Speech and Voice Science

FOURTH EDITION

Alison Behrman, PhD, CCC-SLP
With a Contribution by Donald Finan, PhD

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Preface

I have three distinct, yet interwoven, professional roles: instructor, research scientist, and clinician. This book grew out of my clinical practice. How odd, you might think, for this book is a basic science textbook written primarily for students of speech-language pathology. The role of instructor or research scientist would appear to be a more likely candidate as motivation for this book. Yet I have been struck constantly by the realization of principles of physics and physiology in my interactions with my patients. In truth, the answers for many of the clinical questions raised by speech-language pathologists can be found in the science of voice and speech production and perception. How does one address a deficit in a voice- or speech-disordered individual? Why does a therapeutic technique work for one patient and not for another?

In sum, a solid grounding in speech science makes a speech-language pathologist a better clinician. This book was motivated by my desire to provide students of speech-language pathology with a strong fund of knowledge in speech science—so that they would have this part of the necessary tools with which to become outstanding clinicians and so that they, too, could experience the delightful process of clinical inquiry, problem solving, and, yes, clinical *creativity*. For it is only with a fund of knowledge larger than the moment, greater than one accesses on a day-to-day basis, that one can truly have the freedom to be creative in therapeutic approaches and techniques.

This book is intended primarily for undergraduate and graduate students in speech-language pathology. It should also be of interest to doctoral students and research scientists as a basic reference text. It is my hope that seasoned clinicians, too, will find this book valuable as a reference source when they encounter patients with speech and voice disorders that present therapeutic challenges.

This book addresses the physics, acoustics, and physiology of voice and speech production. An effort is made to provide a sense of history (remote and recent) and, thereby, a sense of the future direction of the field. I have tried to incorporate some interesting and even amusing notes in the shorter side boxes to help lighten some of the admittedly dense material. Other side boxes are central to understanding the content of the chapter. Printed textbooks remain quite linear in their presentation of material. Most college students, however, have become acclimated to the nonlinear information-gathering style of the Internet, and so I suspect that they will enjoy the side boxes without finding them distracting.

New to the Fourth Edition

I am pleased to bring you some exciting changes to this fourth edition. The most important change is the addition of topics related to diversity, a subject long overdue for inclusion in teaching speech and voice science. You will find presentation of dialectical and nonnative language differences in vowel, consonant, and prosody characteristics in Chapters 7 (Vowels), 8 (Consonants), and 9 (Prosody), respectively. The concept of accentedness is addressed—the listener's perception of how closely an individual's speech approaches that of a native speaker of the language. In Chapter 11 (Speech Perception), the concept of indexical properties is discussed—those features about speaker identity that we assume from the acoustic signal. We make judgments about speaker sex, gender, native language, race, and ethnicity from a host of acoustic features and other characteristics of a person's speech. It is hoped that these new sections will serve not only to enlighten readers but

also to stimulate thinking and lively classroom (in-person or virtual) discussion.

The second important change to this fourth edition is increased emphasis on clinical application. To that end, new clinical cases have been added so that Chapters 4, 5, 6, 7, 8, 9, 10, and 11 all have at least one and often two clinical cases. In addition, Chapter 4 (Breathing), Chapter 5 (Voice), and Chapter 8 (Consonants) include new sections providing an overview of breathing disorders, voice disorders, and speech sound disorders, respectively, and their etiologies, symptoms and characteristics, diagnostic approaches, and therapy techniques. These overview presentations of disorders serve to emphasize the clinical application of speech and voice science. Discussion questions are provided at the end of each clinical section. Although each clinical case focuses upon the content of the chapter in which it occurs, information is also drawn from other chapters, with some of the discussion questions addressing topics of other chapters. Thus, instructors may find it useful to help the students reexamine each clinical case in subsequent chapters. For ease of reference, you will find a separate clinical table of contents in the beginning of this textbook with highlights of the topics of each clinical case.

Several other changes have been made to this edition that will, hopefully, enhance teaching and learning. The topic of speech breathing in Chapter 4 (Breathing) has been enhanced, and new illustrations highlight key information about this important topic. Chapters 10 (Theories and Models of Speech Production) and 11 (Theories of Speech Perception) have been reorganized a little and some unnecessary content has been removed to make the chapters more accessible to students. Updated information has also been added, including a new section on the popular Directions Into Velocities of Articulators (DIVA) model in Chapter 10, and the addition of a discussion on mirror neurons and updated information of some of the perceptual theories in Chapter 11. The discussion of the perception of intensity and frequency has been moved out of Chapter 11 and into Chapter 3 to more closely follow the typical class syllabus. The section in Chapter 1 (Introduction) on effective study techniques has been expanded to help students learn the material and earn good grades. Finally, you will notice many new and revised illustrations that clarify and highlight important concepts or simply amuse the reader.

How to Use This Book

The curriculum for speech and voice science varies considerably at the undergraduate and graduate levels across university programs. As such, this book offers some flexibility for faculty. The order of the chapters is organized for a full course in undergraduate speech science. The basic physics of sound (Chapters 2 and 3) lays the groundwork for students' understanding of speech and voice production. Subsequent chapters mirror somewhat the process of speech production—the respiratory, phonatory, resonatory, and articulatory subsystems (Chapters 3–8)—and the interplay of those subsystems in prosody (Chapter 9). Once students have that basic understanding of speech and voice production, they are ready to ponder the theories of speech production and perception (Chapters 10 and 11).

The chapters on voice production (Chapter 5 and 6) are quite in-depth, and the content may be beyond what some instructors need for (or have time in) an undergraduate course in speech science. The chapters are designed such that the more advanced information on phonatory biomechanics and measurement can easily be omitted. And these two chapters work well as part of the curriculum of a graduate-level course in voice disorders.

Don Finan's excellent chapter on instrumentation (Chapter 12) can be used in several ways. Some instructors may want to cover this chapter early in the semester, after Chapters 2 and 3, to prepare students for discussion of the instrumentation sections at the end of Chapters 4 through 8. Other instructors may prefer to address the topic in the order in which it is

presented in the book, so that students have a basic knowledge of speech and voice production within which to explore the gathering of instrumental data. The chapter was written to work well with either of these approaches. The chapter also stands well on its own as a reference for graduate- and doctoral-level students who are conducting research.

Chapters 4, 5, 7, and 8 each contain a short review of the relevant anatomy. It is presumed that students will have taken a course in anatomy and physiology of the speech mechanism or are taking that course concomitant with speech science. Therefore, here, the anatomy is presented as a refresher for students and for easy reference, rather than at a level of detail expected for novel learning of the material. The anatomy sections also serve to highlight some important anatomical features that prepare students for the subsequent speech and voice science topics.

For Chapters 1 through 11, I have used "we" throughout this book in lieu of "I" even though the chapters were largely sole authored. The reason for the plural pronoun is that the knowledge and authority with which I wrote those chapters is drawn from a legion of speech and voice scientists who have contributed the vast amount of data upon which this book is based. They have done all the good cooking. I am just carrying it to the table.

With this fourth edition, we are excited to introduce an accompanying workbook, *Speech and Voice Science Workbook*, authored by Don Finan and myself. The workbook is divided into chapters that correspond to the chapters in this textbook. Within each chapter, you will find four sections: *Foundational Knowledge* questions, *Conceptual Integration* questions, TRY IT! activities, and *Clinical Application* questions. Our intention in creation of this workbook is to offer your students a tool for learning. The contents can be used for student review, self-study and exam preparation, to highlight areas of confusion, to learn concepts, to connect ideas, and to spark new questions and thoughtful discussions. We hope that you and your students find it helpful.

As always, I welcome comments, criticisms, and suggestions for changes to future editions to keep this textbook as useful as possible for instructors and students. You can find me at Alison.Behrman@lehman.cuny.edu.

Acknowledgments

Many individuals contributed to the creation of the three previous editions of this textbook, and without them, this project would never have come to fruition. I am quite indebted to the following people:

To Donald Finan, who contributed a fabulous chapter on instrumentation to this fourth edition.

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To my students across the years, who inspire and teach me, perhaps more than I teach them.

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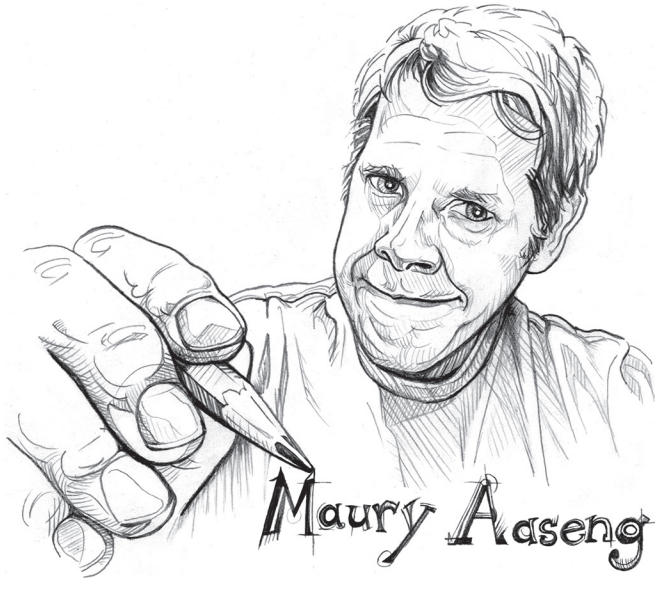
About the Illustrator



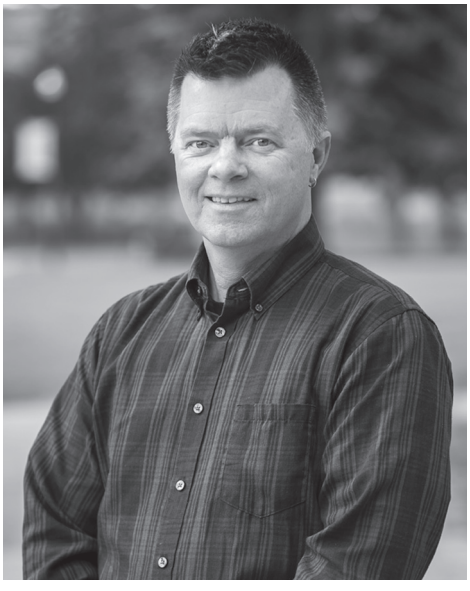
Maury Aaseng is an illustrator who created all of the illustrations for this textbook with the editorial guidance of Alison Behrman.

Maury began illustrating as a freelancer for young-adult nonfiction publications in San Diego, California. While there, his work expanded into the realm of medical and anatomical art. He collaborated with authors and experts to create digitally rendered illustrations for publications that illuminate concepts in the health sciences, the body, and nature. Beyond medical illustration, his range includes cartooning, watercolor, logos, line-art, ink, and digital art. Clients include various publishing companies, podcasts, botanical gardens, lawyers, public works utilities, an opera company, and a creative studio in Melbourne, Australia.

His work first won recognition in the juried exhibition Upstream People Gallery in 2008. In 2016, a collection of his watercolor work was displayed at the Great Lakes Aquarium gallery. He has taught classes covering scientific illustration and nature-inspired watercolor, and recently he has drawn on his experience to create books that demonstrate techniques to other budding artists.

Maury resides with his wife, Charlene, a graphic designer, and their two children in Duluth, Minnesota, near the shores of Lake Superior. They enjoy spending time outdoors as much as possible in the surrounding woods and lakes.

About the Contributor



Donald Finan, PhD, is a professor in the department of Audiology and Speech-Language Sciences at the University of Northern Colorado. He is a speech scientist with a background that encompasses speech-language pathology and audiology, speech physiology, neuroscience, and instrumentation. His research interests include the measurement of noise in relation to auditory exposure, normal speech motor control over the life span, the use of technology in clinical and research settings, and the development of original tools and pedagogies for speech science instruction. Dr. Finan is the codeveloper of the innovative course Musical Acoustics and Health Issues taught at the University of Northern Colorado. In this course, students explore acoustics by constructing cigar box guitars and PVC pipe didgeridoos, among other hands-on projects related to the speech and hearing sciences. Dr. Finan is the inaugural coordinator of ASHA's Special Interest Group 19, Speech Science, and he moderates the Facebook page "Speech Science Toolbox" (https://www.facebook.com/SpeechScienceToolbox/), where resources for teaching speech science are shared. Dr. Finan lives in Loveland, Colorado, with his wife. Their two sons are both pursuing careers in mechanical engineering. In his spare time, Dr. Finan likes to mountain bike, play guitar, and do archery, although never at the same time.

1

Introduction

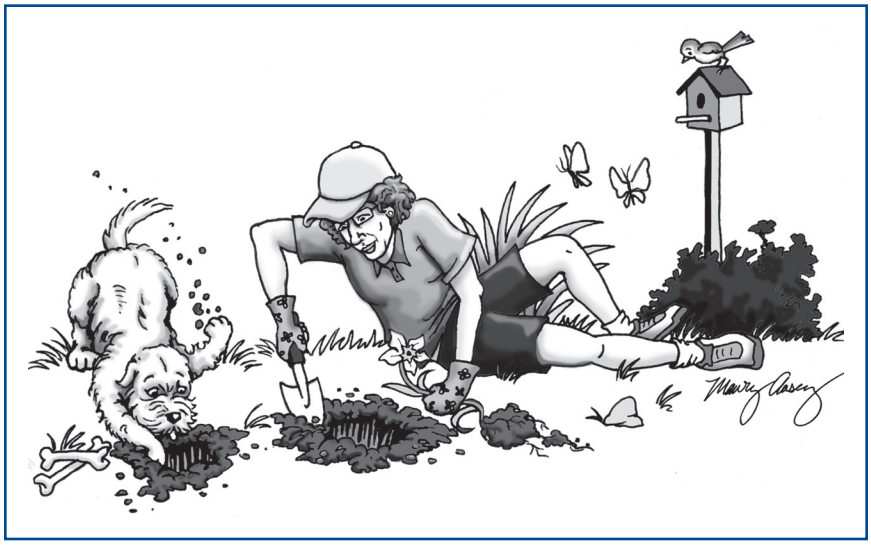


Figure 1–1

I'm scared of this course. I've heard speech science is really hard!

—Unidentified panicking undergraduate student

1.1 The Clinical Usefulness of Speech and Voice Science

Let us right away get to the heart of the question. Why do speech-language pathologists need to study speech science? Certainly, if a student intends to become a research scientist, so the argument goes, then such knowledge is important. But most students of speech-language pathology do not become research scientists. Most students become clinicians who work with, for example, children who have articulation or fluency problems or with adults who have aphasia, voice, or motor speech disorders. Certainly, the study of speech science is not particularly relevant to those students. Or so the argument goes.

Can we understand communication problems, abnormal communicative processes, without understanding the way in which communication is supposed to work typically? No. Thus, we study first the typical processes upon which communication is based. The communication problems that we encounter as speech-language pathologists can be divided broadly into deficits in language and deficits in speech. (Interplay between the two areas occurs, of course, and this fact is addressed intermittently throughout the book.) To address language deficits, we need a strong knowledge base in linguistic rules and the formulation of language. To address speech and voice deficits, we are concerned with the production and perception of speech sounds and the voice source signal. If we do not understand the basics of sound production and of sound perception, then how are we to be effective clinicians? The act of speaking, for all its ordinariness, is remarkably complex. Without this knowledge, we conduct therapy as if wearing blinders, limited in our ability to understand what our client is doing and what we need to do to help the client achieve the goals of therapy. Consider the following scenarios.

Scenario 1

You are asked to evaluate the speech of a 15-year-old girl who is having difficulty being understood in class. Her teachers report that her voice sounds very nasal, she does not speak loud enough to be heard easily, and she does not seem to pronounce her words very clearly. The teachers wonder whether she has some type of structural deformity and, in addition, whether she has an attitude or emotional problem, or whether again she does not try hard enough, or is just a bit lazy in her speech. You quickly determine that she does indeed have an excessive nasal quality to her speech. Her parents report that it has been a problem since she had her tonsils and adenoids removed 6 months earlier. You are aware that, in a small percentage of children, this surgical procedure can result in excessively nasal speech, and you suspect problems with her velopharyngeal port. As part of your diagnostic testing, you select certain words and phrases for her to produce that are likely to be particularly revealing of velopharyngeal port incompetence. The pressure characteristics of the phonemes contained within the speaking test you give her will help you to make your diagnosis. How do you know which words and phrases to select? You assess her articulation, and it is clear to you that she does not have an articulation problem, but, rather, the excessive nasality is interfering with the production of certain phonemes. Features of these phonemes reveal problems with the ways in which she regulates airflow and air pressure within her vocal tract. How do you know this? And, finally, you must explain to her teachers why the student is unable to generate sufficient intensity to be heard clearly and how this is a direct result of hypernasality. What is your explanation? In this case, your knowledge of speech science has enabled you to conduct an evaluation and to address the concerns of the teachers, and it has helped to prevent teachers from forming inaccurate assumptions about the student. (To find out the answers to these questions, you'll need to read Chapters 7 and 8, as well as parts of Chapters 4 and 5. And to understand completely what you read, you'll need some of the information in Chapters 2 and 3 as well.)

Scenario 2

You work with an individual for whom American English is not his native language. He knows that

his accent is making it difficult for colleagues to understand him easily, and he is concerned that it may limit his career growth. He does not want to lose his native cultural identity but would like to make himself more easily understood. Your evaluation reveals that he has difficulty with some of the vowels of English. You note that his vowels tend to be shorter in duration than those of most Americans, he uses almost no diphthongs, and he often rounds his lips when we do not and fails to round them when we do for some of the back vowels in particular. In this case, your knowledge of the acoustics of vowel production helps you know what to listen for in his speech and what features to identify that are calling attention to themselves as different from those of a native speaker of American English. You can explain to your client about these differences, thereby helping him to understand what needs to be addressed in therapy. In this case, your knowledge of speech science has contributed to increasing the sensitivity of your ear to important features of his speech by providing a conceptual framework to help you organize what you hear. In other words, your studies in speech science help you to know what to listen for!

Scenario 3

In February, one of the elementary school teachers at the school where you work comes to see you about her voice. She reports that since she began teaching second grade the previous September, her voice has become progressively worse. It cracks and sounds very hoarse, and her throat hurts when she speaks. By the end of each week, she can barely get a sound out, and it only gets a little better as she rests it on the weekends. Her ear, nose, and throat physician has told her that she has nodules, noncancerous abnormalities of her vocal folds that are caused by incorrect and excessive voice use. You know that teachers are particularly susceptible to voice problems because of the speaking demands of their job. You also know that you cannot tell her simply to speak less or to speak more quietly, because she teaches second grade! Despite using a microphone and nonverbal strategies to get the children's attention, her symptoms persist, and she must be able to use her voice every day for long periods of time, sometimes loudly. You know that by creating the right relationship between the air pressure above her glottis and the air pressure between her vocal folds, she will be able to gain greater intensity more easily and gently. You give her exercises that will help create this appropriate interaction. From where does your understanding of vocal fold vibration and vocal tract pressure waves arise? In this case, your knowledge of speech science allows you to understand the mechanisms that have caused your client to develop a voice problem, and this same knowledge enables you to develop therapeutic exercises to help your client overcome the problem.

All the above scenarios are real. And they emphasize that speech science provides a knowledge base that enables you, the clinician, to solve problems and to be *creative* in your therapies. What do we mean by creative? A common cry by novice clinicians is "I don't know what to do in therapy with this client." A common response by the seasoned clinician is "I can't give you a cookbook of therapy techniques. Each client is different, and *you* must determine what your client needs." And a chasm seems to appear between the two sides, with the novice clinician feeling that, somehow, the more experienced clinician is "holding back" and not sharing the secrets of clinical speech pathology. The creativity comes from understanding the speech production system and being able to solve problems within the diagnostic and therapeutic processes.

1.2 Defining Speech Science

Speech production is the generation of airflow and the creation of air pressures by the displacement (movement) of bodily structures, which, taken together, cause the disturbances of air that constitute phonemes, the smallest meaningful units of sound. Thus, the science of speech production must include the study of the movement of the relevant body structures and the air particles. Therefore, **speech science** includes

the study of aerodynamics, the movement of air and the forces used to generate the movements. Speech science also includes the study of **acoustics**, a branch of physics devoted to the study of sound: its production, transmission, and effects. And speech science includes the study of kinematics and dynamics. **Kinematics** is the study of motion, the positions, velocities, and acceleration of body parts. Whereas kinematics is concerned with movements without regard to the forces that cause the movements, **dynamics** is concerned with the forces that cause the movements. Speech science must also include the study of **psychoacoustics**, an interdisciplinary field of psychology and acoustics that addresses the relationship between the physical properties of a phenomenon and our perception of these properties.

What is the distinction between speech and voice? The *Oxford English Dictionary* provides the following definition of voice: "sound formed in or emitted from the human larynx in speaking, singing, or other utterance." Speech is defined as "the natural exercise of the vocal organs; the utterance of words or sentences; oral expression of thought or feeling." Narrowly, we can define voice as the production of sound waves by vibration of the vocal folds, whereas speech refers to the production of phonemes by structures of the vocal tract above the larynx, particularly the oral cavity. Yet, in later chapters of this book, we will discuss voice production as depending on characteristics of the vocal tract, and so it is not confined only to the larynx. And the presence or absence of voicing is an important feature of phonemes, so that speech production includes the activity of the larynx. Sometimes we will use the general term *speech science* for economy of words instead of saying voice and speech science.

As you progress through your study of speech science, you will learn that speech and voice production is a complex neuromechanical activity that requires coordination of the breathing, phonatory, and resonatory/articulatory subsystems. Neuromechanical means that speech production is regulated by both the neurologic system and the physical properties of the structures that it governs. In Chapters 4, 5, and 6, you will learn that the breathing subsystem provides the aerodynamic power that drives the vibration of the vocal folds to produce the source of the voiced sound. In Chapter 7, you will learn that the resonatory/articulatory subsystem functions as a dynamic (active and changeable) acoustic filter. And in Chapter 8, you will learn that articulation, particularly the movement of the structures of the mouth, alters the spatial configuration of the vocal tract in a specific time-ordered fashion. These dynamic changes to the spatiotemporal configuration of the vocal tract result in changes to its acoustic resonant properties. (By spatiotemporal, we mean a given posture or positioning of the vocal tract as a function of time.) The articulatory subsystem acts not only as an acoustic resonator but also as a sound source separate from the phonatory source. Together, the phonatory sound source, the acoustic filtering, and the articulatory sound sources yield the various speech sounds of our language. If all of this is a bit confusing to you, the student, don't worry. It will become clearer over the course of the following chapters.

An effort has been made throughout all the chapters to emphasize the dynamic nature of speech science. Facts are revisable data about the world. That is, facts originate through scientific study and, as new knowledge is gained, the "facts" can change. The data upon which our knowledge of speech science is based come from experimentation, and the information in this book comes from research studies by many voice and speech scientists. These experiments include observing and measuring how the speech production system functions during routine speaking situations and under a variety of different conditions, such as sustained vowel phonation, running speech, producing loud or soft speech and high and low pitches, or when the speech production system is constrained (restricted) in some unusual way. In addition, much information about speech function has been gained by observing what happens when a structure is damaged, through disease or trauma. Although certain facts about the speech production system have changed little since they were first discov-

ered, others are continually being revised. And much remains unknown, yet to be discovered.

We discover new information about the speech production system through observation and often with the help of instrumentation. Some instrumentation is so complicated and expensive that its use is reserved only for research purposes. Other instrumentation is used commonly in routine clinical practice during evaluation and sometimes during therapy. Instrumentation serves both to expand and to limit the possibilities for physiologic research. That is, instrumentation helps us measure what we cannot measure with our own unaided senses alone, and in that sense, it serves to expand our possibilities for gaining knowledge about the speech production system. Yet all instrumentation imposes certain restrictions upon the individual—perhaps the speaker must remain immobile while being tested, or only certain types of movements can be measured accurately, or events that occur very rapidly cannot be measured at all. All instrumentation has strengths and limitations. A wide selection of speech instrumentation, some reserved for research purposes only and some also used in clinical application, is discussed at the end of Chapters 4 through 8, and Chapter 11 is devoted to the explanation of instrumental arrays and how they influence the data we obtain.

Do you apply every bit of speech science to every client? Of course, you do *not*. Similarly, the physician does not apply all that she has learned in medical school to every patient. But that does not mean that the speech-language pathologist or the physician should study only those areas most relevant to clinical practice. In later chapters, we will learn about the concept of nonlinearity, which means broadly that the relationship between the cause and the effect is not direct or, more colloquially, that the whole is greater than the sum of its individual parts. The various topics contained in this textbook that comprise an introduction to speech and voice science serve as a broad fund of knowledge that, in a cumulative sense, will provide you with a strong understanding of speech production and enable you to solve problems and to be creative in your clinical practice.

To help you grasp the clinical relevance of speech and voice science, Chapters 4 through 11 each begin with a clinical case relevant to the content of the chapter, and each of those chapters contain either a second clinical case at the end of the chapter or a clinical application section addressing a clinical aspect to the content. So, in response to the questions, "Why do we have to know this? When will I ever *use* this? This has nothing to do with speech disorders!" you can respond, "This information is part of the larger base upon which I practice the clinical skills of speech pathology." It has *everything* to do with clinical practice.

Gardeners are fond of saying that one should place a 50-cent plant in a five-dollar hole. In other words, the plant has a better chance of reaching its fullest potential with an investment of time and effort into preparation of the foundation. This text offers the five-dollar hole—a foundation in the science of voice and speech production, upon which to build excellent clinical skills.

1.3 Advice for Students on Effective Study Techniques

"I don't understand. I studied so hard—how did I get such a low grade on the test?"

"I know the material. It's just the way she words the questions on the test that really confuses me."

"I'm so upset. I spent all week studying, and still I did poorly on the exam."

"I know the material. I just get so nervous during the test that I can't think."

"I thought I knew the material, but then I realized when I took the test that I studied the wrong things."

"I really need an A in this course."

Sound familiar? There's an adage: *If you always do what you've always done, then you'll always*

get what you've always got. If you aren't earning the grade you want, then it's time to do something different. Here are some suggestions that have worked for my students.

Study as Though You Are Having a Test Every Week

The course for which you are using this book is dense with facts and conceptually complex, and the information is often not at all intuitive. For most students, waiting until the week (or weekend) before a test and then studying intensively is not a good strategy. If, at the time of the test, you find yourself unable to recall information that you thought you knew, or confused by the way a question is worded, it is likely that you tried to memorize too much information too quickly. You didn't give yourself time to learn it—to understand it and apply it in different situations (e.g., different types of questions).

The solution is to pretend that you will have a test during the first class of each week, and the test will include all the information covered during the prior week. Study seriously for the imaginary test. Four things will happen because of this tactic. First, you will become aware of what you don't understand, and you will have an opportunity to ask your professor in class (or during office hours or via email) well before the real test. Second, you will learn more during class. A great deal of the information in speech and voice science builds on previously learned facts and concepts. When you are well grounded in the prior information, the new class material makes much more sense and becomes easier to acquire. Third, you will be able to answer correctly different types of questions, even when the questions approach the information in a different way than you studied, such as the ability to draw inferences. The reason is that you will have given yourself more time overall to learn the information. Rather than only memorizing facts, you will *understand* the information. Fourth, you will enter the test feeling more confident and, therefore, calmer, which will enable you to think more clearly and access the information you know more readily.

A common objection to this advice to study each week is lack of time. You have other demanding courses that you are taking this semester. If you spend so much time studying for this course each week, you will have no time to do your other work. Or so you say. That's not true. Let's say that the course for which you are using this textbook is 3 credits, and your semester load is 15 credits. You should be spending about 2 to 3 hours per week for every credit hour. Let's take the higher number, so we'll say that you should be spending 9 hours studying every week for every course, for a total of 45 hours (3 hours × 15 credits or, similarly, 9 hours × 5 courses). Add the 45 hours to your in-class hours, and you come out with a workweek of about 60 hours. That's typical for many adults in the workforce (including, ahem, your professors). (Ask your parents how many hours a week they put in at their jobs.) A 60-hour workweek gives you plenty of time to be with your friends, in person and through social media. Do the math on your own workweek currently. Be honest. It's probably well below 60 hours. If, truly, you are putting in the hours but you're not getting the results (grades) you want, another possibility is that your study time is not effective. So here's another tip.

Study With a Partner or Group

Take 2 of the 9 study hours per week and devote them to partner or group sessions. Don't wait until the week before the test to form a group. Do it the first week of class and work together consistently throughout the semester. Quiz each other. Explain concepts and define vocabulary words to each other. Compare notes. Explaining a concept to another person is one of the best ways to learn it. You may have a misconception about something and not even realize it. You may have missed something in class or in your reading. You may have written something in your notes that is incorrect. Your partner or

group will help reveal those errors. Yes, it can be challenging to find a common time when a group of students is available. But you can do it. If your schedule is that difficult, then find a partner rather than a group, or use Skype or Google Hangouts or another online meeting application.

Reach Beyond Memorization to Understand the Material

Often, when a student shows up in my office seeking advice on how to improve her grade, I start by asking, "How are you studying currently?" Typically, the student tells me that she rewrites her notes and highlights information to study, or she makes study note cards of key facts and quizzes herself. Well, that's fine, but it's insufficient. What if you forgot to include certain information on your study note cards? What happens when the test requires that you access that information differently from how you studied it? More often than not, you will be unsuccessful.

Here are some examples of how to memorize *and understand*. Let's say you are studying respiration, and you need to learn about Boyle's law. Memorize the law. But then reread the relevant sections of the text and study your class notes to understand the relevance of Boyle's law to breathing and the physiologic mechanisms by which Boyle's law is maintained. This type of studying gives you a deeper understanding of the material beyond memorization and enables you to answer test questions that require you to draw connections between concepts. To help guide you in drawing connections, work with the Study Guide questions found in the PluralPlus website that accompanies this textbook. (More on that in a moment.)

Figure 1–2

Administer Self-Exams

Frequently, students say that they test themselves on material. But often, they test themselves using flashcards, for example, and if the answer doesn't readily come to them, they look at the answer. Try a different method. Write out a quiz or a test (depending on the amount of material you are studying). You may even want to create the test using your study partner or group, so that you are not familiar with the questions. Then, take the test but simulate true test conditions. Give yourself an appropriate amount of time, as you would have in class. Then, take the test. Do not check answers until you have completed the test. Allowing yourself to struggle to recall correct answers, as you might during the actual test, will let you know what confusion you have and what you need to study more. And practice will help build your confidence to manage test anxiety.

Stay Mindfully Present in Class

Do not fall into the habit of being a mindless note taker. Taking notes in class without thinking, with the expectation that you can study the information later, is an inefficient use of class time. It creates more work for you outside of class. Instead, commit to being mindfully present in class. Listen to the lecture, participate in discussion, think about the material on which you are taking notes, try to relate the information to prior facts that you have learned in class, and interject questions when you don't understand.