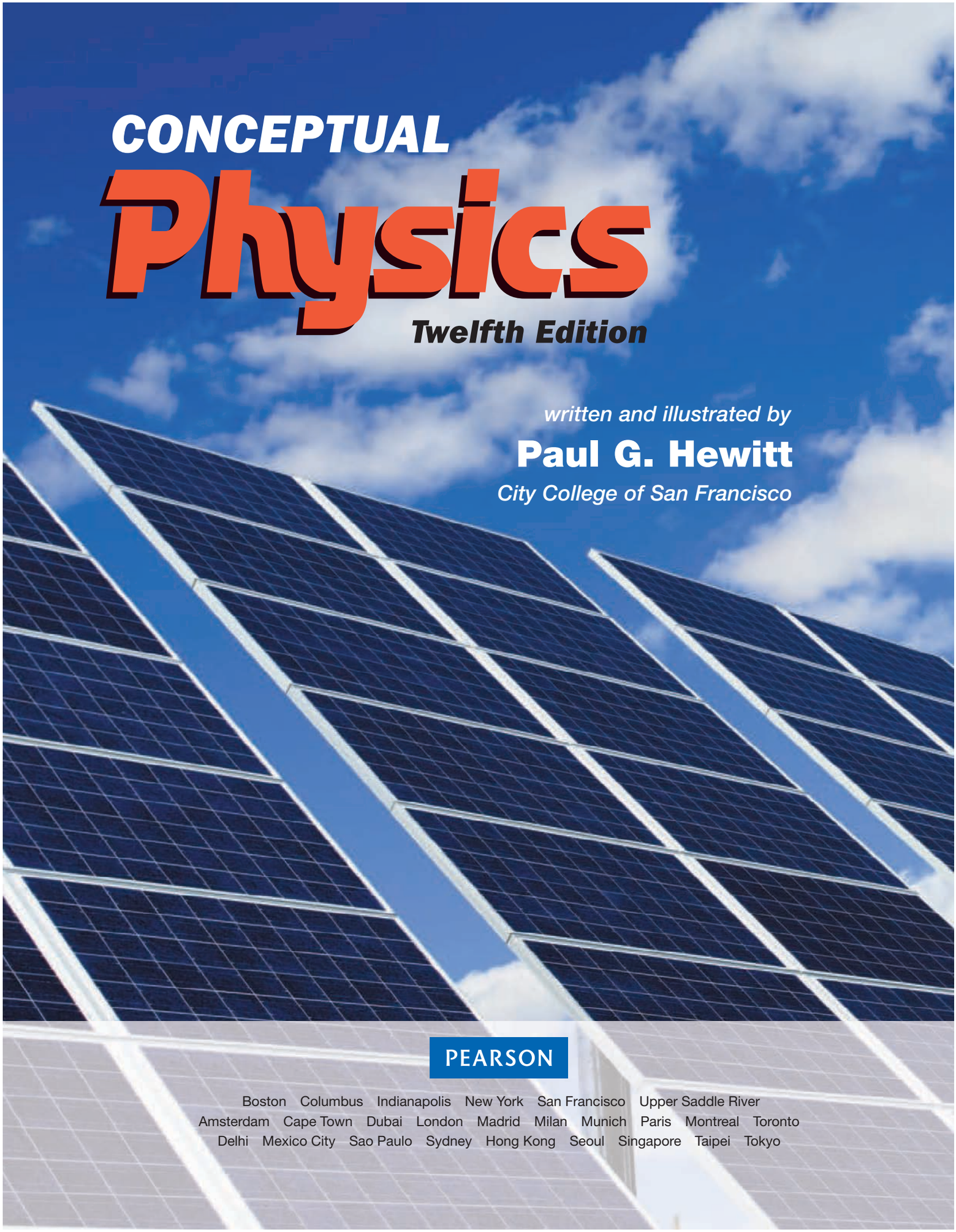

CONCEPTUAL Physics

Twelfth Edition

written and illustrated by

Paul G. Hewitt

City College of San Francisco

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To my grandchildren, Manuel, Alexander, Megan, Grace, and Emily
and to all students who struggle to learn physics

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The *Conceptual Physics* Photo Album

Conceptual Physics is a very personal book, reflected in its many photographs of family and friends, who overlap with colleagues and friends worldwide. Many of these people are identified in chapter-opening photos, and with some exceptions I'll not repeat their names here. Family and friends whose photos are Part Openers, however, are listed here. We begin on page 1, where great-nephew Evan Suchocki (pronounced "su-hock-ee" with a silent c) holds a pet chickie on my lap.

Part One opens on page 19 with Charlotte Ackerman, the daughter of friends Duane Ackerman and Ellen Hum. Part Two opens with Andrea Wu (also on pages 131 and 492), daughter of my friend in Hawaii, Chiu Man Wu (page 322). Part Three opens on page 244 with four-year-old Francesco Ming Giovannuzzi from Florence, Italy, grandson of friends Keith and Tsing Bardin (page 244). Part Four on page 355 shows Abby Dijamco, daughter of my last CCSF teaching assistant, dentist Stella Dijamco. In Part Five, on page 405, is my granddaughter Megan, daughter of Leslie and Bob Abrams. Part Six, page 485, opens with Lillian's nephew, Christopher Lee. Part Seven, page 452, shows William Davis, son of friends Alan and Fe Davis. My granddaughter Grace Hewitt begins Part Eight on page 657.

City College of San Francisco friends and colleagues open several chapters and are named there. Photos that are figures include Will Maynez, the designer and builder of the air track displayed on page 100, and again burning a peanut on page 298. Diana Lininger Markham is shown on pages 29 and 159. Fred Cauthen drops balls on page 127.

Physics instructor friends from other colleges and universities include Evan Jones playing with Bernoulli on page 264 and showing LED lighting on page 573. Egypt's Mona El Tawil-Nassar adjusts capacitor plates on page 423. Sanjay Rebello from Kansas State University, Manhattan, is shown on page 138. Hawaii's Walter Steiger is on page 588. Chuck Stone of Colorado School of Mines, Golden, shows an energy ramp on page 185.

Physics high school teacher friends include retired Marshall Ellenstein, who swings the water-filled bucket on page 146 and walks barefoot on broken glass on pages 263 and 544. Other physics teachers from Illinois are Ann Brandon, riding on a cushion of air on page 268, and Tom Senior, making music on page 403.

Family photos begin with wife Lillian and me, showing that you cannot touch without being touched on page 81. Another updated photo that links touching to Newton's third law shows my brother Stephen with his daughter Gretchen on page 87. Stephen's son Travis is on page 154, and his oldest daughter Stephanie on pages 230 and 543. My son Paul is shown on pages 305 and 340. Daughter-in-law

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Ludmila Hewitt holds crossed Polaroids on page 556. The endearing girl on page 215 is my daughter Leslie Abrams, earth-science coauthor of the *Conceptual Physical Science* textbooks. This colorized photo of Leslie has been a trademark of *Conceptual Physics* since the Third Edition. A more recent photo with her husband Bob is on page 486. Their children, Megan and Emily (page 554), along with son Paul's children, Alex (page 90) and Grace (page 391), make up the colorful set of photos on page 510. Photos of my late son James are on pages 150, 394, and 536. He left me my first grandson, Manuel, seen on pages 234 and 383. Manuel's grandmom, my wife Millie, who passed away in 2004, bravely holds her hand above the active pressure cooker on page 306. Brother David and his wife Barbara demonstrate atmospheric pressure on page 269. Their son also David, an electrician, is on page 445, and grandson John Perry Hewitt is on page 276. Sister Marjorie Hewitt Suchocki, author and emeritus theologian at Claremont School of Theology, illustrates reflection on page 522. Marjorie's son, John Suchocki, author of *Conceptual Chemistry*, Fifth Edition, and chemistry coauthor of the *Conceptual Physical Science* textbooks, is also a singer-songwriter, known as John Andrew; he strums his guitar on page 472. The group listening to music on page 399 is part of John's and Tracy's wedding party: from left to right, late Butch Orr, niece Cathy Candler (page 136 and her son Garth Orr on page 226), bride and groom, niece Joan Lucas (page 39), sister Marjorie, Tracy's parents Sharon and David Hopwood, teachers Kellie Dippel and Mark Werkmeister, and me.

Photos of Lillian's family include her dad (my father-in-law) Wai Tsan Lee, showing magnetic induction on page 457, and her mom (my mother-in-law), Siu Bik Lee, making good use of solar power on page 315. My nephew and niece, Erik and Allison Wong, dramatically illustrate thermodynamics on page 346.

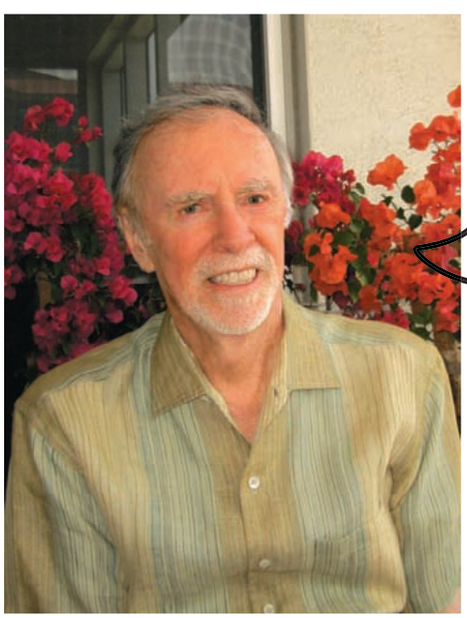
Personal friends who were my former students begin with Tenny Lim, a rocket engineer at the Jet Propulsion Lab in Pasadena, drawing her bow on page 115. This photo has appeared in every book since the Sixth Edition. She is seen with her husband Mark Clark on Segways on page 144. Another of my protégés is rocket-scientist Helen yan, who is involved in satellite imaging sensoring for Lockheed Martin in Sunnyvale, in addition to teaching physics part-time at CCSF (page 121), and again posing with Richard Feynman and Marshall Ellenstein on page 544. On page 150 Cliff Braun is at the far left of my son James in Figure 8.50, with nephew Robert Baruffaldi at the far right. Alexei Cogan demonstrates the center of gravity on page 143, and the karate gal on page 85 is Cassy Cosme.

Three dear friends from school days are Howard Brand on page 90, Dan Johnson on page 336, and his wife Sue on page 39 (the first rower in the racing shell). Dan and Sue Johnson's grandson Bay plays the piano on page 396. Other cherished friends are Ryan Patterson, resonating on page 383, and Paul Ryan, who drags his finger through molten lead on page 331. My science influence from the sign-painting days is Burl Grey, shown on page 30 (with a sample sign-painting discussion on page 27), and Jacques Fresco is on page 133. Dear friend Dennis McNelis is eating pizza on page 309. Larry and Tammy Tunison wear radiation badges on page 582 (Tammy's dogs are on page 320). Greta Novak floats on very dense water on page 263, and her son Bruce Novak displays two versions of the color spectrum on page 489. Duane Ackerman's daughter Emily looks through novel lenses on page 537. Peter Rae of Arbor Scientific is on page 187. Paul Stokstad of PASCO is shown on page 132, and David and Christine Venier are on page 109.

The inclusion of these people who are so dear to me makes *Conceptual Physics* all the more my labor of love.

To the Student

You know you can't enjoy a game unless you know its rules; whether it's a ball game, a computer game, or simply a party game. Likewise, you can't fully appreciate your surroundings until you understand the rules of nature. Physics is the study of these rules, which show how everything in nature is beautifully connected. So the main reason to study physics is to enhance the way you see the physical world. You'll see the mathematical structure of physics in frequent equations, but more than being recipes for computation, you'll see the equations as **guides to thinking**.



I enjoy physics, and you will too — because you'll understand it. So go for comprehension of concepts as you read this book, and if more computation is on your menu, check out *Problem Solving in Conceptual Physics*, the ancillary book by Phil Wolf and me. Your understanding of physics should soar.

Enjoy your physics!

Paul G. Hewitt

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To the Instructor

The sequence of chapters in this Twelfth Edition is identical to that in the previous edition. New to this edition are expanded personality profiles at the beginning of every chapter, highlighting a scientist, teacher, or historical figure who complements the chapter material. Each chapter begins with a photo montage of educators, and sometimes their children, who bring life to the learning of physics.

As in the previous edition, Chapter 1, "About Science," begins your course on a high note with coverage of early measurements of the Earth and distances to the Moon and the Sun. It is hoped that the striking photos of wife Lillian surrounded by spots of light on the sidewalk beneath a tall tree will prompt one of my favorite projects that has students investigating the round spot cast by a small hole in a card held in sunlight—and then going further to show that simple measurements lead to finding the Sun's diameter. This project extends to the *Practice Book* and the *Lab Manual*.

Part One, "Mechanics," begins with Chapter 2, which, as in the previous edition, presents a brief historical overview of Aristotle and Galileo, progressing to Newton's first law and to mechanical equilibrium. Force vectors are introduced, primarily for forces that are parallel to one another. Continuation of the discussion of vectors and their components awaits Chapter 5. The high tone of Chapter 1 is maintained as simple force vectors are treated before the concepts of velocity and acceleration. Students enter a comfortable part of physics before being introduced to kinematics.

Chapter 3, "Linear Motion," is the only chapter in Part One that is devoid of physics laws. Kinematics has no laws, only definitions, mainly for *speed*, *velocity*, and *acceleration*—likely the least exciting concepts that your course has to offer. Too often kinematics becomes a pedagogical "black hole" of instruction—too much time for too little physics. Being more math than physics, the kinematics equations can appear to the student as the most intimidating in the book. Although the experienced eye doesn't see them as such, this is how *students* first see them:

$$\varsigma = \varsigma_0 + \delta$$

$$\varsigma = \varsigma_0 + \tfrac{1}{2}\delta^2$$

$$\varsigma^2 = \varsigma_0^2 + 2\delta\varsigma$$

$$\varsigma_a = \tfrac{1}{2}(\varsigma_0 + \varsigma)$$

FPO

If you wish to reduce class size, display these equations on the first day and announce that class effort for much of the term will be on making sense of them. Don't we do much the same with the standard symbols?

Ask any college graduate two questions: What is the acceleration of an object in free fall? What keeps Earth's interior hot? you'll see what their education focused on because many more will correctly answer the first question than the second. Traditionally, physics courses have been top-heavy in kinematics with little or no coverage of modern physics. Radioactive decay almost never gets the attention given to falling bodies. So my recommendation is to pass quickly through Chapter 3,

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making the distinction between velocity and acceleration, and then to move on to Chapter 4, "Newton's Second Law of Motion," where the concepts of velocity and acceleration find their application.

Chapter 5 continues with Newton's third law. The end of the chapter treats the parallelogram rule for combining vectors—first force vectors and then velocity vectors. It also introduces vector components. More on vectors is found in Appendix D and especially in the *Practice Book*.

Chapter 6, "Momentum," is a logical extension of Newton's third law. One reason I prefer teaching it before teaching energy is that students find mv much simpler and easier to grasp than $\frac{1}{2}mv^2$. Another reason for treating momentum first is that the vectors of the previous chapter are employed with momentum but not with energy.

Chapter 7, "Energy," is a longer chapter, rich with everyday examples and current energy concerns. Energy is central to mechanics, so this chapter has the greatest amount of chapter-end material (80 exercises). Work, energy, and power also get generous coverage in the *Practice Book*.

After Chapters 8 and 9 (on rotational mechanics and gravity), mechanics culminates with Chapter 10 (on projectile motion and satellite motion). Students are fascinated to learn that any projectile moving fast enough can become an Earth satellite. Moving even faster, it can become a satellite of the Sun. Projectile motion and satellite motion belong together.

Part Two, "Properties of Matter," features chapters on atoms, solids, liquids, and gases, which are much the same as the previous edition. New applications, some quite enchanting, enhance the flavor of these chapters.

Parts Three through Eight continue, like earlier parts, with enriched examples of current technology. New lighting with CFLs and LEDs in Chapter 23 has added treatment in Chapter 30. The chapters with the fewest changes are Chapters 35 and 36 on special and general relativity, respectively.

At the end of each of the eight parts is a **Practice Exam,** most featuring 30 multiple-choice questions. Answers appear at the end of the book. New to this edition, odd-numbered answers and solutions to *all* chapter-end material are given at the end of the book.

As in previous editions, some chapters include short boxed essays on such topics as energy and technology, railroad train wheels, magnetic strips on credit cards, and magnetically levitated trains. Also featured are boxes on pseudoscience, culminating with the public phobia about food irradiation and anything nuclear. To the person who works in the arena of science, who knows about the care, checking, and cross-checking that go into understanding something, pseudoscientific misconceptions are laughable. But to those who don't work in the science arena, including even your best students, pseudoscience can seem compelling when purveyors clothe their wares in the language of science while skillfully sidestepping the tenets of science. Our hope is to help stem this rising tide.

End-of-chapter material begins with a **Summary of Terms**. Following are **Reading Check Questions** that summarize the main points of the chapter. Students can find the answers to these questions, word for word, in the reading. The answers and the solutions to **Plug and Chug** exercises, as well as solutions to all chapter-end material, as said, are new to this edition. As introduced in the previous edition, many good comments have come from the **Think and Rank** exercises. Critical thinking is required in comparing quantities in similar situations. Getting an answer is not enough; the answer must be compared with others and a ranking from most to least is asked for. I consider this the most worthwhile offering in the chapter-end material.

Think and Explain exercises are the nuts and bolts of conceptual physics. Many require critical thinking, while some are designed to connect concepts to familiar

situations. Most chapters have from 50 to 60 of them, separated into **Think and Discuss** sections (which are tailored for student discussion). More math-physics challenges are found in the sets of **Think and Solve** exercises. These problems are much less numerous than Think and Explains and Think and Ranks. Many more problems are available in the student supplement, **Problem Solving in Conceptual Physics**, coauthored with Phil Wolf. While problem solving is not the main thrust of a conceptual course, Phil and I, like most physics instructors, nevertheless love solving problems. In a novel and student-friendly way, our supplement features problems that are more physics than math, nicely extending *Conceptual Physics*—even to courses that feature problem solving. We think that many professors will enjoy the options offered by this student supplement to the textbook. Problem solutions are included in the Instructor Resources area of MasteringPhysics.

The most important ancillary to this book is the **Practicing Physics Book**, which contains my most creative writings and drawings. These work pages guide students step by step toward understanding the central concepts. There are one or more practice pages for nearly every chapter in the book. They can be used inside or outside of class. In my teaching I passed out copies of selected pages as home tutors.

The **Laboratory Manual** coauthored with Dean Baird that accompanies this edition provides a great variety of activities and lab exercises. The polishing that Dean gives this material is extraordinary.

Next-Time Questions, familiar to readers of *The Physics Teacher* as *Figuring Physics*, are available electronically and are more numerous than ever before. When sharing these with your classes, please do not show the question(s) and the answer(s). Allow sufficient "wait time" between the question and the answer for your students to discuss the answer before showing it "next time" (which at a minimum should be the next class meeting, or even next week). Thus the title named appropriately "Next-Time Questions." More learning occurs when students ponder answers before being given them. Next-Time Questions are included on the Instructor Resource DVD (IRDVD). They are also available at the Arborsci.com website.

The **Instructor Manual** for the textbook and *Laboratory Manual*, like previous ones, features demonstrations and suggested lectures for every chapter. It includes answers to the end-of-chapter material as cited above. If you're new to teaching this course, you'll likely find it enormously useful. It sums up "what works" in my more than 30 years of teaching.

The **Instructor Resource DVD** provides a wealth of presentation tools to help support your instruction. In a word, it is *sensational*! It includes "everything you could ask for: as a teaching resource," including lecture outlines for each chapter in PowerPoint and chapter-by-chapter weekly in-class quizzes in PowerPoint for use with Classroom Response Systems (easy-to-use wireless polling systems that allow you to pose questions in class, have each student vote, and then display the results in real time). The IRDVD also provides all the art and photos from the book (in high-resolution jpeg format), the Test Bank, Next-Time Questions, and the Instructor Manual in editable Word format.

Last but not least is MasteringPhysics. . . .

All of these innovative, targeted, and effective online learning media are easily integrated into your course using an online gradebook (to "assign" the tutorials, quizzes, and other activities as out-of-class homework or projects that are automatically graded and recorded), simple icons throughout the text (highlighted key tutorials, interactive figures, and other online resources), and the Instructor Resource DVD. A chapter guide section on Mastering summarizes the media available to you and your students, chapter by chapter.

For more information on the support ancillaries, see http://www.pearsonhighered.com/physics, contact your Pearson representative, or contact me at pghewitt@aol.com.

New Features in This Edition

The greatest addition to this edition is the **Hewitt-drew-it screencasts** (more than 130) that have been featured on youTube since 2012. QR codes throughout the book link the student to these tutorial lessons that have been created by me and polished by my wife. I feel that these lessons are my most recent and important contribution to making physics correct and understandable. They nicely complement the chapter material of this edition. Simply scan the QR codes in the book with your smartphone or tablet. First, download a QR code reader. you can download free apps from your app store or use a built-in code reader if your device has one. Next, scan the code using the QR code reader. you will be able to view the Hewitt-drew-it screencasts online. (Note: Data usage charges may apply.)

The profiles of physicists and physics educators in the previous edition are still included, with new people added throughout. By learning more about the people behind the chapter content, the reader gets a more personalized flavor of physics.

More on force and velocity vectors is in this edition and more on climate change. New updates to current-day physics are found throughout the book New boxes include 3-D printing, GPS operation, and the Higgs boson.

The chapter-end material has been reorganized, with consecutive numbering to assist in making assignments.

I regard this as the best physics book I have ever written.

Acknowledgments

I remain enormously grateful to Kenneth Ford for checking accuracy and for his many insightful suggestions. Many years ago, I admired one of Ken's books, *Basic Physics*, which first inspired me to write *Conceptual Physics*. Today I am honored that he has devoted so much of his time and energy to making this edition a beautiful book. Errors invariably appear after manuscript is submitted, so I take full responsibility for any errors that have survived his scrutiny.

For insightful additions I thank my wife Lillian, Bruce Novak, Marshall Ellenstein, and Evan Jones. I appreciate the suggestions of Tomas Brage, J. Ronald Galli, John Hubisz, David Kagan, Sebastian Kuhn, Carlton Lane, Anne Tabor-Morris, Derek Muller, Fred Myers, Chris Thron, Jeff Wethehold, and P. O. Zetterberg.

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I remain grateful to the authors of books that initially served as influences and references many years ago: Theodore Ashford, *From Atoms to Star*; Albert Baez, *The New College Physics: A Spiral Approach*; John N. Cooper and Alpheus W. Smith, *Elements of Physics*; Richard P. Feynman, *The Feynman Lectures on Physics*; Kenneth Ford, *Basic Physics*; Eric Rogers, *Physics for the Inquiring Mind*; Alexander Taffel, *Physics: Its Methods and Meanings*; UNESCO, *700 Science Experiments for Everyone*; and Harvey E. White, *Descriptive College Physics*.

I remain thankful to Robert Park, whose book *Voodoo Science* motivated me to include boxes on pseudoscience.

For the *Problem Solving in Conceptual Physics* ancillary, coauthored with Phil Wolf, we both thank Tsing Bardin, Howard Brand, George Curtis, Ken Ford, Herb Gottlieb, Jim Hicks, David Housden, Evan Jones, Chelcie Liu, Fred Myers, Diane Riendeau, Stan Schiocchio, John Sperry, and David Williamson for valuable feedback.

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