How Things Work

DESIGNING A COURSE

While *How Things Work* is actually a relatively straightforward and satisfying course to teach, my experience with it over the past five years has taught me a few lessons that I'll pass along.

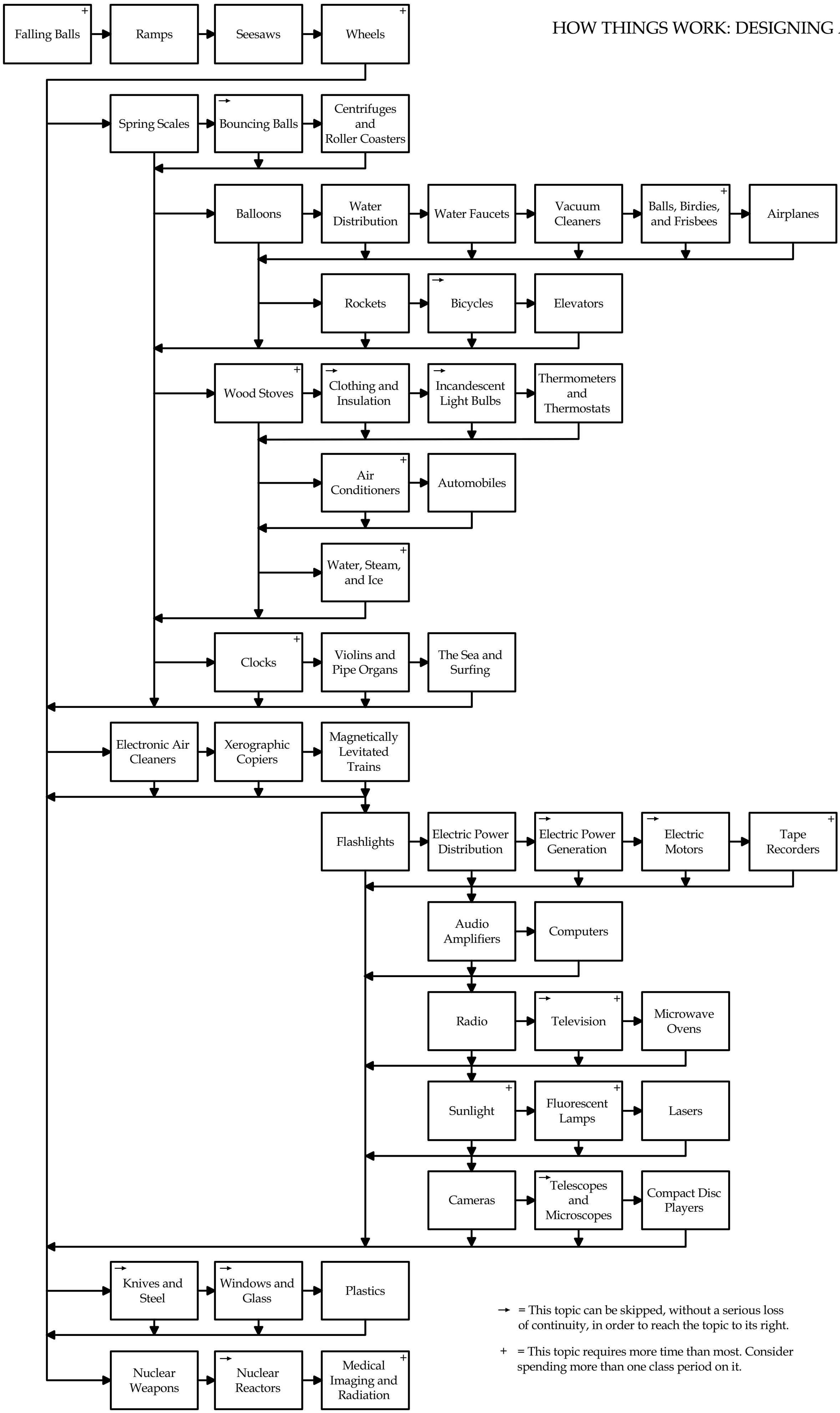
1. There is much more to this course than just teaching physics. If you concentrate less on trying to cover all of physics and more on trying to prepare your students for life in the physical world, the students will find it a much more valuable experience. That's because, while few of them will become physicists, all of them will have to make decisions involving technological and scientific issues. Moreover, the students are far more curious about the objects in their world than they are about physics itself. If you make the effort to reach out to them and teach them what they want to learn, they'll learn the physics, too, and even enjoy learning it.

2. Try to illustrate the book with demonstrations. Words, drawings, and photographs can only go so far in helping the students to understand the concepts of physics. The next step is for the students to see those concepts in action. Many students have told me that they are "visual learners" and that seeing physical concepts demonstrated dramatically enhances their abilities to understand and retain those concepts. That's why it's so important to show the concepts in class with demonstrations. While it might be even more effective to have the students perform the demonstrations themselves as an official laboratory, good demonstrations with familiar objects will provide enough insight for most students. However, the course should use the real world as its unofficial laboratory—if the equipment is simple enough, the more motivated students will try some of the demonstrations themselves. Encourage the students to experiment with the world around them.

3. Encourage the students to ask questions. Many of the objects discussed in *How Things Work* are ones that students naturally wonder about and even the most science-phobic of them will have questions they'd like to ask. Encourage them to ask those questions. For example, they'll want to know why you're not supposed to put metal in a microwave oven or why halogen light bulbs are supposed to be better than normal bulbs. These question are non-threatening to science-phobic students because they don't appear to involve physics. But because the answers do involve physics, these questions provide a perfect vehicle with which to give science-phobic people an understanding of physics without scaring them away from it.

4. Try to keep the physics in context, rather than making it abstract principles. While mature physicists may be comfortable dealing with the basic laws of physics as abstract principles, separated from the situations in which they apply, beginning students of physics will not experience such comfort. It's hard enough for these students to follow the principles if they can't see what's happening; it's harder still if they don't even have a real situation to imagine. You can help them enormously by keeping an object or a real situation in mind as you and the students discuss physical concepts. While it might seem that such specificity will weaken the students' abilities to generalize principles, the students can't begin to generalize something if they don't understand it at all. A related observation is that going off on a tangent about things that are related only by physical principles is much more interesting to physicists than it is to beginning physics students. The students usually don't see the connections and quickly get lost.

5. Try to demystify physics and objects whenever possible. There are natural tendencies among physicists to revel in the beautiful simplicity of the physical laws and to celebrate the great complexity of the objects that are based on them. Both of these tendencies are appropriate for *How Things Work*. With time and practice, the students may develop those same tendencies, too. However, it is not appropriate for an instructor to revel in the great complexity of the physical laws or to celebrate the beautiful simplicity of the objects that are based on them—in other words, avoid "blowing away" the audience. An instructor who, consciously or unconsciously, goes about proving that physics is too complicated for mere mortals or who claims that objects are all simple in the eyes of a seasoned physicist, may be respected and feared by students but won't teach them very much. The course should bring the instructor and students closer together, not separate them further. That is why demysti-



→ = This topic can be skipped, without a serious loss of continuity, in order to reach the topic to its right.

\+ = This topic requires more time than most. Consider spending more than one class period on it.

fication is so important. *How Things Work* is about giving away as many trade secrets as possible.

6. Don't be afraid to skip topics. Most students will take *How Things Work* as a first *and last* course in physics. Because you aren't preparing these students to be physicists, their exposure to physics doesn't have to be comprehensive. It's more important that they learn to see the roles of physics and science in their world, and that they learn to think physically, than it is that they learn every physics concept. If you try to cover too much, the students won't learn more; they'll just get frustrated and confused.

Covering the entire book requires two semesters. The book can be used to teach a full year course or, as I have done at UVA, to teach two independent one-semester courses. Both formats are discussed below. However, most instructors will want to offer *How Things Work* as a single one-semester course. This can easily be done by being selective—keeping some topics and skipping others. If you choose this format, you will have to take shortcuts through the book.

The book is structured in a way that should make these shortcuts easy. The chapters and sections are written to be relatively independent of one another so that it's often possible to skip the final section(s) in a chapter or even entire chapters without damaging the flow of the course. The students will still learn a considerable range of physics concepts, but their exposure will be somewhat less complete.

To make it easier to find shortcut paths through the book, ones that don't leave gaping holes in the development of concepts, I've prepared a flowchart showing the conceptual flow through the sections. Any path that always follows the arrows from section to section should produce a complete course—one that introduces concepts in an appropriate order and that rarely tries to build upon concepts that weren't introduced previously. Naturally, skipping topics will leave a few holes here and there, and the instructor will have to compensate occasionally for omitted material. However, if I truly thought that certain topics weren't important, I wouldn't have included them at all. You'll note that all the paths through the book begin with the first four sections. These sections lay the groundwork for everything that follows and shouldn't be omitted from any course. If you skip any of them, you will have a lot of explaining to do. A few topics, marked with arrows (→), can be skipped in moving toward the right. While most topics can be covered adequately in a single class period, the topics marked with pluses (+) may require more time to discuss completely.

Suggested Courses

Here are a few suggested paths through the book. They are certainly not the only paths that will produce a successful course and they don't consider the supplementary sections found in Part 4 of this instructor's manual. Given that this course is probably the only physics course your students will take, you can't really go too far wrong in choosing which topics to keep and which to omit. It's mostly a matter of taste—yours and your students'. I have found that between 25 and 30 topics is enough to keep the class busy for a semester. In the following suggestions, I have kept the number of topics in that range.

1. Full Year Course: If you have a full year to work with, you can cover the entire book from cover to cover. This path will leave the fewest possible holes and give the students a relatively complete picture of the physics in their everyday world. If you allot two class periods to the topics marked with pluses on the flowchart, the course will cover 51 topics in 63 class periods.

2. One Semester on Mechanics, Fluids, Heat, and Resonance: This is the course that I teach in the fall at UVA and it follows Chapters 1 through 10 in order. It is a relatively straightforward course because its topics are the least abstract and therefore the most accessible to students—they can easily visualize what is happening on a roller coaster, in a wood stove, or on a violin string. If you allot two class periods to the topics marked with pluses on the flowchart, the course will cover 26 topics in 33 class periods.

<u>**Chapter 1. The Laws of Motion**</u>

1.1 Falling Balls
1.2 Ramps
1.3 Seesaws
1.4 Wheels

<u>**Chapter 2. Simple Mechanical Objects**</u>

2.1 Spring Scales
2.2 Bouncing Balls
2.3 Centrifuges and Roller Coasters

Chapter 3. Fluids
- 3.1 Balloons
- 3.2 Water Distribution

Chapter 4. Fluids and Motion
- 4.1 Water Faucets
- 4.2 Vacuum Cleaners
- 4.3 Balls, Birdies, and Frisbees
- 4.4 Airplanes

Chapter 5. Mechanical Objects and Fluids
- 5.1 Rockets
- 5.2 Bicycles
- 5.3 Elevators

Chapter 6. Heat
- 6.1 Wood Stoves
- 6.2 Clothing and Insulation
- 6.3 Incandescent Light Bulbs
- 6.4 Thermometers and Thermostats

Chapter 7. Thermodynamics
- 7.1 Air Conditioners
- 7.2 Automobiles

Chapter 8. Phase Transitions
- 8.1 Water, Steam, and Ice

Chapter 9. Resonance
- 9.1 Clocks
- 9.2 Violins and Pipe Organs

Chapter 10. Mechanical Waves
- 10.1 The Sea and Surfing

3. One Semester on Electricity and Magnetism, Light, Materials Science, Nuclear Physics, and Modern Physics: This is the course that I teach in the spring at UVA and it begins with Chapter 1 and then continues with Chapters 11 through 19 in order. It is a more challenging course because its topics are relatively abstract and complicated—the students can't see current or electric and magnetic fields, and they have no direct experience with nuclear power plants. However, this course also deals with topics that interest the students the most: they are fascinated by televisions, microwave ovens, tape recorders, computers, lasers, and compact disc players, and they are concerned about nuclear weapons and reactors. If you allot two class periods to the topics marked with pluses on the flowchart, the course will cover 29 topics in 35 class periods.

Chapter 1. The Laws of Motion
- 1.1 Falling Balls
- 1.2 Ramps
- 1.3 Seesaws
- 1.4 Wheels

Chapter 10. Mechanical Waves
- 10.1 The Sea and Surfing

Chapter 11. Electric and Magnetic Forces
- 11.1 Electronic Air Cleaners
- 11.2 Xerographic Copiers
- 11.3 Magnetically Levitated Trains

Chapter 12. Electrodynamics
- 12.1 Flashlights
- 12.2 Electric Power Distribution
- 12.3 Electric Power Generation
- 12.4 Electric Motors
- 12.5 Tape Recorders

Chapter 13. Electronics
- 13.1 Audio Amplifiers
- 13.2 Computers

Chapter 14. Electromagnetic Waves
- 14.1 Radio
- 14.2 Television
- 14.3 Microwave Ovens

Chapter 15. Light
- 15.1 Sunlight
- 15.2 Fluorescent Lamps
- 15.3 Lasers

Chapter 16. Optics
- 16.1 Cameras
- 16.2 Telescopes and Microscopes
- 16.3 Compact Disc Players

Chapter 17. Material Science
- 17.1 Knives and Steel
- 17.2 Windows and Glass
- 17.3 Plastics

Chapter 18. Nuclear Physics
- 18.1 Nuclear Weapons
- 18.2 Nuclear Reactors

Chapter 19. Modern Physics
- 19.1 Medical Imaging and Radiation

4. One Semester Broad Survey: Covering a wide range of physics topics demands that you be very selective. Here is a list of sections that will give the students a broad introduction to physics. It will cover 28 topics in 36 class periods. Another 4 optional topics (student favorites) are included in brackets. However, be careful about trying to teach too many topics in a semester—one or two of the optional topics will probably be all that will fit.

Chapter 1. The Laws of Motion
- 1.1 Falling Balls
- 1.2 Ramps
- 1.3 Seesaws
- 1.4 Wheels

Chapter 2. Simple Mechanical Objects
- 2.1 Spring Scales
- 2.2 Bouncing Balls
- 2.3 Centrifuges and Roller Coasters

Chapter 3. Fluids
- 3.1 Balloons

Chapter 5. Mechanical Objects and Fluids
- 5.1 Rockets

Chapter 6. Heat
- 6.1 Wood Stoves
- 6.2 Clothing and Insulation
- 6.3 Incandescent Light Bulbs

Chapter 7. Thermodynamics
- 7.1 Air Conditioners
- 7.2 Automobiles

Chapter 8. Phase Transitions
- 8.1 Water, Steam, and Ice

Chapter 9. Resonance
- 9.1 Clocks
- 9.2 Violins and Pipe Organs

Chapter 10. Mechanical Waves
- 10.1 The Sea and Surfing

Chapter 11. Electric and Magnetic Forces
- 11.1 Electronic Air Cleaners
- 11.2 Xerographic Copiers
- 11.3 Magnetically Levitated Trains

Chapter 12. Electrodynamics
- 12.1 Flashlights
- 12.2 Electric Power Distribution
- [12.5 Tape Recorders]

Chapter 14. Electromagnetic Waves
- 14.1 Radio
- [14.2 Television]
- [14.3 Microwave Ovens]

Chapter 15. Light
- 15.1 Sunlight

Chapter 16. Optics
- 16.1 Cameras
- [16.3 Compact Disc Players]

Chapter 18. Nuclear Physics
- 18.1 Nuclear Weapons

Chapter 19. Modern Physics
- 19.1 Medical Imaging and Radiation

5. One Semester Survey of the Physics of High Technology: Here is a list of sections that will give the students an introduction to the physics of high technology. It will cover 30 topics in 38 class periods. This list is probably a topic or two too long for a semester—perhaps the easiest way to shorten it would be to omit one or more of the topics in Chapter 17.

Chapter 1. The Laws of Motion
- 1.1 Falling Balls
- 1.2 Ramps
- 1.3 Seesaws
- 1.4 Wheels

Chapter 2. Simple Mechanical Objects
- 2.1 Spring Scales

Chapter 6. Heat
- 6.1 Wood Stoves
- 6.3 Incandescent Light Bulbs

Chapter 9. Resonance
- 9.1 Clocks

Chapter 11. Electric and Magnetic Forces
- 11.1 Electronic Air Cleaners
- 11.2 Xerographic Copiers
- 11.3 Magnetically Levitated Trains

Chapter 12. Electrodynamics
- 12.1 Flashlights
- 12.2 Electric Power Distribution
- 12.5 Tape Recorders

Chapter 13. Electronics
13.1 Audio Amplifiers
13.2 Computers

Chapter 14. Electromagnetic Waves
14.1 Radio
14.2 Television
14.3 Microwave Ovens

Chapter 15. Light
15.1 Sunlight
15.2 Fluorescent Lamps
15.3 Lasers

Chapter 16. Optics
16.1 Cameras
16.3 Compact Disc Players

Chapter 17. Material Science
17.1 Knives and Steel
17.2 Windows and Glass
17.3 Plastics

Chapter 18. Nuclear Physics
18.1 Nuclear Weapons
18.2 Nuclear Reactors

Chapter 19. Modern Physics
19.1 Medical Imaging and Radiation

6. One Semester Survey of the Physics of Sound and Light: Here is a list of sections that will give the students an introduction to the physics of sound and light, along with their applications in such objects as tape recorders and televisions. It will cover 27 topics in 33 class periods. The supplement section on Telephones, contained in this manual, may also be useful.

Chapter 1. The Laws of Motion
1.1 Falling Balls
1.2 Ramps
1.3 Seesaws
1.4 Wheels

Chapter 2. Simple Mechanical Objects
2.1 Spring Scales

Chapter 3. Fluids
3.1 Balloons
3.2 Water Distribution

Chapter 4. Fluids and Motion
4.1 Water Faucets
4.2 Vacuum Cleaners

Chapter 9. Resonance
9.1 Clocks
9.2 Violins and Pipe Organs

Chapter 10. Mechanical Waves
10.1 The Sea and Surfing

Chapter 11. Electric and Magnetic Forces
11.1 Electronic Air Cleaners
11.2 Xerographic Copiers
11.3 Magnetically Levitated Trains

Chapter 12. Electrodynamics
12.1 Flashlights
12.2 Electric Power Distribution
12.5 Tape Recorders

Chapter 13. Electronics
13.1 Audio Amplifiers

Chapter 14. Electromagnetic Waves
14.1 Radio
14.2 Television

Chapter 15. Light
15.1 Sunlight
15.2 Fluorescent Lamps
15.3 Lasers

Chapter 16. Optics
16.1 Cameras
16.2 Telescopes and Microscopes
16.3 Compact Disc Players

7. One Semester Survey of the Physics of Transportation: Here is a list of sections that will give the students an introduction to the physics involved in transportation. It will cover 29 topics in 34 class periods.

Chapter 1. The Laws of Motion
1.1 Falling Balls
1.2 Ramps
1.3 Seesaws
1.4 Wheels

Chapter 2. Simple Mechanical Objects
2.1 Spring Scales
2.2 Bouncing Balls
2.3 Centrifuges and Roller Coasters

Chapter 3. Fluids
- 3.1 Balloons
- 3.2 Water Distribution

Chapter 4. Fluids and Motion
- 4.1 Water Faucets
- 4.2 Vacuum Cleaners
- 4.3 Balls, Birdies, and Frisbees
- 4.4 Airplanes

Chapter 5. Mechanical Objects and Fluids
- 5.1 Rockets
- 5.2 Bicycles
- 5.3 Elevators

Chapter 6. Heat
- 6.1 Wood Stoves

Chapter 7. Thermodynamics
- 7.1 Air Conditioners
- 7.2 Automobiles

Chapter 11. Electric and Magnetic Forces
- 11.1 Electronic Air Cleaners
- 11.2 Xerographic Copiers
- 11.3 Magnetically Levitated Trains

Chapter 12. Electrodynamics
- 12.1 Flashlights
- 12.2 Electric Power Distribution
- 12.3 Electric Power Generation
- 12.4 Electric Motors

Chapter 17. Material Science
- 17.1 Knives and Steel
- 17.2 Windows and Glass
- 17.3 Plastics