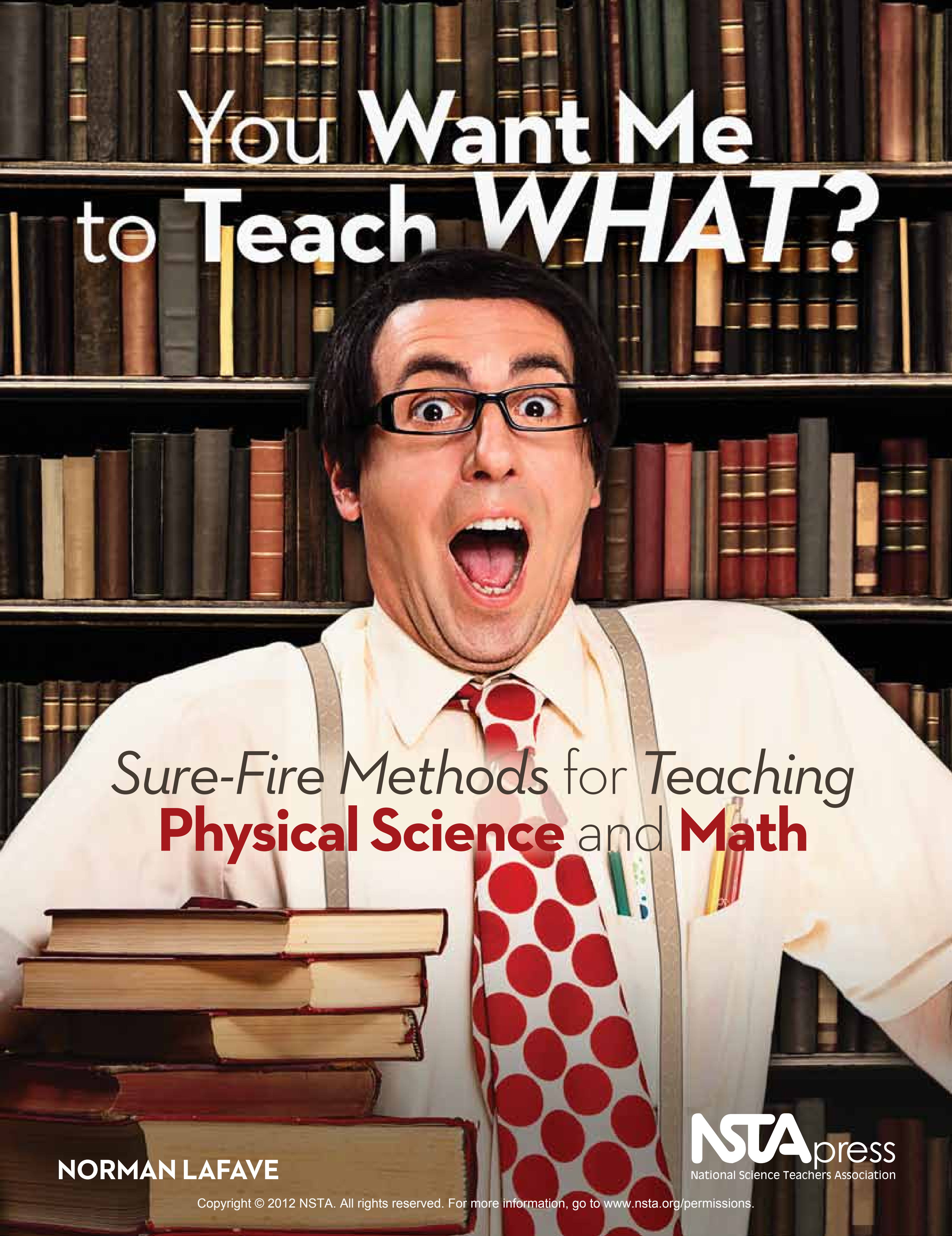

You Want Me to Teach *WHAT?*

Sure-Fire Methods for *Teaching*
Physical Science and **Math**

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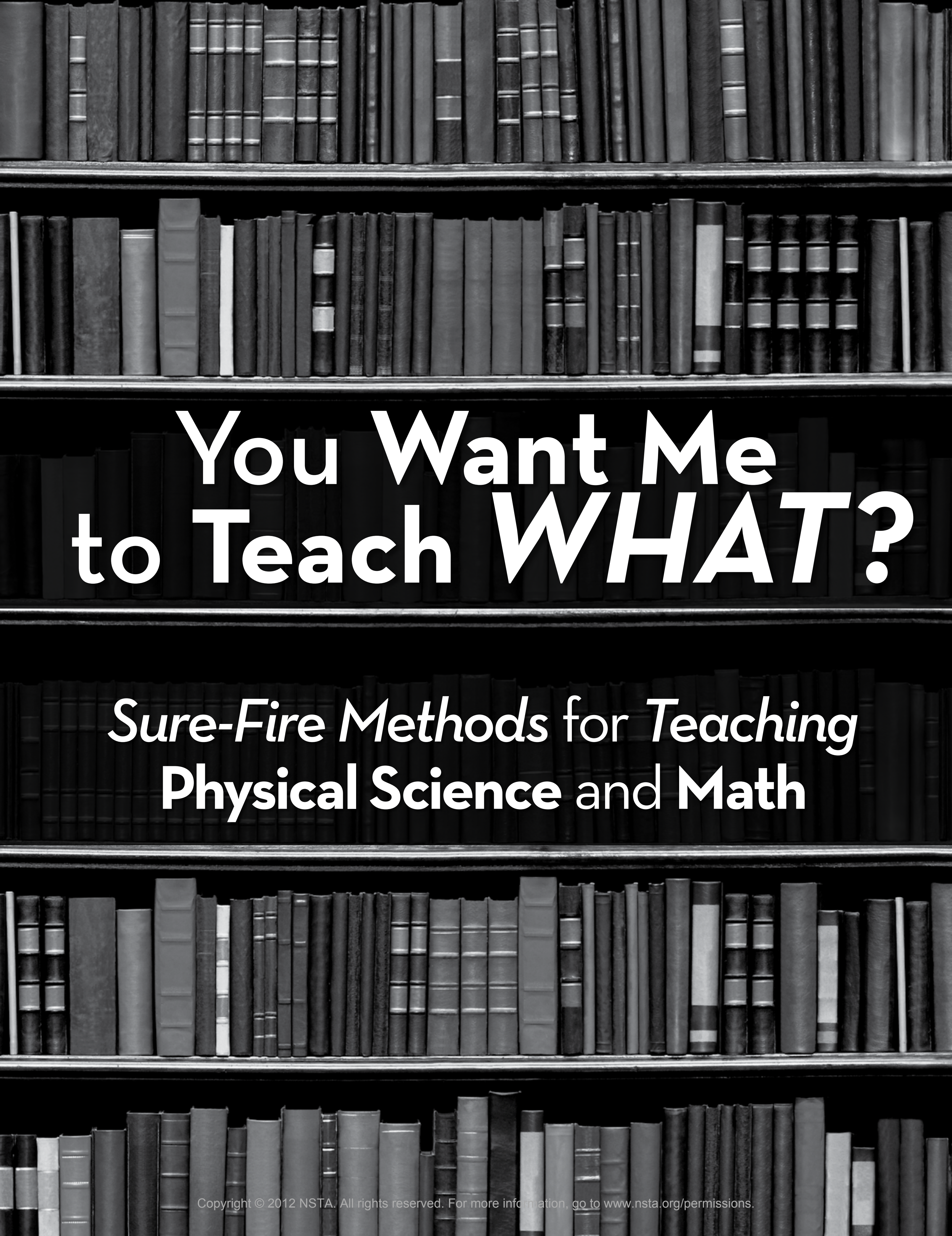

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PREFACE

Why This Book and Why Should You Listen?

So, why am I writing this book? I am certainly not the first educator to write a tome on the nuts and bolts of teaching science and mathematics. However, with new policy requirements for schools and districts to improve their standardized test scores, increased performance pressures on teachers, and severe shortages of teachers in science and mathematics comes an urgent need for proven methods to help new or struggling science and math teachers.

The teacher shortages are especially problematic. Here are some facts (Hackwood, Dynes, and Reed 2006; Hampden-Thompson, Herring, and Kienzl 2008; Markow, Moessner, and Horowitz 2006; NCCTQ 2007):

- Teachers of mathematics and science leave the field at a significantly higher rate than teachers in other subject areas. Annual turnover for science and mathematics teachers stands at 16%, compared to 14.3% for all teachers and the 11% turnover rate for all other professions. Causes for the higher turnover rate are primarily pay and professional support, with many of the teacher losses occurring within the first six years a teacher is employed. Projections for many states demonstrate that retention of science and mathematics teachers will continue to be a problem well into the future.
- The retention problem is disproportionately more acute in high-poverty schools. Data suggest that a significantly higher number of teachers who change schools or leave the field came from schools in high-poverty communities rather than from other communities. The increase compared to all schools is more than 2% in both areas.
- Many mathematics and science teachers lack adequate preparation, and this is even more acute in schools catering to high-poverty communities. More than 20% of science teachers, more than 50% of physical science teachers, and more than 25% of mathematics teachers in high schools do not have majors or minors in the field they teach. The comparative data for middle schools are even more alarming. Approximately 40% of all science teachers, more than 80% of physical science teachers, and more than 50% of mathematics teachers lack minors or majors in

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> the field they teach. In addition, these numbers are 10% higher in high-poverty schools than in low-poverty schools. Projections suggest that these numbers will likely increase for the foreseeable future.

Due to these shortages, school districts often are forced to place teachers in teaching assignments well outside their comfort zones, with little initial support. Courses that had been the venue of the most experienced master teachers are now being forced on young teachers with little or no experience, often without significant coursework in the field they are asked to teach. Interviews of teachers at conferences and professional development sessions demonstrate serious concern and apprehension regarding this trend. For instance, it was enlightening to observe the number of new teachers at a recent advanced placement (AP) physics institute, fresh out of a college program, who were asked to teach AP physics, sometimes with only a biology or chemistry background. The trepidation of these young teachers during problem solving and laboratory sessions displayed the crux of the problem. Many are well aware that they have the added burden of achieving high standardized test scores to receive positive professional evaluations, which adds to their stress.

Another group of teachers entering the pool comes from industry. These teachers have little or no teaching experience outside their certification programs, and although often very knowledgeable, they feel a certain degree of inadequacy from a pedagogy standpoint. It is the lack of teaching experience, not material knowledge, that these teachers must deal with in their new occupation.

Then the act of achieving learning in the students must be considered. No teaching can be called truly effective without measurable assessment of learning by the students. Achieving this efficient dissemination of knowledge requires techniques that include everything from teaching methodologies to inspiration initiatives to effective classroom management.

So, why should you listen to me? Because I have a unique perspective on the problem due to the three stages in my own professional teaching career. My experiences have allowed me to develop a system that has proven successful in helping students learn science and mathematics more effectively from a variety of perspectives: methodology, inspiration, and classroom management. In addition, my work as a professional scientist and engineer has provided methodologies from those fields that were employed in the refinement and testing of the teaching techniques presented in this book.

My first exposure to teaching science came as a graduate student. I was assigned to teach engineering physics laboratory and then physics laboratory for education majors two years later. During this era, when I primarily taught freshmen, I gained a surprising realization of the varying capabilities of students coming out of high school in science and mathematics. I can still remember grading the first lab reports and the first physics tests for students who were at the university to become engineers. I was

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shocked to observe so many deficiencies in their knowledge base from subjects that these students were supposed to have mastered before entering the university.

During this time, concerned about the number of students who were falling behind in their classes, I set up tutorials on my own to try to mitigate some of these deficiencies and keep these students in school. The question I kept asking myself was, "How did these deficiencies occur in the first place?" Discussions with the students provided me with a vague idea as to the causes, but not the specific details. I had success getting some of these students back on track with their studies, but others—overwhelmed by the pace and difficulty of their studies and too far behind to catch up—fell by the wayside.

It should be noted that I considered many of these failing students to be quite intelligent, but it became obvious that they were unprepared in the area of their foundation of base knowledge and skills. Many came to college with so many deficiencies that they just could not maintain a reasonable pace. I remember one student who came to me to let me know he was dropping out of college. Here was a young man who was leaving school with thousands of dollars in student loans to pay back and no degree. I wish I could tell you this was an isolated occurrence in my experience at the university, but it was not. I must say that this wasting of talent and potential bothered me greatly and fueled my first interest in the development of teaching techniques.

Later in my life, I offered my services as a tutor to students in high school mathematics and science courses. With more direct access to these students during their actual high school experience, I began to see more of the details of the deficiencies and how to resolve them. Many of the students I tutored had deficiencies in study and organizational skills and higher-order thinking abilities. They struggled to organize their learning and work, resulting in disorganized thought processes. They lacked foundational abilities, such as the ability to memorize facts and procedures. Furthermore, they failed to see the patterns underlying the subjects they were learning, thus struggling to get a grip on a basic requirement of good problem solving.

During this time, I began the development of the first rough methods that eventually evolved into the methodologies presented in this book. My tutoring provided an excellent test-and-refine environment for developing the techniques, and I found that after some trial, error, and refinement, my students had great improvement in their grades. Still, most of this was done with small groups of students in an isolated environment. I knew that to be useful for the classroom teacher with many students, some refinements and trials would have to be done in an actual classroom environment with representative populations.

Finally, I found my way to teaching at a high school. I started my career as a chemistry teacher in an at-risk high school and now teach physics at the same school. Having a true class environment at my disposal, I began to refine the methodologies I had developed to account for the realities of the modern classroom. Methods that I had used successfully with 2–8 students had to be altered and tested with classes of 24–30

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students and within the constraints of a scholastic environment. New methodologies specific to classroom teaching were developed and added to the tool set, many in the areas of classroom management and study habit development.

The tools and techniques presented in this book are not purely research-based recommendations, but a set of classroom-tested methods developed over a 20-year period. These methods have demonstrated results with a wide range of students in a variety of science and mathematics courses over several years. The methodologies cover seven areas pertaining to teaching and learning, most—but not all—specific to the mathematics and science classroom: student psychology in the classroom, mastery learning techniques, study habits and skills, concept acquisition, higher-order thinking, problem-solving methods, and analytical thinking for the laboratory. In each case, I have attempted to give a basic description with enough detail to allow the teacher to try the technique in the classroom and enough flexibility so that a teacher can customize the technique to specific classroom realities and student needs. Like all techniques, the amount of success will vary due to many factors in our complex education environment. Still, the methods have been found to work across a wide variety of lessons, students, and learning environments.

Over time, I have shared many of these techniques with colleagues who have used them successfully in their own classrooms. With a growing deficit in the number of mathematics and science teachers, many new teachers are being enlisted to teach upper-level math and science courses right out of college or certification programs, much earlier in their careers than would have been the case in the past. It is my hope that these teachers, as well as others looking to improve their success rates, will find the techniques outlined in this book useful in their classrooms and will attain the improvement and success for their students that I have found with mine.

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ABOUT THE AUTHOR

Dr. Norman LaFave has spent the past 30 years as a scientist, engineer, author, and educator. He has performed science and engineering work for the U.S. Navy, U.S. Air Force, NASA, the FAA, and Lockheed Martin Corporation. In addition, he has managed an engineering consulting company, Dynamica Research, that has performed work for various companies and entities.

His work in theoretical physics has included research in space-time structure and quantum gravity. His aerospace engineering projects have included work on the Space Shuttle, International Space Station, lunar gravitational wave observatory design, the conception and design of a commercial space launcher for the X-Prize competition, and project management of the FAA's Integrated Terminal Weather System.

Interest in the education of young people and the innovation of inspirational teaching methods in science has led Dr. LaFave to a high school classroom, where he is currently involved in the development of a laboratory engineering concept to teach science and mathematics to at-risk students through creative and innovative projects in engineering.

Dr. LaFave has a bachelor of science degree in physics and mathematics from Carnegie-Mellon University and a doctorate in mathematical physics from the University of Texas at Austin. He has been awarded an Air Force Weapons Laboratory Fellowship and a National Research Council Associateship and has received awards for his work as an engineering project manager and physics instructor, including the NASA award for engineering excellence, the FAA Award for Outstanding Project Management, and the Texas Exes Award for Outstanding Teachers for 2010.

Dr. LaFave is the author of more than 20 professional publications in physics and aerospace engineering and recently released his first science fiction novel, *Nanomagica*.

Dr. LaFave has been married for 27 years to his wife, Shannon, and has two children, Jillian and Brock. He has a keen interest in the arts, literature, sports, and public policy. He resides in Houston, Texas.

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CHAPTER 3

Yes, Virginia, Study Habits and Learning Techniques Are Key!

The Importance of Lower-Order Thinking Skills: Memorization

Teachers like to point out in discussions pertaining to higher-order thinking that their students often struggle with lower-order thinking. Their point is well taken. There has been a trend away from making students memorize material. For example, the advent of the calculator has perpetrated a trend away from memorizing multiplication tables in many schools. The big question becomes the following: How can we expect a student to memorize complicated problem-solving processes if they can't even memorize simple lists of names or facts?

In the endeavor to push the attainment of higher-order thinking skills in students, educators often forget that the lower-order skills provide the foundation. It is important that students be re-engaged with tasks that require memorization, such as memorizing multiplication tables or state capitals, especially in early learning to set the stage for learning the higher-order skills later.

Teachers can assist students in mastering these lower-order skills by giving them memory tools such as mnemonics. As an example, consider these two mnemonics: "FACE" and "Every Good Boy Deserves Fudge." The first one gives the notes on the spaces of a music staff, and the second gives the notes on the lines of the music staff. Lists of useful mnemonics for mathematics and science may be found in a variety of sources (Math Mnemonics; Mnemonic Devices). Mnemonics are just one example of a variety of systems available for assisting memorization of materials that include word mnemonics, number mnemonics, rhyme mnemonics, shape mnemonics, link methods, story methods, alphabet techniques, roman room systems, major systems, and journey systems. Presentations and examples of each of these important memorization aids can be found in a variety of sources (Jones 1995; *Mind Tools* 1996).

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In addition to the memory techniques listed above, teachers can improve memory by remembering three keys:

- Make sure that all sensory modalities are engaged. Engaging sight, sound, and even touch can make the learned information more real for the student. Laboratories and multimedia are good sources for this kind of teaching.
- Try to make the information interesting, relevant, or useful to the student. Research suggests that when information has one or more of these attributes, students will remember what they have learned more easily.
- Find ways to link the information with information already integrated into a student's memory. This technique actively models how information is integrated into memory, thus accelerating the integration.

The responsibility for developing memorization skills in students lies squarely with elementary and junior high school teachers. The younger the student is when developing and practicing these skills, the better they are able to master and use them later. However, memorization skills can be improved at any age, and teachers in later grades need to work memorization tasks into their curriculum, especially for students who may have missed out on them in earlier grades. Again, success in developing higher-order thinking skills is fundamentally linked with mastery of these lower-order thinking skills.

Why Taking Notes Is Important

In this age of emphasis on student-centered learning, educators sometimes forget to consider skills that are required for success in the traditional classroom. Students often demonstrate deficiencies in note-taking, even in upper-level courses.

Why is good note-taking an important learning skill?

- *The student becomes active in the process of learning and listening.* Simply listening to a lecture or presentation is rarely effective in eliciting comprehension and can lead to boredom and off-task behavior.
- *The student develops a history and synopsis of the course content.* Through the notes, the student has a ready synopsis of the lessons that can delineate the overall structure and development of the subject.
- *The student has information necessary for preparation for assessments.* The notes provide a foundation for study and review that is more targeted than a textbook alone.
- *The student reinforces what is communicated verbally and in writing.* The notes provide a structured recording of the lessons that assists the transfer of the lesson from teacher to student.

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In addition, being able to take notes accurately and efficiently is a critical skill for success in a college classroom, where the traditional teacher-centered approach often still dominates.

Students must be capable of summarizing the presentation given by an instructor with sufficient detail and accuracy and in real time. Most students have to learn this skill; it is not something that they can do without practice. Learning the skill in secondary school is important because the pace of material presentation accelerates in college. If the student cannot record the information at a sufficient pace with adequate accuracy, it can adversely affect the successful completion of a degree.

Secondary teachers should integrate enough traditional teaching into their lessons to allow the mastery of the note-taking skills. Grading the notebooks periodically is a good way to get students to take the skill seriously.

Muskingum College has provided a comprehensive presentation of note-taking strategies and techniques that teachers may review for insight. The website also contains a comprehensive overview of learning strategies in a wide variety of topics (Muskingum 2011). The particular note-taking topics covered in this book have been found to be particularly effective.

Cornell Notes

One particularly effective method of note-taking is called Cornell Notes (Pauk 2001), which was developed by education professor Walter Pauk at Cornell University for the purpose of improving student mastery and retention of course material. The system is designed to take note-taking beyond the passive recording of presented material to an active tool for promoting student comprehension and memorization of the subject material.

See Figure 3.1 (p. 36), which illustrates how a page is divided into three sections for taking Cornell notes. Section 1 is for the recording of presented material—the information that comes from lectures, demonstrations, or audiovisual material. Section 2 allows for quick summarization of points in the material by the student and the expression of questions pertaining to information recorded in Section 1 that the student may have (answers can be recorded here also). Finally, Section 3 provides an area for the student to summarize what he or she learned.

The goal of Cornell notes is to elicit active thinking by the student during note-taking rather than the often passive recording of traditional outlining techniques. By making the student formulate questions about the material, the student goes beyond the simple recording of words or pictures and must think about the inherent meaning. Furthermore, the summary deepens this consideration by the student by urging them to put their understanding of the material in his or her own words. If the teacher demands a succinct summary, the students are forced to get to the heart of what they have learned.

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FIGURE 3.1

Cornell Notes Page Layout

2 1/2 inches

Cue Column

Questions and Cue words: As soon after a class finishes as possible, formulate questions and cue words based on the notes in the right-hand column. Formulating questions helps to clarify definitions, relationships, and processes. This also strengthens memory of the material.

Recite: Cover the note-taking column with a sheet of paper. Then, looking at the questions or cue words in the question and cue column only, say aloud, in your own words, the answers to the questions, facts, or ideas indicated by the questions or cue words.

6 inches

Note-Taking Column

Record: During the lecture, use the note-taking column to record the lecture or other presentation material. Notes from active reading and observation of multimedia material can also be recorded in this column.

Reflect: Reflect on the material by asking yourself questions, for example: "What's the significance of these facts? What principle are they based on? How can I apply them? How do they fit in with what I already know? What's beyond them?

2 inches

Summary

After class, summarize the notes in this box.

Review: Spend at least 10 minutes every week reviewing all your previous notes. If you do, you'll retain a great deal for current use, as well as for the exam.

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It should be noted that this technique is not limited to science and mathematics and has been found to be effective for note-taking in a wide variety of courses. Students should be encouraged to use it in the entirety of their classroom note-taking efforts.

A student-produced example of Cornell notes is given in Figure 3.2 (p. 38).

Interactive Notebooks

A modern method for executing active note-taking is the interactive notebook (Bower, Lobdell, and Swenson 1999), a system developed for note-taking and the exhibition of understanding of the material by the student. This technique has been found to enhance learning because it conforms to modern brain-based learning research (Blakemore and Frith 2005; Underwood 2006). For the student to execute an interactive notebook, the following materials are necessary:

- 8.5 × 11 in. bound notebook with at least 100 pages of lined paper
- Glue stick
- Colored pens
- Crayons or colored pencils
- 3 different color highlighters

Interactive notebooks have been successfully incorporated by many teachers in a variety of subjects. The notebooks have become an integral part of the success of the AVID program (AVID 2006), whose goal is to prepare at-risk students displaying academic potential for entry into challenging college programs.

Each notebook has a cover, a page for grades to be recorded, a page for the grading rubric, and several pages for a table of contents, where titles and page numbers are recorded for each note page. The remaining pages are designated for notes and activities, with the right-hand pages specifically designated for input given to the student (class notes, video notes, notes from reading) and the left-hand pages used specifically for student output (written descriptions, problem solving, drawings, concept maps, and any other demonstration of student understanding of the material). See Table 3.1 (p. 39) for a complete description of the interactive notebook.

The notes on the right-hand page should use the Cornell notes format as described previously (see Figure 3.1).

The key to effective use of the interactive notebook system is creativity on the left-hand pages. Students should be encouraged to highlight vocabulary in colors, make colored drawings to demonstrate a concept or principle, paste in articles and pictures they find that demonstrate concepts and principles, paste in foldable constructions that demonstrate understanding, and so on. Anything is allowed as long as it directly addresses the learning objectives as outlined on the right-hand pages. The creativity aspect promotes engagement in the learning tasks not available using traditional note-

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FIGURE 3.2

Student Example of Cornell Notes

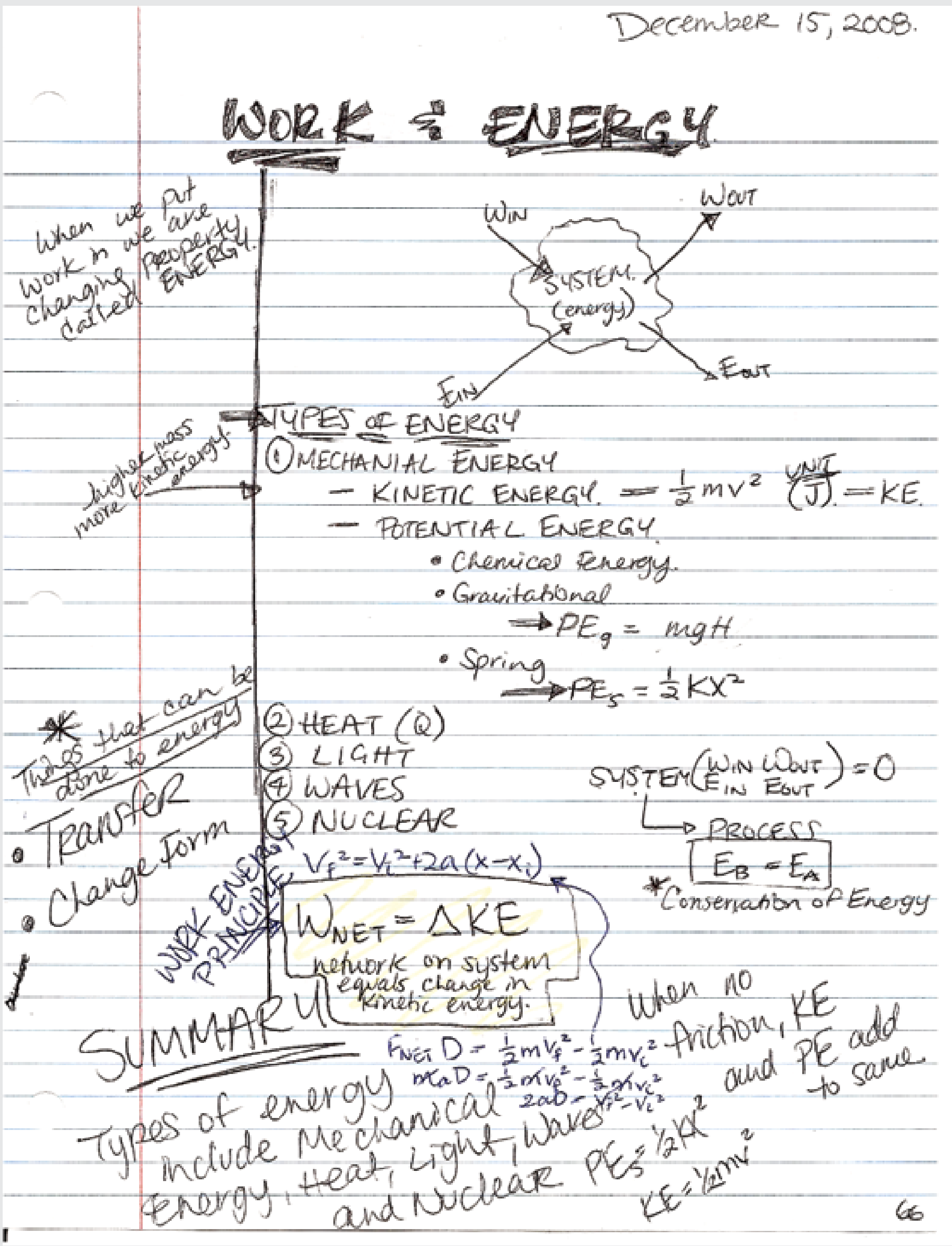

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TABLE 3.1

Overview for an Interactive Notebook

Left Side **Students Process New Ideas**	**Right Side** **Teacher Provides New Information**
• Reorganize new information in creative formats • Express opinions and feelings • Explore new ideas	• Class notes • Discussion notes • Reading notes • Handouts with new information

Materials Needed: colored pencils and markers, scissors, glue stick, rulers, etc.

Left-Hand Side	**Right-Hand Side**
The left side of the notebook (the "output" side) is primarily used for processing new ideas. Students work out an understanding of new material by using illustrations, diagrams, flow charts, poetry, colors, matrices, cartoons, etc. Students explore their opinions and clarify their values on controversial issues, wonder about "what if" hypothetical situations, and ask questions about new ideas. They also express their feelings and reactions to activities that tap into intrapersonal learning. And they review what they have learned and preview what they will be learning. By doing so, students are encouraged to see how individual lessons fit into the larger context of a unit. The left side of the notebook: • Stresses that writing down lecture notes does not mean students have learned the information. They must actively do something with the information before they internalize it. • Clearly indicates which ideas are the teacher's and which are the student's. Everything on the left side is student ideas and belongs to the student. • Gives students permission to be playful and experimental since they know the left side is their page and they will not be interfering with class notes. • Allows students to use various learning styles to process social studies information.	The right side of the notebook (the "input" side) is used for recording class notes, discussion notes, and reading notes. Typically, all "testable" information is found here. Historical information can be organized in the form of traditional outline notes. However, the right side of the notebook is also an excellent place for the teacher to model how to think graphically by using illustrated outlines, flow charts, annotated slides, T-charts, and other graphic organizers. Handouts with new information also go on the right side. The right side of the notebook: • Is where the teacher organizes a common set of information that all students must know. • Gives students the "essentials" of the social studies content. • Provides the teacher with an opportunity to model for students how to think graphically. There are many visual ways to organize historical information that enhance understanding.

*Courtesy of Laurie Swigart

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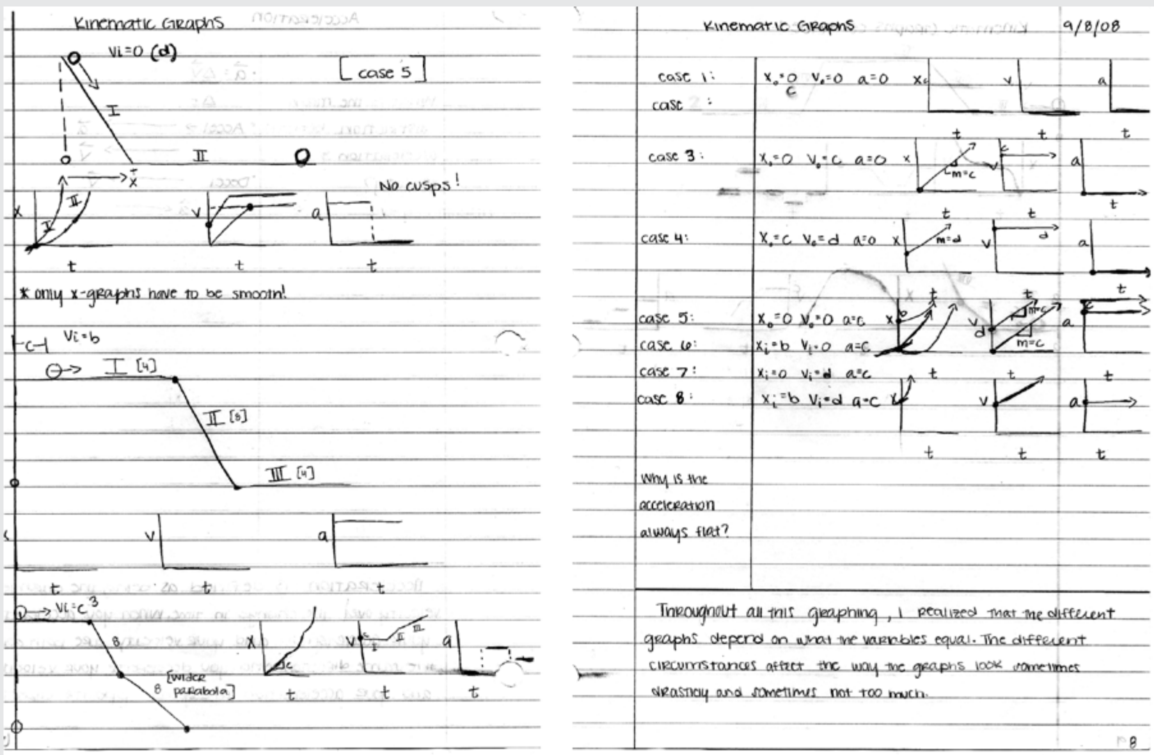
FIGURE 3.3

Student Example of an Interactive Notebook



taking techniques. Appendix B provides a rubric for grading an interactive notebook. Figure 3.3 displays a student example of pages from an interactive notebook.

Note-Taking and Listening

No matter what technologies a student uses to take notes, and no matter the techniques, the student needs to be able to do more than copy information. The student must be able to record fast enough to keep up with the presentation of information and have enough time to listen. Listening is often lost in the rush to record, but it is just as important to learning and comprehension.

Accelerating the rate of note-taking can be a daunting task, especially when the presentation of material is being done by electronic means. In addition, the rate at which information is presented becomes greater as students enter a collegiate environment. Couple this with the fact that many students have difficulty writing legibly, and the challenge becomes clear.

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In the face of these challenges, what strategies can a student use? Here are some recommendations:

- *Use outlines and/or concept maps.* Sometimes students try to write down every word, written or spoken, from the teacher. This is unnecessary. By creating outlines or concept maps, a student can capture the information in a more compact form.
- *Use shorthand.* Students should be encouraged to develop their own system of shorthand to replace words in their notes. For example, you can use a double-lined arrow for what the word implies or abbreviations for longer words.
- *Use recording technologies.* Use tape recorders or computer recording technologies during lecture presentations. This allows the student to listen better and concentrate on diagrams and other nonverbal information. Students may be able to use video recording and capture the entire presentation, although there is the danger that the student's mind will wander for lack of activity. Note that the student may need to ask permission of the teacher to execute recording of material.
- *Get the notes from the teacher.* Acquiring complete or guided partial notes from the teacher can provide the student with significantly more time to listen and comprehend presented information. Guided notes, where the student has opportunities to enter information into blanks in the notes, are especially effective because they prompt the student's thinking and help them maintain concentration and focus.

Rewriting Notes

When I first began my own collegiate experience, I often struggled with studying for tests and quizzes, especially tests covering large amounts of material taught over a significant period of time. I felt overwhelmed with the sheer quantity of material and limited time to prepare. The result was less-than-efficient studying for the assessments. My grades were decent, but I knew they could have been better.

A professor recommended that I change my philosophy and approach to studying by rewriting my notes from classes soon after the class in which the notes were composed. He suggested that the act of rewriting and re-organizing my notes was a better study technique and would result in better understanding and recall. He was right.

My grades improved significantly, and the amount of time necessary to do the final preparations for tests and quizzes was drastically reduced. In fact, I found that the extra time I spent rewriting the notes allowed me to be more efficient and, ultimately, saved time. In addition, my confidence level during the assessment was significantly better, allowing for better concentration and less trepidation.

The key to the effectiveness of rewriting notes is that the process of rewriting the notes is more than preparation of study material; the process actually helps integrate the material into the knowledge base of the student.

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Here are some suggestions for students to execute the rewriting of their notes:

- Rewrite notes the same day they are taken in class. Maximum efficiency and benefit will occur when the course material is fresh in the mind. It also keeps the student from falling behind the class schedule and losing the benefit of time management.
- Organize the rewritten notes in a logical structure using outline format or graphic organizers—whatever format best fits the student's learning style. Matching notes to learning style and improving the organization of the material improves the learning aspect of the process and provides better notes for assessment preparation.
- Use library resources and reputable websites to fill in information that was unclear during the initial taking of notes in class. Using resources to improve the notes by research further enhances the learning aspect of the rewriting process. This is one of the most important steps in the process, as it clears up naive conceptions well before the assessment and further integrates the knowledge into the student's synaptic map. Note that it is important to use reputable resources in the process. Employing the websites of well-known universities and institutes for the research is a good way to make sure the information is of good quality.

It is important for teachers to get parents to buy into this process, as students will rarely execute rewriting notes on their own. Initially, students see the rewriting process as extra work and often fail to understand the nature of the benefits until they have experienced them for themselves. Having parents direct the early efforts is key to attaining student buy-in to the process.

The Note Collage

Computers, both desktops and laptops, have become prevalent in the modern student's life. Much is made of the effects this technology has on students, both good and bad. Many teachers, fearful of the technology and news reports of abuses surrounding computers and the internet, shy away from integrating computers into their lesson planning. However, the technology isn't going away, and it behooves educators to find positive ways to apply the technology to improve the education process. Many states and school districts are forcing the issue by investing in computerized education technology, with mandates concerning its use in the classroom.

Given the new hardware placed in my own classroom (each student has desktop access and a wireless tablet computer), I directed my effort to ascertaining the best and most efficient way to integrate the technology into the learning process. This effort has lead to a new method of note rewriting that takes full advantage of the strengths of the technology. This method is called a note collage, a method of rewriting notes that integrates full multimedia and active simulation into the rewritten notes.

All of the rules for note rewriting are still applied for a note collage, but the following must also be followed:

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- The student must use a word-processing program for the note rewrite that has automated content tables, an equation editor, and the ability to insert hyperlinks into the text. This will allow equations and information from the internet to be inserted into the notes. Microsoft Word and Corel WordPerfect both have these attributes. If graphic organizers better fit the student's preferred learning style, online graphic organizer software such as Cmap or Inspiration may be used (discussed in a later section of the book). The Microsoft program OneNote is an excellent tool for note-taking if students have access to tablet PCs. The program interfaces easily with all other Microsoft programs in the Microsoft Office suite and provides a flexible interface for forming and organizing notes for a note collage. It has the capability to take typed information or handwritten input with a stylus and includes character recognition to convert handwritten text to printed text.
- The note collage must be formed as a single document with numbered and dated pages. The note collage should begin with an unnumbered title page, rubric page (provided by the teacher), and automated table of contents. Each page of the note collage after the table of contents should have a heading, followed by the note content. The headings become part of the automated table of contents. The purpose of these attributes of the note collage is to make finding information in the notes quick and easy during study for assessments.
- In addition to the text-based outlines or graphic organizers of typical note rewrites presented in the last section, documents, graphics, photos, movies, and simulations from the internet are linked into the documents. These links become part of the outline or graphical organizer structure. This is the strength of the note collage. Paper notes are limited in that they can only present static information. But a note collage, composed and used on the computer, is dynamic and interactive. Graphics and photographs from paper media and the internet can be printed and pasted into paper notes, but formulating the notes on the computer allows movies and simulations to be included. Movies provide a better way to study and understand any time-dependent phenomenon as the time dependence can be observed explicitly by the student.
- Even more important to effective learning is the ability to integrate links to simulations and applets into the notes. These interactive programs (often freely available from a variety of reputable sources) allow the student, individually or as part of a group, to actively explore concepts and principles through manipulation of parameters and observation of the resulting simulation response. This activity provides an efficient and inexpensive supplement to laboratory work for the exploration of new concepts and principles as the simulations and applets mimic real laboratory phenomena. These simulations and applets can be found by internet search for almost any topic from a variety of reputable sources. Many universities and some research institutes and companies have large banks of them

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that can be accessed for free as long as they are not used for commercial gain. In contrast, some companies provide access to simulations for a fee. Note that in some cases, use of the simulation or applet will require the download of supplementary software.

Teachers should assess students' note collages to provide incentive to the students to do an adequate job on them while learning the process. Teachers should encourage students to record the learned skills and knowledge gained from viewing movies and manipulating simulations and applets into the note collage near the associated link. This enforces effective learning from the dynamic media. Often, the simulations and applets are accompanied by lessons and questions to direct student learning. Teachers need to encourage students to work through these lessons.

Keeping an Equation Sheet

In addition to keeping good notes, students should be encouraged to keep an equation sheet (or card) on which each equation is written as it is introduced in the course. Each equation should be written in standard form, and each variable in the equation should be defined. This equation sheet (or card) can be used by the student during problem solving to keep the student focused on the process of solution instead of the search for an equation. It will also allow the student to re-examine and apply equations at later stages of the course as they re-appear in the context of other learning units.

Studying for Tests

I once asked a student who had failed a test how he had studied for it. His response was surprising and enlightening: "I read over my notes."

Typical tests in mathematics and physical science involve three types of questions. The first pertains to understanding concepts through definition and behavior. The other two types of problems involve problem solving and laboratory questions for science courses. The problem-solving questions ordinarily comprise the largest part of the points on an exam.

It often surprises teachers that students do not understand that these types of courses require a different type of study than other courses. Problem solving, whether mathematical or conceptual, is the true key to mastery and needs to be the focus of preparation for summative assessment. A student who can solve any problem pertaining to the principles of a given unit has truly demonstrated mastery. It means that the student understands the structure of the principle and concepts, can recognize the applicability of the principle in a given problem, can apply the principle in generally applicable situations, and has mitigated any naive conceptions about the concepts and principles that often occur during learning.

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Students must realize that in general they are not being asked to memorize facts, but to understand principles and be able to apply these principles. In other words, students need to place reasoning above factual knowledge. Indeed, recent research into the effect of learned factual science knowledge on science reasoning suggests that there is little or no effect (Gorder 2009). The study compared reasoning skills of students in China, where there is significantly more knowledge of science facts, with U.S. students, where there was significantly less knowledge of science facts. Contrary to recent thinking, there was no perceptible difference in reasoning abilities between the two sets of students.

Students sometimes become angry when the same problems they had worked during their learning are not on the test. This demonstrates a common misunderstanding that often occurs when students don't comprehend the purpose of their learning in a course of this type. Teachers must make sure the students understand they are expected to know the principles and procedures necessary to solve any problem of a given type. It isn't about memorization of facts, but understanding of principles and memorization of processes. It isn't about solving a given problem, but the process necessary to solve a class of problems.

Students attain this kind of mastery one way: by working enough problems that they comprehend the pattern of processes and the application of principles necessary for all problems of that type.

Maps on Paper = Maps in the Head

The effectiveness of graphic organizers as teaching tools lies in two attributes. The first has to do with connecting with students whose visual intelligence exceeds their printed word or mathematical-logical intelligence. This encompasses a fairly large percentage of students. Indeed, researchers have found pictorial representations to be superior in eliciting memorization in most students and that they are preferred by 80% of students in surveys (Chanlin 1997; June and Huay 2003; Nooriafshar and Maraseni 2005). Even for those students who prefer textual or symbolic presentation of material, the use of graphic organizers, along with the text or symbolic representations, can enhance their understanding.

The second attribute has to do with the close connection with how the brain stores knowledge by integrating the new knowledge within a pre-existing synaptic map of previously learned concepts. The new knowledge is integrated into the old map through a rewiring of the synapses and connections to related concepts within the map. Graphic organizers can mimic this map and thus aid in the rewiring process.

Graphic organizers come in different styles, and teachers often develop styles to meet their own needs and teaching methods (e.g., bubbl.us, Cmap, Inspiration, Make Sense Strategies, Mindmeister, Thinking Maps):

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- *Thinking Maps:* This collection of eight maps is designed to mimic common thought processes to elicit higher-order thinking skills (*www.thinkingmaps.com*). They may be used separately or combined to model more complex representations and processes. Thinking Maps, Inc., provides documentation on their usage in the classroom and professional development for the teacher. Figure 3.4 displays the eight maps.
- *Make Sense Strategies:* An extensive collection of graphic organizer templates are available at *www.graphicorganizers.com* and may be downloaded for free.
- *Inspiration:* A software package that produces colorful and highly visual graphic organizers (*www.inspiration.com/Inspiration*), Inspiration is also capable of translating a graphic organizer directly into an outline. There are more than 120 templates available in the software package for a variety of subjects. This is an excellent choice for the artistic students in a class. Figure 3.5 (p. 48) displays a graphic organizer for the laws of motion, as produced using Inspiration.
- *bubbl.us:* A free online tool for creating colorful graphic organizers that may be printed, e-mailed, saved as an image, or mounted in blogs or websites (*http://bubbl.us*)
- *Mindmeister:* An online and collaborative tool for creating graphic organizers. A limited version can be downloaded for free for evaluation (*www.mindmeister.com*).
- *Cmap:* Cmap is a powerful online tool for creating graphic organizers that takes full advantage of online capabilities (*http://cmap.ihmc.us/conceptmap.html*). Created by the Institute for Human and Machine Cognition (IHMC), Cmap is a free tool that creates graphic organizers that may be linked to documents, multimedia, websites, and other graphic organizers online, even those created by other users. This software is especially useful for forming note collages in a graphical manner. Figure 3.6 (p. 49) displays a Cmap graphic organizer for the properties of water created by NASA as part of a large set of linked maps for Mars exploration.

Regardless of the tools used to produce the graphic organizers, here are recommendations for increasing the effectiveness of graphic organizers:

- *Keep the organizer as simple and clear as possible.* Graphic organizers should enhance learning and memory, not inhibit them. Organizers with too many nodes and branches, or too many crossing connectors, can act as a deterrent to learning by overwhelming the student's ability to comprehend the implied pattern. One good approach to simplification is to make smaller graphic organizers with links between them. This is particularly easy to do with Cmap software.

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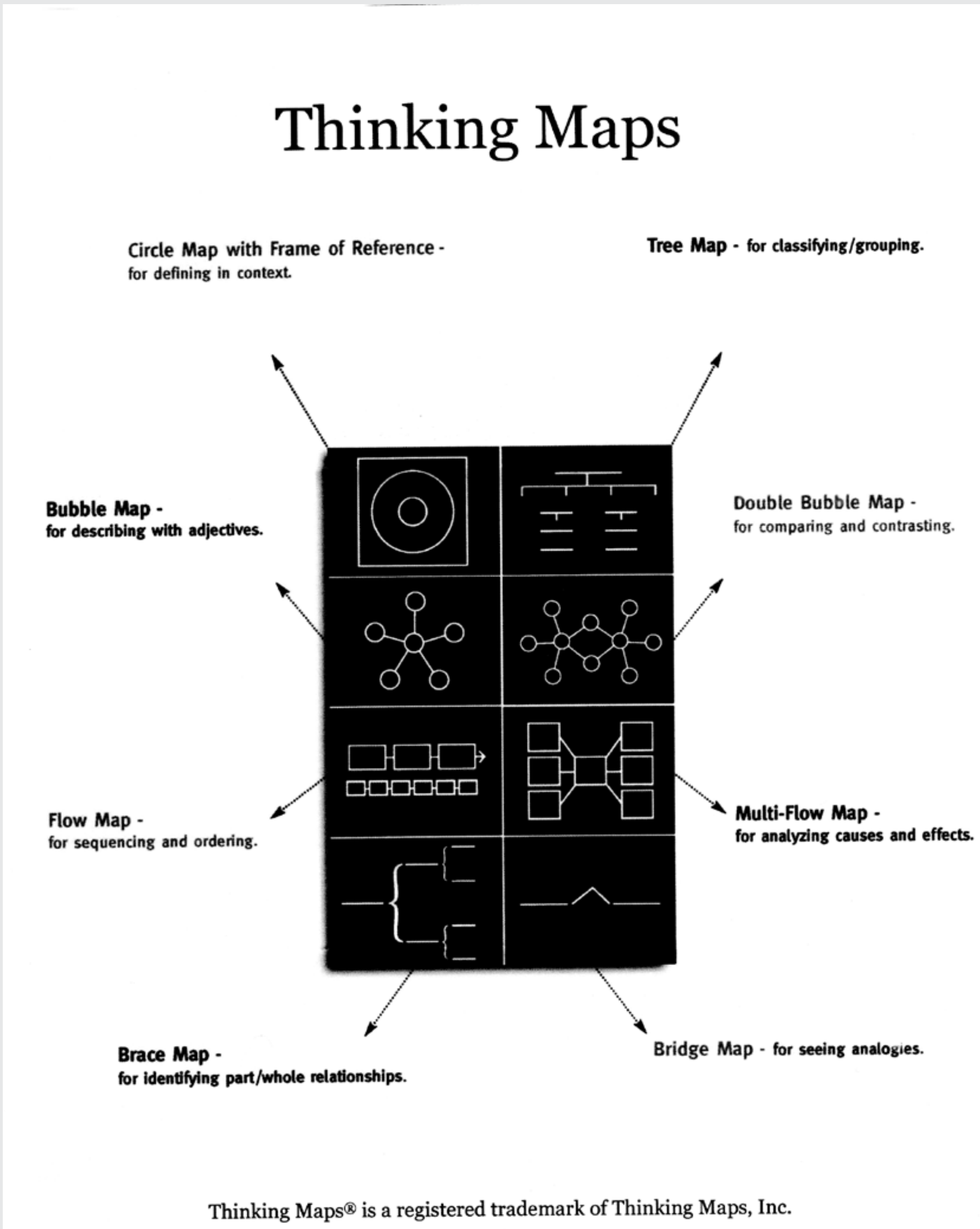
FIGURE 3.4

Thinking Maps



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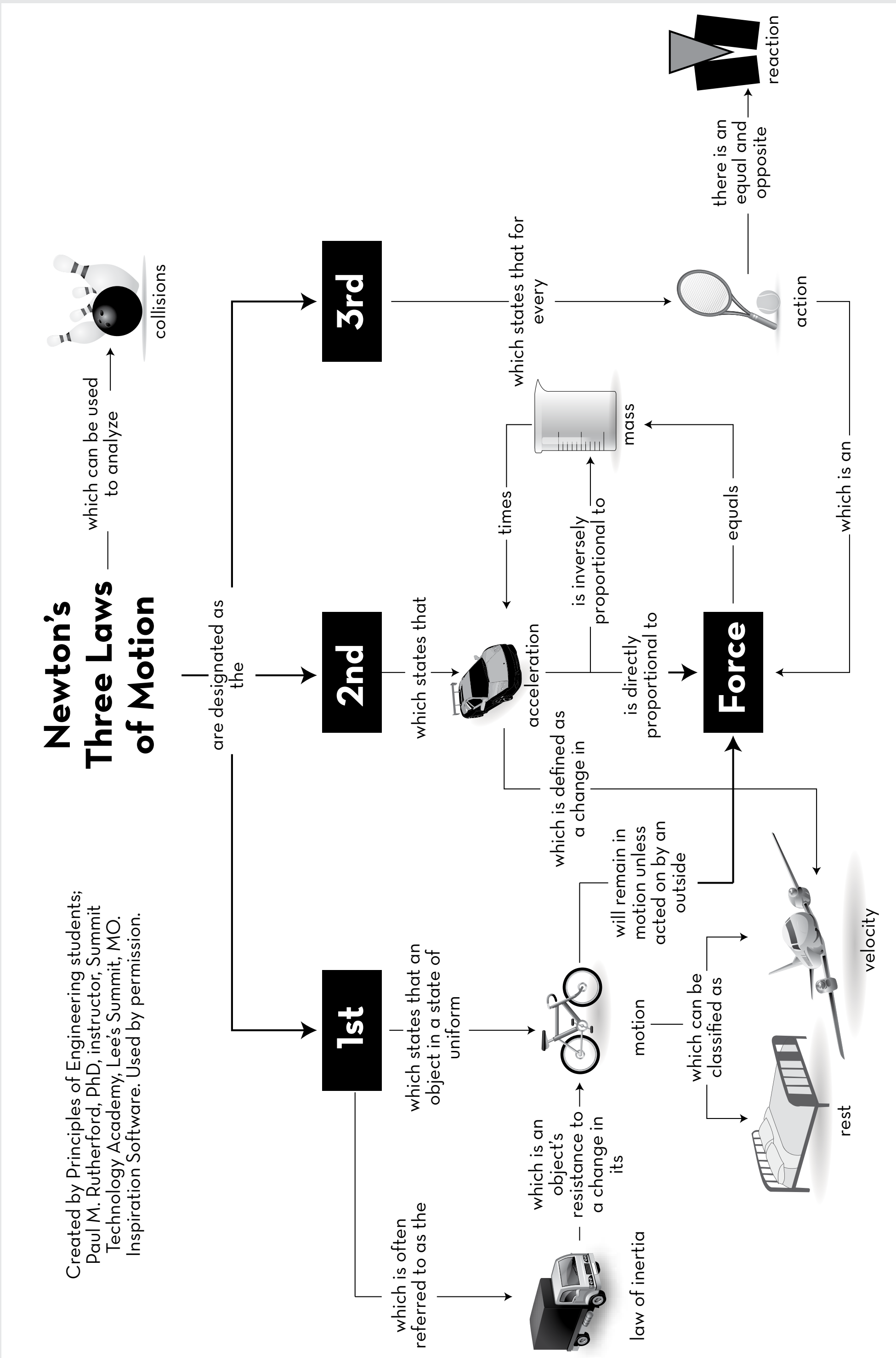

FIGURE 3.5

A Graphic Organizer: Laws of Motion Inspiration

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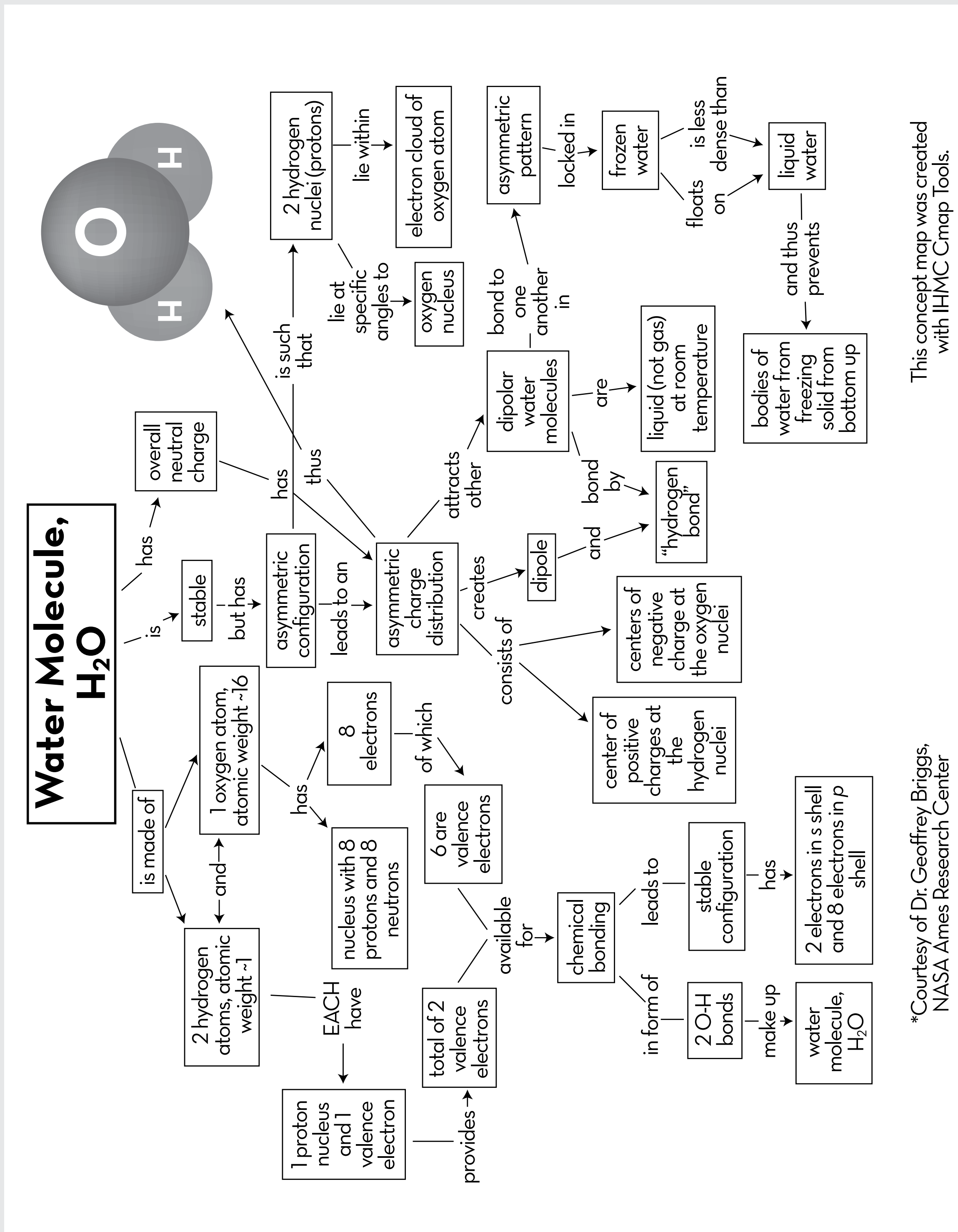
FIGURE 3.6

NASA Graphic Organizer Cmap



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- *Organize your organizers.* Oftentimes, organizers for a subject can be made to follow a standardized pattern that can be repeated for each new introduced concept. For example, when introd cing physical concepts, you might always have a bubble for units, a bubble for a word definition, a bubble for an equation, and a bubble for naive conceptions. As students become comfortable with the standardized format used, they will find it easier to understand and integrate the map into their own synaptic maps.
- *Map concepts, rules, laws, and processes.* Having an organizer or set of organizers that can handle all of the types of information or processes that a teacher might introduce is useful. Thinking Maps are a good foundation for formulation of organizers to handle logical processes and attributes in the learned material. These maps provide a set of representational tools that model various logical processes in learning, such as attributes, similarities and differences, processes, and categorization.
- *Make direct connections to previously learned concepts within the maps.* By making these connections explicit, the teacher helps the student form the new connections with their internal synaptic map.
- *Make students formulate their own maps.* Once a teacher has made their students comfortable with a style of organizer, it will enhance learning and memory if the students can formulate their own maps for the subject material.

Figure 3.7 displays a student example of a graphic organizer.

Less Homework, More Class Work!

Homework is the source of much consternation among teachers and disagreements among researchers and policy makers (Buell 2009; Center for Public Education 2007; Keates 2007; Penn State 2005; Penn State 2007; Sharp, Keys, and Benefield 2001). Students' failure to do or complete homework is a common complaint among teachers. For some reason, many teachers place great stock in the effectiveness of homework in learning, and assign hours of problems and questions for after-school time. Ironically, though, this work is rarely given that much weight in computing grades compared to tests, quizzes, labs, reports, or projects. Without the incentives, students often put little time into the homework. In addition, much of the homework is given a simple completion grade, as the teachers find they cannot possibly grade it all for correctness or review entire assignments with today's modern class sizes and time constraints.

The disagreement between research studies on the correlation of homework hours and achievement is almost contentious, with some studies showing benefits and others pointing toward comparisons with schools from different nations that seem to suggest little or anti-correlation between more homework hours and achievement. The problem comes down to the number of variables that can influence how effective homework is in the learning process. Here are some of these factors:

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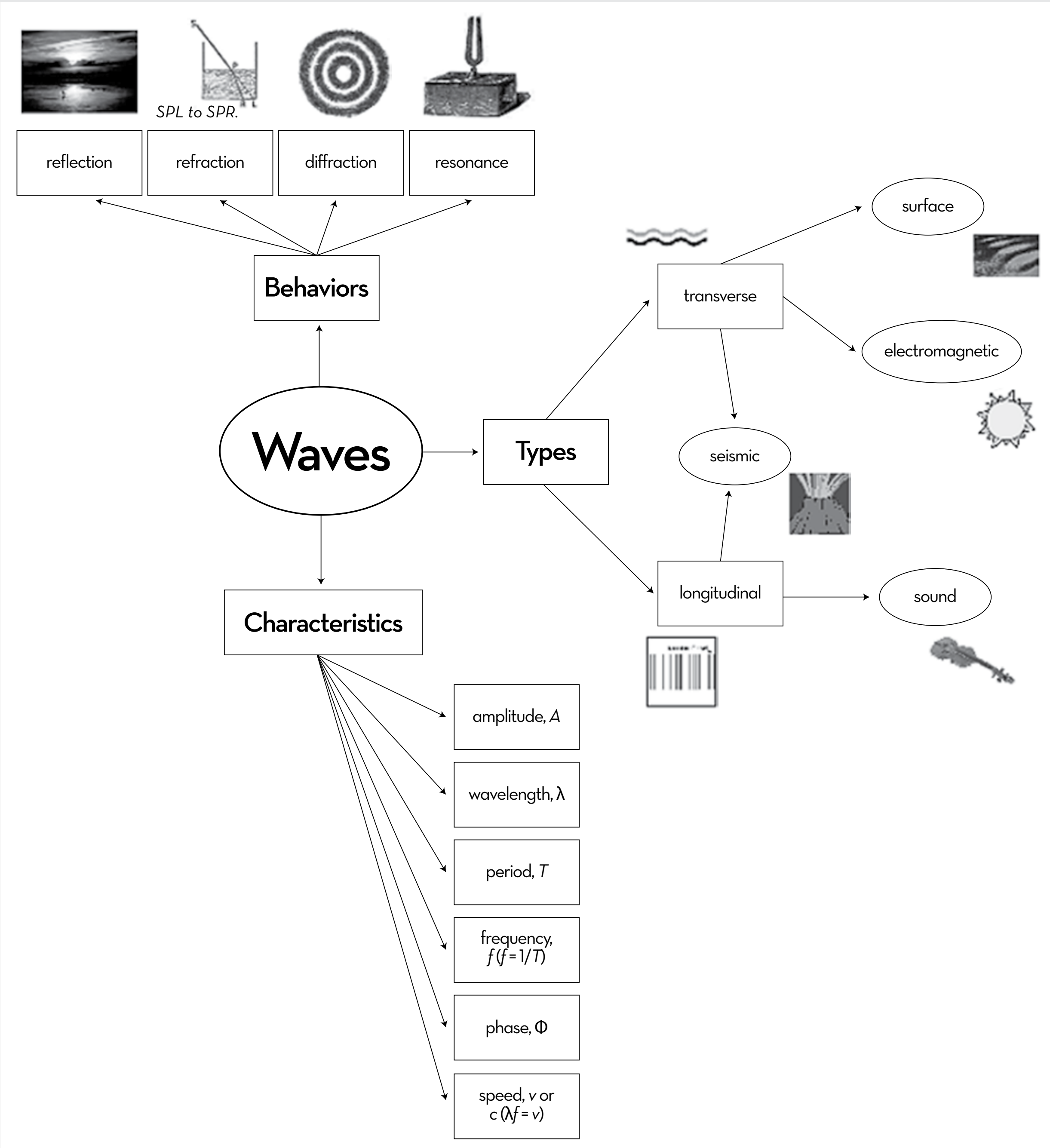
FIGURE 3.7

Student Example of a Graphic Organizer



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- *Age of the student:* Younger students require less time with homework while older students require more. Studies show positive effect of homework on secondary school students, while the studies for primary school students are, in general, inconclusive. The experts recommend two hours of homework for grades 6–9 and two and a half hours of homework for grades 10–12. Despite this, some students are performing four hours or more of homework per night, leading to little time for relaxation and other activities, boredom, and loss of necessary sleep time.
- *Home environment:* The quality of the home environment can affect a student's ability to benefit from homework. This can include amount of distraction, support from parents, and availability of help. These factors can vary widely over a group of students, with teachers having little control over the situation except to make recommendations to the parents.
- *Graded versus ungraded:* Research clearly shows that students take homework much more seriously if it is graded. However, as stated earlier, grading a large amount of homework is often impossible with the larger class sizes and new responsibilities of the modern classroom.
- *Focusing curriculum:* Many experts suggest that the real problem comes down to focusing the curriculum. For example, U.S. textbooks often cover many more topics than comparative textbooks in other nations. This lack of focus often causes a need for more homework to cover the broad set of objectives. These experts recommend that the curriculum and resulting homework be focused on a smaller set of learning objectives.

With other factors such as course type, student gender, and socioeconomics also showing some influence on the effect of homework on the learning process, it is not hard to see why there is so much disagreement.

So the question is, What real benefit comes from assigning large amounts of homework to students? Let's examine some practical arguments against homework:

- *Homework places time stress on students.* U.S. students spend an average of four hours per night on homework assignments. The stress of this much homework can inhibit learning by taking any fun out of the process, especially if it inhibits a student's ability to participate in leisure activities. Drudgery is not an ally to effective learning; it is the enemy. It is important that children have time to be children and participate in activities that can make them well-rounded individuals.
- *Homework is rarely effective in learning, but is effective in solidifying mastery.* Without the dynamic feedback, many students struggle to complete challenging homework assignments in the home environment. In many cases, parents lack the knowledge and abilities to assist the student on difficult assignments. This

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struggle can lead to frustration and a sense of failure in students. Homework is better geared for practice toward final mastery rather than initial learning of the subject matter.

- *Homework for completion grades is merely busywork.* If homework is not adequate for learning and isn't being assessed, what exactly is its purpose? The answer is often that there is no real purpose except late-stage practice for mastery before summative assessments.

So, what should be done about homework? It is not being suggested here to eliminate homework completely, but rather to simply decrease the amount and focus on a smaller set of objectives. Here are some suggestions that have been found to be effective in formulating and assigning homework:

- *Replace as much of the homework with classwork as possible.* Providing class time to tackle difficult assignments allows the teacher to dynamically monitor a student's progress and stem any naive conceptions (using active observation and formative assessment probes) that may arise during the process. This is in contrast with homework, which is often unmonitored and ungraded. Unfinished classwork is assigned as homework for completion.
- *Provide the students with three- to four-week homework schedules.* Giving the students a calendar of their assignments well in advance of the due dates allows the student to plan a schedule better and prevents homework from piling up before due dates.
- *Keep homework short and to the point.* Longer homework assignments rarely have added value in learning. Questions and problems should be chosen to attack the specifics of what the teacher is focusing on and what should be graded and reviewed. Two problems for each objective or skill are plenty if the student is also tackling similar problems in the classroom environment.
- *Save homework time for projects, papers, and reports.* There is no choice for these types of assignments other than being produced, in whole or in part, at home. These types of assignments often require substantial time to be prepared adequately. The time necessary for these types of assignments should not be robbed from the schedule by simple question or problem assignments.
- *Save homework for mastery rather than initial learning.* Homework is a good way to get practice just before a summative assessment. Use it in that context, not for initial learning.

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Don't Throw Away Anything!

Have you ever examined the folder of a typical student? I remember examining a student's folder where all of the returned assignments and handouts were crumpled into balls and stuffed into pockets. Of course, this is a worst-case scenario; however, it is not atypical to find students who throw out their handouts and assignments, even when there is a final exam looming at the end of the course or semester. Even when all the materials are kept, students often place them in the notebook haphazardly, making use of them for later study difficult.

Teachers must make students aware of the importance of keeping assignments and handouts in an orderly folder and encourage them to do so. Like their notebooks, these folders will become increasingly important to their success in later academic pursuits, especially in college or trade school programs.

Some suggestions with regard to these folders can be made:

- *Fasten the sheets, no pockets.* There is a reason the words *loose* and *lose* sound so much alike. Teachers should discourage students from placing sheets in pockets and encourage the use of folders with rings or other types of fasteners to keep the paper in place and in order. Reinforcements are an excellent tool to make sure handouts and returned assignments do not tear out of the binder over time.
- *Have students place handouts and returned materials in a folder by date or topic.* Keeping the material in a logical order will allow the material to be accessed more efficiently during study activities at a later date, especially when reviewing for a final or semester exam.
- *Grade the binder.* Like the notebook, students sometimes require an incentive to keep a well-ordered binder. Giving a grade can do that. Giving this grade once every six weeks should be adequate for this purpose.

Safety in Numbers: Group Work

The advantages of cooperative learning (group work) as a learning technique are undeniable. Studies of its effectiveness are well documented (Slavin 1992; Susman 1998; Ziegler 1981), but the best practices on how it is implemented have changed over time. Unlike whole-class instruction, which is often about competition, group work requires cooperation. This cooperation is the key to its effectiveness, as all members of the group bring their individual strengths and ideas to the group.

There is much to be said for using as much group work as possible in teaching, but there are also pitfalls that must be avoided. Some of the obvious benefits of group work are the following:

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- *Students are exposed to a collaborative environment, much like the one they will be exposed to in the workplace.* Students learn to handle the psychology and dynamic of working with people who have different ideas and work habits.
- *Students in a group environment become answerable to the group, thus enhancing responsibility.* Placing students in an environment that encourages responsibility prepares them for the rigors of later adult work environments.
- *Group work gets to the heart of student-centered learning.* The group lessons allow for greater student autonomy and self-exploration while providing a forum for the exchange and debate of ideas. Teachers act as facilitators and monitors in this environment.
- *Group work is effective in learning.* Research has proven that group work is more effective in student comprehension and retention of subject matter than traditional whole-group lecture instruction.

Even with these significant benefits, getting the most out of group activities requires vigilance on the part of the teacher in the identification and mitigation of potential problems. Some potential problems that could surface include the following:

- *Students drift.* Sometimes the purpose of the work may be misunderstood by the group or lost in their discussions and activities. The group may go off on tangents that are far afield of the learning objective of the task. The teacher, acting as a facilitator, can prompt the group back on task by asking leading questions that help the group focus. Here are some examples of possible leading questions:

    - What is the relationship implied by your data table (or graph)? Can you write the relationship as an equation?
    - What numbers can you extract from your graph?
    - What model do you think explains the phenomenon you are observing and why?
    - What systematic errors in your experiment did you observe? How could you eliminate or lessen them?
    - Where in your experience have you observed a phenomenon like this? How is it related to your experiment?

- *Students accept roles within the group.* It is human nature to gravitate to roles that fit your comfort zone. Some students gravitate toward leadership, others toward active follower, and still others toward passive roles. There will always be those students who attempt to slide by and let others in the group produce the learning product. It is imperative that teachers observe the working groups and discourage this tendency. To be truly effective, all students within a group must be forced

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to participate to the fullest extent and stretch outside their comfort zone. This applies as much to the leader types as to slacker types.

The approach to cooperative learning taken 20 years ago involved having the teacher assign the roles and then change the roles often to make sure everyone was working, being exposed to all aspects of collaborative work, and learning. This has changed because this approach was found to be ineffective in keeping all members of a group engaged at all times and did not guarantee that all group members learned the target material at the same level. The most recent research encourages the teacher to have all of the individuals in the group fully engaged with all tasks. There are two ways in particular that students can become disengaged from their groups or the whole group can become dysfunctional:

- *Group becomes a social club.* This is probably the most common problem that arises. Teachers must work hard to keep the groups focused and on task. Challenging these groups to produce a hard product within the class period can force this issue when prompting fails. In addition, the teacher should monitor and challenge groups with questions about their activities as they are conducted to keep the groups on task.
- *Social friction in a group.* Every group dynamic has the potential for friction among the participants. It is human nature. It might seem that the teacher should try to separate students who can't get along and redefine groups of students that result in a minimum of arguing; however, real-life group work does not have this luxury, and students need to learn to cope with different personalities and viewpoints. Instead of avoiding conflicts, the teacher should arbitrate disagreements and teach students methods for dealing with this natural dynamic as part of their education. Patience, sensitivity, and humor are the teacher's best tools for working with groups suffering from social dysfunction. Make sure that the group's attention is directed toward the task and away from personality conflicts by using leading questions to elicit constructive conservation and promote quality progress toward a product.

In math and science classes, cooperative learning often revolves around problem-solving activities or laboratory investigations, but group work can be used throughout a learning unit. A recent book by Dr. Bertie Kingore stressed the importance of using diverse groupings for group instruction as a way to meet the diverse instructional needs of students (Kingore 2004). Table 3.2 displays each of the four types of groupings, their advantages and disadvantages, and the type of instruction for which they are best suited.

Given the strengths of each of the grouping types, there is a logical order of application of the groups to the stages of instruction for a learning unit:

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TABLE 3.2

Diverse Groupings for Instruction

Grouping Type	Advantages	Disadvantages	Application
Whole-class instruction	• Students learn to interact with everyone in the class. • Less labor-intensive and more effective for initial presentation of the lesson material	• Students tend to be less engaged. • Pace and level of instruction may not be optimal for all students.	• Introduction of material for a learning unit • Assessment reviews • Project presentations • Class discussions • Final review discussions
Mixed-readiness small groups	• Modeling of real-world work environment • Diverse ideas • Students tutoring fellow students • Perception of equal expectations	• Learning groups geared to the middle of the group's capability levels, which limits effectiveness for advanced and struggling students • Some students tend to take too much or too little responsibility for the tasks.	• Student tutoring of fellow students • Initial practice activities • Real-world social interaction activities • Laboratory activities
Similar-readiness small groups	• Pacing and complexity of material can be uniform for all members of a group. • Comfort of learners	• Lack of role models for less-skilled students • Danger of labeling the capability of the students	• Advanced practice activities • Extension of knowledge for advanced students • Focused remediation for struggling students
Individual work	• Matching of students' paces, levels, and interests • Individual responses to questions for pre-assessment • Preparation for assessments	• Less-motivated learners tend to get off task. • Students become isolated; lacks social interaction • Labor-intensive for teacher	• Assessment preparation • Practice for mastery • Elaboration

Note: Adapted from Kingore, B. 2004. *Differentiation: Simplified, realistic, and effective.* Austin, TX: Professional Associates Publishing.

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- *Introduce the material with whole-group instruction.* The beginning of any unit requires that the teacher disseminate a certain amount of basic material to the class. Lecture and whole-class activities are the most efficient ways to place this basic information in front of all the students. Teachers must make sure that students are engaged and active during this type of instruction. Using a mixture of leading questions and short, student-centered activities helps greatly with this.
- *Use tutoring, initial practice, and laboratory work with mixed-readiness groupings.* Humbling as it may be to teachers, sometimes students learn best with assistance from their fellow students. Forming groups with a good mixture of skill levels allows the upper-level students to assist struggling students. Many of the highly skilled students find it rewarding to help their fellow students, and having the students help allows the teacher to move more quickly from group to group for monitoring and assistance. This type of grouping is particularly effective for laboratory work, as it results in a good mixture of opinion and approaches to the work; however, teachers must carefully monitor the lab activities to make sure all members of the group are active and engaged in the work.

  It is not recommended that mixed-readiness groupings be used for all practice work for a unit. One disadvantage of this type of grouping is that it tends to concentrate on the middle of the group's capabilities. Highly capable students eventually become bored if they are not challenged, and struggling students can become lost.
- *Achieve mastery of the material through similar readiness groupings.* Once a basic level of skill is acquired by all the students, it is most efficient to place students in similar readiness groupings to work toward mastery. These groupings allow students to work with the same materials and advance at a rate similar to their fellow group members without the risk of anyone getting intimidated or bored. Teachers should be cautioned that this type of grouping can be the most challenging to monitor. Students from groups that are struggling will try to monopolize the teacher's time or get off task, while highly skilled students will need advanced material to extend their mastery.
- *Use whole-class instruction for assessment reviews.* Reviewing for an assessment is most efficiently accomplished through whole-class instruction. This process allows students to benefit from questions asked by their fellow students and the answers given by the teacher. Again, teachers must use a series of probing questions and short activities to guarantee student engagement during this kind of instruction.
- *Incorporate individual work for assessment preparation.* Students do not generally take assessments in groups. Therefore, individual work must constitute the last stage of instruction before the assessment to guarantee students are ready for

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the exam. During this practice, teachers should walk around the classroom, monitoring engagement and offering assistance when students are struggling.

Here are some suggestions to teachers for implementing cooperative learning in their classes:

- Make all students in a group responsible for the same deliverables individually. This discourages the tendency for one or two group members to produce most of the work and keeps all individuals of the group engaged. The group as a whole needs to guarantee that every member of the group produces a good product through discussions and assistance. All members of the group should be able to answer probing questions posed by the teacher.
- Grading should be done on individual and group aspects of the work. Each individual should get a grade for his or her own work, with a separate grade given for the group responsibility of making sure all members have produced and learned (swim or sink together). This grading approach makes sure the cooperative aspects of group work are encouraged. Group members need to understand up front that they are all responsible for that aspect of their grade. This understanding discourages off-task behavior and personality conflicts.
- Group membership should be dynamic, changing as needed within the Kingore diverse groupings model and class needs (circumventing personality conflicts, for instance). The teacher must work hard to monitor the work of each group and be conscious of potential conflicts among group members. One tactic that is effective in cases of conflict is to pose a question and make both parties responsible for the answer. Again, the goal is to encourage cooperation.
- Make safety the responsibility of all group members. All group members should be aware of potential safety threats and be able to state the mitigation strategies formulated by the group.

There are many excellent books on group work and cooperative learning. The books by Johnson, Johnson, and Holubec (1994) and Kagan (1994) are highly recommended. The key to group work is to encourage a cooperative mentality and approach to the work (all sink or swim together) while making sure that each individual contributes and takes responsibility for a significant deliverable. Every member of the group is made responsible for the learning of all members. These books provide the research basis for cooperative learning, tools to encourage cooperation, cooperative learning activities, and strategies teachers can use in the classroom to foster successful group work.

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The Digital Child

Susie wakes up to a world of digital technology. This world contains televisions, home computers, laptop computers, mobile phones with cameras and internet, video games (consoles and handhelds), high-definition televisions (HDTV), digital recorders, and handheld digital music and movies. She is bombarded by multimedia from a variety of sources and participates in blogging, wikis, podcasts, and social networking. Everything in her world reaches her in color, motion, and sound, fast and furious. She chooses what she sees and when, often changing from one source to another at a whim. So, how can a teacher standing in front of a whiteboard with a marker compete with that?

The truth is, he can't, unless he is willing to embrace the technology himself and integrate it into his lessons. Students are no longer the passive listeners of the past, and they require active roles in the learning environment. The good news is that school districts and media providers are embracing the challenge and have created and implemented a wide variety of targeted technologies to address the needs of education and educators. These technologies include digital whiteboards, laptop and tablet computers, multimedia libraries, online tutoring and homework services, streaming video, online textbooks, digital probeware, virtual laboratories, simulations, and many other aids to deliver content to students.

The sheer variety of the offerings can be daunting to any teacher. The key to navigating the choices is to match the technologies to the nature of the lesson content by trial and experimentation and to modify and adapt the technologies over time to increase the efficiency and effectiveness of the technology in the specific course. Not all technologies will be right for your particular course content or teaching style, while others will be too expensive or impractical for your particular situation.

For example, dynamics problems in physics where there are moving objects are best served by video media rather than still media because the dynamic nature of these problems can be best visualized by moving media. Simulations and virtual laboratories are even more effective as learning tools as they provide for active manipulation and experimentation by the student, which allows them to ask questions and be actively engaged.

Take advantage of any expertise in the school district or from reputable online and off-line sources when making technology decisions and planning the use of technology in instruction. This should include participation in a multitude of professional development opportunities. In addition, your fellow teachers, who have already integrated technology into their teaching, can often be the best resource in your own planning, and many will be happy to assist you in the effort.

There isn't enough room in this book to talk about all the issues that must be addressed in teaching the digital child. However, it is important that teachers make an effort to keep abreast of new offerings, issues, and ideas, many of which will be advertised in education periodicals, professional development sessions, or presented at education conferences. Changing and modifying technologies used in your classroom will keep the students excited and engaged with the technology-assisted lessons, while ensuring that the students don't become bored with them.

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In addition, it is crucial that teachers work toward balance so their teaching doesn't become more about the technology than about course content. Stepping back from the technology regularly and using low-tech approaches, such as class discussions and paper-and-pencil group work, is advised to keep this balance and ensure that students don't become jaded about the technology.

Finally, patience and diligence are necessary for effective integration of technology in the classroom. In the course of technology integration, not all ideas will work as planned, and significant time may be needed to address issues and execute changes. Teachers need to understand this, stay positive, and be flexible in adjusting their approach.

All Hail the 5E Learning Cycle!

Constructivist models of education have been found to be extremely effective in the learning process. These models allow the student to discover, comprehend, and apply concepts and principles, rather than getting them directly from textbooks. By having students discover the concepts and principles and develop their own understanding of them, learning and retention are enhanced. Several constructivist learning cycle models have been proposed, but the current one used in many schools, with good results, is the BSCS 5E learning cycle (Boddy, Watson, and Aubusson 2003; Bybee et. al. 2006; CSCOPE 2007).

The 5E learning cycle is composed of five parts:

1. *Engagement:* A question is posed or a demonstration is presented to the students to elicit discussion on the concepts and principles of the lesson. The teacher provides motivation and enthusiasm. Engagement makes initial connections between these new concepts and principles and the student's prior knowledge. In science, a demonstration involving new concepts and principles is most effective for eliciting these connections. In math, the teacher may propose an application that requires the new concept or principle and ask the students how they would approach the application.
2. *Exploration:* The student uses laboratory investigations and simulations to discover the properties of the new concepts and principles for themselves. The teacher acts as a facilitator and guide. Students develop their own comprehension of the lesson. The discussion of laboratory work that will be presented in Chapter 8 is based on this approach.
3. *Explanation:* The student communicates his or her understanding of the new concepts and principles. The teacher provides guidance and clarification and promotes discussion. This is where understanding is refined and naive conceptions are discovered and mitigated. In science, student presentations, formative assessments (formative assessment probes presented in Chapter 2), and laboratory discussions provide a check on the understanding gained in the exploration step.

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4. *Elaboration/Extension:* The student applies the new concepts and principles, extends the learned material to new applications and topics, and uses new terminology. The teacher provides guidance and encourages new learning based on the previously learned material. In science and mathematics, this is where problem solving becomes important. True understanding of concepts and principles requires that the student be able to apply them to real-world application problems. This is where the subtleties of the subject matter and hidden naive conceptions may be discovered and mitigated. A systematic method for problem solving will be discussed in Chapter 5. This method has been found to have a positive effect on the efficiency and success of student problem solving.
5. *Evaluation:* The student's understanding of the concepts and principles is assessed. The teacher assesses student knowledge and skills and encourages students to assess their own learning. These assessments may take the form of traditional paper tests, laboratory or project reports, oral assessment, or portfolio activities that can be evaluated by the teacher. Teachers can also use the results of these assessments to modify and refine their lessons.

Figure 3.8 displays an excellent example of a 5E lesson plan developed by a participant in the E3 Program, a National Science Foundation Research Experience for Teachers project at Texas A&M University.

FIGURE 3.8

Example of a 5E Lesson

Unit Topic: Chemical reactions
Note: This lesson may take two days to complete.
Title of Lesson: Water Resources Engineering
Class: Chemistry
Student Objectives: The student will be able to

1. evaluate the impact of research on scientific thought, society, and the environment.
2. describe the connection between chemistry and future careers.
3. identify oxidation-reduction processes.
4. demonstrate and explain effects of temperature and solute material properties on the solubility of solids.
5. develop general rules for solubility through investigations with aqueous solutions.
6. evaluate the significance of water as a solvent in living organisms and in the environment.
7. describe effects of acids and bases on an ecological system.

Materials

- Soil Profile handout
- Enough of the following materials for each student: clear plastic cups, spoons, Rice Krispies treats, M&M's, peanut butter, crushed chocolate graham crackers, shredded coconut
- Overhead/computer
- Transparencies/PowerPoint presentation

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FIGURE 3.8 *(continued)*

I. Engagement: This should puzzle and motivate students in an activity or lesson.

☺ You will need a focus activity/question to engage students in the task/assignment at hand.

Focus Questions

What is engineering? (general)

What is water resources engineering? (specific)

II. Exploration: This should allow students to explore today's topics.

☺ You will need a task/assignment/lab that allows student to work individually or in small groups with little or no help from the instructor.

Soil Profile Activity

Students work individually.

The students will receive handouts to build their own soil profiles.

Allow 2 or 3 min. to read and explain the handout prior to starting the profile and 7–9 min. to complete the profile.

III. Explanation: This allows for focusing/narrowing in on today's objectives.

☺ Have students present/discuss their observations of the topic.

Class Discussion

What observations did students make? Discuss as a class.

Key point during discussion should be observation made when colored water was trickled down the profile.

For instance, on what layer did the colored water seem to stop? Why?

Answer: *Students should have noticed that the colored water seemed to stop trickling down once it got to the peanut butter representative of the B horizon. The B horizon—combined with the O, A, and E horizons—makes up a region of the soil known as the solum, which means true soil. The B horizon is the Zone of Accumulation, where chemicals leached out of the topsoil accumulate. It is has a higher content of clay (particle size 0.002 mm). Furthermore, most of the roots of the plants grow in the solum.*

Write down (as a class) the different crops that are grown in the Rio Grande Valley.

Corn, sugarcane, carrots, palm trees, cabbage, onions, oranges, watermelons, etc.

Use sugarcane as the prime example since the excel spreadsheet uses sugarcane as the example.

Key Point: Valley agriculture is important to the economy. Transition into Water Resources Planning Engineering.

☺ Teacher narrows in on objectives:

Factual info (mainly from Background Information):

Discuss the importance of water to crops. How do we determine the amount of irrigation supplied according to amount of rainfall?

What happens if there is a lot of rain or not enough? The amount of water is critical to the crop yield.

Chemistry: What happens when farmers supply sufficient water but harvest a poor quality crop? Insufficient plant nutrients may be the issue.

IV. Elaboration: Allow students to comprehend and apply the information.

☺ You will need a homework, worksheet, etc. to assign.

*Example lesson courtesy of Enrichment

Homework

Experiences in Engineering

Ion and Solubility Rules/Oxidation Number worksheets (E3) Program at Texas A&M University.

Closure

What do you think about engineering now?

V. Evaluate: Allow students to demonstrate knowledge and comprehension of objectives.

☺ Plan for a future test/quiz over these objectives.

Solubility Rules

Oxidation Numbers

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The challenge of implementing the 5E model often lies in time management. It takes time to incorporate the entire cycle, and this often runs contrary to the required scope and sequence of a course and the actual number of classroom days in a year. Teachers must use judgment in the implementation, determining how much time that can be allocated for each part of the cycle. New teachers should acquire guidance and suggestions from experienced teachers and attend professional development courses pertaining to the 5E learning cycle. It is also recommended that teachers reflect on their first implementations of the cycle so that efficiencies and improvements may be found for the next time the 5E cycle is executed.

The Joy of Modeling Instruction

Modeling Instruction adds structured knowledge to the 5E learning cycle by organizing course content around a small number of scientific models, thus making the course coherent (Hestenes 1987, 1997, 2006; Jackson, Dukerich, and Hestenes 2008; Megowan-Romanowicz, 2010a, 2010b, 2011; Wells, Hestenes, and Swackhamer 1995). Students are taught from the beginning that modeling is a central activity of scientists, engineers, and businesspeople, and that "the game of physics is to develop and validate models of physical phenomena" (Hestenes 1992, p. 740). In two- to three-week modeling cycles, students engage collaboratively in building scientific models, evaluating the models, and applying them in concrete situations. A modeling cycle has these two stages:

Stage 1: Model development begins with description. A demonstration of some physical phenomenon is followed by a guided class discussion that prompts students to identify some fundamental relationship to explore (e.g., the relationship between force and acceleration in a modified Atwood's machine; the relationship between pulling force and length for a stretched spring). Then students, in small groups, plan and execute a laboratory investigation to uncover the relationship. Afterward, each group writes their findings on large (24 × 32 in.) whiteboards, using multiple representations for the data they have collected. Then, the class gathers as a whole group for a "board meeting," during which students examine each others' representations and interpretations of their data and make sense of the general model for the relationship they have uncovered. The teacher acts as a discourse manager, facilitator, and guide. Terminology and tools are suggested by the teacher as needed to refine the models and stimulate discussions. The teacher is aware of typical naive conceptions that can occur for the phenomenon in question and uses this knowledge to guide classroom discourse in ways that will assist the students in the development of their models.

Stage 2: In the model deployment stage, the students test the boundaries of the model by using it to solve progressively more challenging problems and make reasonable predictions when engaging in real-world lab practices. These activities

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are again done in small groups and discussed as a class using representations on whiteboards prepared by the individual groups. Formative assessment tasks are used frequently throughout the course of each instructional unit to assess the coherence of students' conceptual models as they develop. Paper-and-pencil testing and occasionally lab practicum assessments are administered at the end of the unit to summatively assess students' final understanding.

An example of the application of the Modeling Instruction cycle is given in Figure 3.9 (courtesy of J. Jackson, C. Megowan-Romanowicz, and L. Dukerich of Arizona State University). It is recommended that teachers become familiar with the reference articles mentioned above.

Modeling Instruction is a highly effective pedagogy (Expert Panel Reviews 2001, 2000). However, it is a very different design for the learning environment from traditional science courses you may have experienced. For this reason, the Modeling Instruction Program strongly recommends that teachers attend a three-week workshop before attempting a full implementation of modeling pedagogy. Workshops are offered at universities and in school districts across the country each summer. (Visit *http://modeling.asu.edu* to locate a workshop near you.)

Note that just as with the 5E cycle, there may be time-management challenges with the scope and sequence of the course that must be taken into account by the teacher while he or she learns to use Modeling Instruction. As with the 5E cycle, professional development, experienced guidance, and active reflection are recommended.

FIGURE 3.9

Example of a Modeling Instruction Lesson

Modeling Cycle Example: The Constant Velocity Model

I. Model development

Prelab discussion: The teacher demonstrates battery-powered vehicles moving across the floor and asks students to make observations. Students suggest possible influences on the motion and eventually agree on the most important variables. Then each group of three or four students designs a laboratory investigation to describe the vehicle's motion and relate the variables.

Lab investigation: Each group collects position and time data for a vehicle, from which they generate a graph by hand or use data-collection technology. From the graph, they develop an equation. On a 2 ft. × 2.5 ft. whiteboard, they specify their system (the vehicle modeled as a point particle) and describe their model with diagrammatic, verbal, graphical, and algebraic representations. In this case, the diagrammatic representation is a motion map, the graph of position versus time is linear, and the slope is the average velocity.

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FIGURE 3.9 *(continued)*

Postlab discussion: Groups refer to their whiteboards as they present and justify their conclusions to the class, including a formulation of their model of the vehicle's motion and evaluation of their model by comparison with data. The teacher introduces technical terms and concepts as needed to sharpen the descriptive model of constant-velocity motion and improve the quality of discourse. Student lab notebooks and lab reports emphasize model development.

II. Model deployment

Worksheets and formative assessment: Working in small groups, students complete practice problems by applying the constant-velocity model to new situations. They write their solution strategies on a whiteboard, using multiple representations and appealing to the model developed on the basis of experiment. The teacher listens and guides the whole-class discourse, more by questioning than by telling. The teacher presses for explicit articulation of students' thinking, often by asking, "Why do you say that?" and "How do you know that?" to address lingering naive conceptions. Formative assessment includes quizzes, which students complete individually to demonstrate their understanding of the model and its application. Students must explain their problem-solving strategies.

Lab practicum: As a culminating activity that helps students review key principles for the unit test, the class completes a lab practicum using the constant-velocity model to solve a real-world problem. Students test their solution with battery-powered vehicles.

Unit test: As a final check for understanding, students take a unit test. The constant-velocity unit is the first unit. In later units, students develop causal particle models that incorporate models developed earlier; this is an example of the spiral nature of Modeling Instruction.

Wow! There Is a Reason They Taught Me Algebra!

When students are exposed to chemistry and physics classes, they often realize why they were required to learn algebra and geometry. Mathematics in these science classes becomes less about formal manipulation and more about application. The variable names that students have become comfortable with in their mathematics classes (x and y, for instance) are replaced with variable names or combinations that fit the concepts introduced. The unfamiliar variable names can make it harder for some students to recognize equation types and patterns. This poses a challenge to the science teachers to assist the students in seeing the patterns they know from their mathematics classes in algebraic expressions containing these new variables.

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One recommendation to mathematics teachers is that these types of variable names and combinations be introduced during the mathematics classes so students become accustomed to seeing them earlier, before they take the actual science classes. This will allow students to become comfortable with these variables while learning the manipulation rules. This goal is best accomplished by collaboration between science and mathematics teachers.

Math and Science Teachers Should Be Partners.

It is not uncommon for the science and mathematics staffs at a school or in a school district to work in isolation from each other, rarely sharing techniques, knowledge, or materials. This is an unfortunate state. The two fields share a common foundation and purpose, albeit with different emphasis: Mathematics teachers concentrate on the teaching of rules, concepts, and manipulation skills, while science teachers emphasize mathematics application. Given this close relationship, why do the two entities insist on working and planning apart?

This problem often seems to start at the district level, with science and mathematics coordinators caught up in political haggling. It is crucial that district superintendents encourage coordinators and department heads in science and mathematics to work together closely on curriculum so that the needs of both subjects are met.

Strengthening the Mathematical Foundation

The most common complaint heard from upper-level science and mathematics teachers is that their students arrive at their courses with inadequate prerequisite mathematics skills. We have already discussed how this can be mitigated, but precious time could be saved if we could figure out how to avoid the problem in the first place.

To improve the comprehension and retention of math skills, teachers need to work together on strategies that reinforce learned material. Science teachers can be a great help to math teachers by reinforcing the use of mathematics rules in the performance of work in their class, thus pushing the knowledge and skills deeper into long-term memory. Science teachers can also assist the mathematics teachers in the formulation of practical word problems that allow the student to get experience in applying the calculation skills they are learning before they take the science class.

Mathematics teachers can also be a big help to science teachers. Collaboration between the two departments would allow the mathematics teachers to know what skills are vital to science and need to be stressed in the lesson planning. In addition, the collaboration would allow the joint production of preassessments for prior knowledge as discussed earlier.

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Students Can Build Calculation and Analytical Skills (Despite Themselves).

Reaching for Higher-Order Thinking

As students prepare for the rigors of college, it is important that they have the ability to think at a high level, performing creative, analytical, and evaluative skills at the top end of Bloom's taxonomy (Bloom 1956; Forehand 2005; Krathwohl 2002) as part of the collegiate courses. These skills are developed through a process of hands-on investigation and elaboration (encompassed by the 5E cycle and modeling instruction discussed earlier) that builds them from the student's knowledge foundation. Figure 3.10 (p. 69) displays the typical skills and processes a scientist might perform in a course of study. Teachers need to develop the sophistication of these skills in the students by providing incrementally more sophisticated tasks for the students to perform. In this way, the students have these skills in place before handling the rigors of college course work.

Teachers need to keep in mind that students will develop these skills at varying paces and levels of difficulty. Flexibility, encouragement, and patience are the keys to success with this type of teaching.

The First Step in Many Directions

Even if the student has no intention of pursuing a career in mathematics, science, medicine, or engineering, the skills developed in mathematics and science courses are closely linked to skills that are helpful in any professional environment. Evaluative, creative, and analytical thinking are as applicable to business as they are to engineering or science. Algebraic manipulation is universal, appearing in many professions.

It is important that teachers in science and mathematics use tactics that elicit critical thinking and creativity to develop these skills for later execution. It is often helpful to talk to the students who are not in pursuit of technical careers about the big-picture view of these higher-order thinking skills so they have a broader appreciation of the importance of mathematics and science education for their future.

The Importance of the Foundation: Lower-Order Thinking Skills

As stated earlier, the lower-order thinking foundation should not be ignored. The best approach integrates the development and refinement of both lower-order and higher-order skill development in the student. Students who start college with these integrated skills in place have an excellent foundation for success in their college curriculum and subsequent career.

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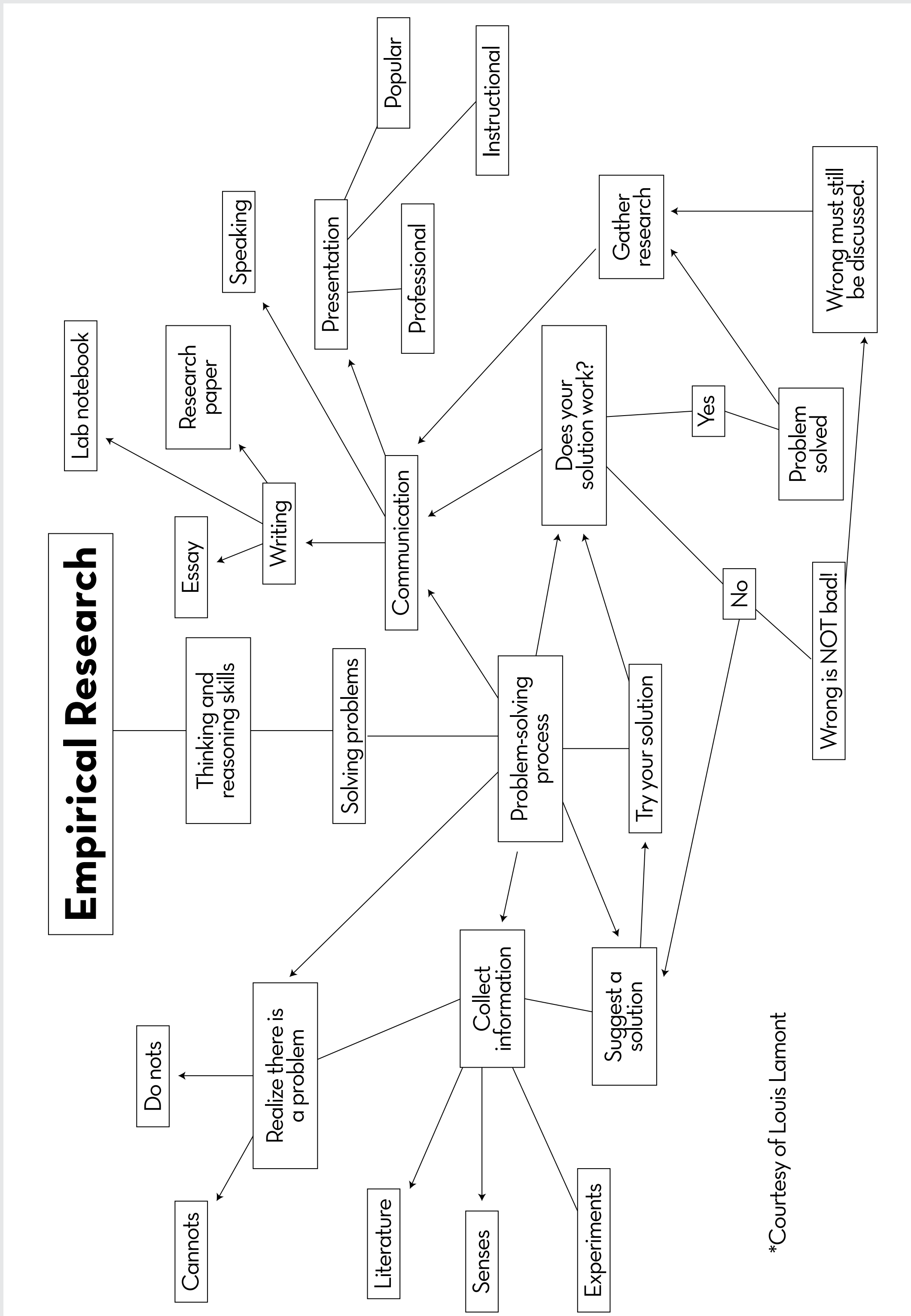
FIGURE 3.10

Research Scientific Processes



*Courtesy of Louis Lamont

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For this reason, teachers should refrain from using equation sheets and cheat sheets for all assessments. Students need to have the impetus to memorize the equations and concepts so memorization skills are in place. As was stated earlier, these skills are developed through practice and experience. In addition, students need to be forced to memorize processes as well as facts so they are ready to learn complex skills.

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You Want Me to Teach *WHAT?*

LIKE A TALK with a wise mentor, reading *You Want Me to Teach What?* can help you prepare for the challenge of teaching upper-level science and math and then get you up to speed—fast. You can integrate the book's tried-and-true methods into your classroom and lesson plans starting from the first day of class.

Author Norman LaFave avoids long discussions of education theory and specific lesson plans; instead, he concentrates on general techniques for approaching a variety of problems and enhancing your teaching skills in science and math. The book covers student psychology, classroom management, planning, instruction, problem-solving techniques, laboratory methods and reporting, assessment, and professional development, all in an engaging manner.

Without feeling overwhelmed, you'll find a wealth of sensible guidance, regardless of whether you're a collegiate education major wanting to teach physical science or math, a new teacher looking for practical methods to integrate into your instruction, or an experienced teacher in search of fresh ways to improve in the classroom. The proven methods included in *You Want Me to Teach What?* are sure to help any teacher feel more comfortable and excited about teaching.

Grades 9–12

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