HOW LEARNING WORKS

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How Learning Works

Seven Research-Based Principles for Smart Teaching

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Foreword by Richard E. Mayer

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To the faculty and graduate instructors of Carnegie Mellon, whose dedication to student learning continues to inspire us.

FOREWORD: APPLYING THE SCIENCE OF LEARNING TO COLLEGE SEACHING

In 1899, the famous American psychologist, William James published a little book called *Talks t Teachers,* in which he sought to explain how to apply psychology to education—that is, he sought use what he called "the science of the mind's workings" to generate practical advice for classroo teachers. At the time, the book was not much of a success, largely for two reasons: (a) there was a lac of research evidence on how learning works (that is, the science of learning), and (b) there was a lac of research-based principles concerning how to help people learn (that is, the science of instruction).

Much has happened in the learning sciences in the past 100 years, particularly in the last fe decades. We finally have the makings of a research-based theory of how people learn that educationally relevant (that is, the science of learning) and a set of evidence-based principles for ho to help people learn that is grounded in cognitive theory (that is, the science of instruction). Indee these are exciting times if you are interested in fulfilling William James's mission of applying th science of learning to education.

The book you are holding—*How Learning Works: Seven Research-Based Principles for Sma Teaching*—is the latest advancement in the continuing task of applying the science of learning education—particularly, college teaching. The authors are experts in helping college teache understand how research in the science of learning can improve their teaching. If you are interested what research in the science of learning and instruction has to say for you as a college teacher, the this book is for you.

The book is organized around seven learning principles—each a gem that is based on researc evidence from the science of learning and the science of instruction. The principles concern the role the student's prior knowledge, motivation, and developmental level, as well as opportunities for th student to practice, receive feedback, and learn to become a self-directed learner. Each chapter focus on one of the principles, such as "Students' prior knowledge can help or hinder learning." Eac chapter begins with a concrete scenario in college teaching that exemplifies the principle bein highlighted in the chapter, provides a clear statement and rationale for the principle, summarizes th underlying research and its implications, and offers specific advice on how to apply the principle.

Consider the following scenario: You are teaching a course in your field. Based on years of stud and work, you are an expert in your field—but you are certainly not an expert in how to teach othe about your field. In fact, you have almost no training in how to teach. Yet a fundamental part of you job involves college teaching. You have devised a teaching style that works for you, but you wonde whether there is any way to base what you are doing on scientific principles of learning and teachin This description fits many college teachers.

The book you are holding is based on the idea that you wish to consider taking an evidence-base approach to college teaching—that is, you wish to inform your instructional decisions with researc evidence and research-based theory. Why should you take an evidence-based approach? You coul base your instructional choices on fads, ideology, opinions, expert advice, or habit—but thes approaches may not be ideal if your goal is to be an effective teacher. Admittedly, advice from exper and your own personal experience can be useful aids to you in planning instruction, but they may b incomplete. In taking an evidence-based approach, you seek to add to your knowledge base b discovering what works and how it works. In short, it is helpful to understand what the science learning has to offer you in your role as a college teacher.

Where should you look for help in improving your college teaching? Consider three commo choices:

Sources that are too hard—You could try to digest research articles in the field of learning an instruction, but you might find them somewhat tedious and perhaps daunting. This approach is to

hard because it focuses on scientific evidence without much focus on how to apply the evidence
teaching.

Sources that are too soft—You could read self-help guides that offer practical advice that is n
necessarily based on research evidence or research-based theory. This approach is too soft because
focuses on practical advice without supporting evidence or theory to back up the advice.

Sources that are just right—You could read this book, which synthesizes empirical research evidenc
and research-based learning theory into practical advice for how to improve your college teaching.
short, the strength of this book is that it combines research evidence and practical advice to produ
an evidence-based approach to improving your college teaching. If you are interested in what t
science of learning has to contribute to your college teaching, then this book is for you.

What should you look for in this book? In reading this book, I suggest that you look to make su
that it meets four basic criteria for applying the science of learning to your college teaching:

Theory-grounded: the advice is grounded in a research-based theory of how people learn

Evidence-based: the advice is supported by empirical research evidence showing how to help peop
learn

Relevant: the advice has clear and practical implications for how to improve your teaching

Clear: the advice is understandable, concrete, and concise

As you read about each of the seven basic learning principles in this book, you will find advice th
is grounded in learning theory, based on research evidence, relevant to college teaching, and easy
understand. The authors have extensive knowledge and experience in applying the science of learni
to college teaching, and they graciously share it with you in this organized and readable book.

I congratulate you for your interest in improving your teaching and commend you for taking t
important step of reading this book. If you want to improve your teaching, it is useful to understa
what research says about how learning works and about how to foster learning. In light of these goa
I welcome you to the feast of evidence-based advice you will find in this volume.

Richard E. Mayer University of California, Santa Barbara

ACKNOWLEDGMENT

Writing this book was a significant undertaking, which we would not have been able to comple without the help of many friends and colleagues. Although many faculty colleagues across disciplin and institutions have found these principles helpful and encouraged us to publish them, it was Ri Mayer who, after seeing a presentation of our learning principles, convinced us to share them with t larger education community. Little did he know that his encouragement would lead to more work f him! We are thrilled and grateful to Rich for writing the Foreword to this book.

We are forever in debt to Judy Brooks, our talented graphic designer, who cheerfully endured ou endless wordsmithing, listening carefully, and asking insightful questions, in order to help us put ou ideas into images for the figures in this book. Judy, we salute you! We also cannot express enoug thanks to Hilary Franklin, a Ph.D. student working with us, who read every chapter with h characteristic precision and intelligence and provided invaluable feedback that forced us to recogni and address our own "expert blind spots." Aimee Kane joined our group late in the writing proces and yet we cannot imagine how we functioned before she became our colleague. Her thoughtful an reflective responses to the chapters added a fresh and indispensable perspective and left an indelib mark on the finished product. We were also extremely lucky to have had the help of our forme colleague Anne Fay throughout the early phases of planning and writing the book. Her ability remember and access every research study she has ever read was truly awe inspiring. In addition, ou "internal" editor, Lisa Ritter, applied her exacting standards and patience to the job of copy editing th manuscript, thus freeing us to continue revising ad infinitum; we thank her for a job well done.

We are also thankful for an outstanding set of colleagues, both at Carnegie Mellon and at oth universities in the United States and abroad, who were willing to take time from their busy schedul to read and provide insightful feedback on different chapters. These colleagues include Vince Aleven, Ryan Baker, Rebecca Freeland, Scott Kauffman, Edmund Ko, Ken Koedinger, Norma Ming Matt Ouellett, Ido Roll, and Christian Schunn.

Finally, we would never have embarked upon this endeavor in the first place if it were not for th thousands of faculty members and graduate students with whom we have worked over the years. W are humbled by your ongoing dedication to your students and by your willingness to share your stori and experiences, open up your courses to us, and reflect thoughtfully on and refine your teachin practice. We continue to learn and benefit from our interactions with you, and we hope this boo provides something useful in return.

ABOUT THE AUTHORS

Susan A. Ambrose is associate provost for education, director of the Eberly Center for Teachin Excellence, and teaching professor in the Department of History at Carnegie Mellon. She received h doctorate in American history from Carnegie Mellon in 1986 and has been at the Eberly Center sinc its inception. Her major responsibilities include identifying and responding to changing education needs that impact faculty and graduate students, maintaining overall operation of the Eberly Cente and overseeing the Intercultural Communication Center and the Office of Academic Developmen Susan Ambrose has been a visiting scholar for the American Society of Engineering Education and th National Science Foundation, and was awarded an American Council on Education fellowship to stud leadership styles of two university presidents. She has coauthored three books and published mo than twenty-five chapters, articles, and commissioned reports in such areas as faculty satisfactio engineering education, teaching and learning, and women in science and engineering. In recent yea she has received funding from the National Science Foundation, the Alfred P. Sloan Foundation, th Fund for the Improvement of Postsecondary Education, the Lilly Endowment, the Carneg Corporation of New York, the Eden Hall Foundation, and the ALCOA Foundation. She also teach courses on immigration, particularly Mexican and Asian immigration to the United States.

Michael W. Bridges is the director of faculty development at University of Pittsburgh Medic Center (UPMC) St. Margaret Hospital, where he works with family practice residents and fellows. H received his doctorate in social psychology from Carnegie Mellon in 1997. He has applied h background in the psychology of personality and motivation to help develop courses across a broa range of topics and disciplines. He has also provided survey research consultation to numerous client including Carnegie Mellon's Deliberative Polling Program, a campuswide first year experience calle Big Questions and Fathom Designs. His research interests include the role of motivation in goa directed behavior, the relation between stress and disease, and the role of personality in traumatic li events. He teaches courses in personality and stress and coping.

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Marsha C. Lovett is associate director for faculty development at the Eberly Center for Teachin Excellence and associate teaching professor in the Department of Psychology at Carnegie Mellon. Th question that drives her work is how people learn. She has studied this question from variou perspectives, as a graduate student, postdoctoral researcher, and assistant professor in Carneg Mellon's Psychology Department. Her research combines computational and mathematical modelin controlled experiments, and classroom observation. She has studied learning in several discipline including geometry, physics, linear algebra, programming, and statistics, at the high school an college levels. She designed and developed *StatTutor,* a computer-based tutor that helps students lea the skills of data analysis. Her teaching has included undergraduate and graduate courses on researc

methods, the analysis of verbal data, and the nature of expertise. At the Eberly Center, Lovett appli theoretical and empirical principles from cognitive psychology to help instructors improve the teaching. She has published more than thirty research articles on learning and instruction and is c editor of the book *Thinking with Data*. In recent years, she has received funding from the Nation Science Foundation, the Office of Naval Research, and the Spencer Foundation.

Marie K. Norman is a teaching consultant and research associate at the Eberly Center for Teachin Excellence, and adjunct professor of anthropology in the history department at Carnegie Mellon. Sh received her doctorate from the University of Pittsburgh's Department of Anthropology in 199 where her research, funded by a Fulbright doctoral studies grant, focused on the effects of tourism c caste relations in Nepal. At the Eberly Center, Marie Norman consults with junior and senior facul who want to improve their teaching, helps run the Wimmer Faculty Fellows Program, and conducts variety of workshops and seminars on teaching and learning. She is particularly interested in cros cultural issues in the classroom. In addition to her work with the Eberly Center, she teaches courses o medical anthropology, gender, tourism, and South Asia. She has served on the faculty of th University of Pittsburgh's Semester at Sea Program (2004), is an academic advisor for the Bachelor o Humanities and Arts Program at Carnegie Mellon, and co-edits the journal *Ethnology*. Norman committed to applying anthropological approaches to practical problems, and has worked as consultant on research studies for St. Margaret's Hospital, Allegheny College, and Fathom Designs.

Introduction: Bridging Learning Research and Teaching Practice

Learning results from what the student does and thinks and only from what the student does and thinks. The teacher can advance learning only by influencing what the student does to learn.

HERBERT A. SIMON,[1] one of the founders of the field of Cognitive Science, Nobel Laureate, and University Professor (deceased) at Carnegie Mellon University

As the quotation above suggests, any conversation about effective teaching must begin with consideration of how students learn. Yet instructors who want to investigate the mechanisms an conditions that promote student learning may find themselves caught between two kinds of resource research articles with technical discussions of learning, or books and Web sites with concre strategies for course design and classroom pedagogy. Texts of the first type focus on learning but a often technical, inaccessible, and lack clear application to the classroom, while texts of the secon type are written in accessible language but often leave instructors without a clear sense of why (even whether) particular strategies promote learning. Neither of these genres offers what man instructors really need—a model of student learning that enables them to make sound teachin decisions. In other words, instructors need a bridge between research and practice, between teachin and learning.

We wrote this book to provide such a bridge. The book grew out of over twenty-nine years experience consulting with faculty colleagues about teaching and learning. In these consultations, w encountered a number of recurring problems that spanned disciplines, course types, and student ski levels. Many of these problems raised fundamental questions about student learning. For exampl Why can't students apply what they have learned? Why do they cling so tightly to misconception Why are they not more engaged by material I find so interesting? Why do they claim to know so muc more than they actually know? Why do they continue to employ the same ineffective study strategie

As we worked with faculty to explore the sources of these problems, we turned to the research o learning, and from this research we distilled seven principles, each of which crystallizes a key aspe of student learning. These principles have become the foundation for our work. Not only have w found them indispensable in our own teaching and in our consultations with faculty, but as we hav talked and worked with thousands of faculty from around the world, we have also found that th principles resonate across disciplines, institution types, and cultures, from Latin America to Asia. our experience, these principles provide instructors with an understanding of student learning that ca help them (a) see *why* certain teaching approaches are or are not supporting students' learning, (b generate or refine teaching approaches and strategies that more effectively foster student learning specific contexts, and (c) transfer and apply these principles to new courses.

In this book, we offer these principles of learning, along with a discussion of the research th supports them, their implications for teaching, and a set of instructional strategies targeting eac principle. Before briefly summarizing the full set of principles and discussing the characteristics the share and some ways that this book can be used, we begin by discussing what we mean by learning.

WHAT IS LEARNING?

Any set of learning principles is predicated on a definition of learning. In this book, we defi learning as a *process* that leads to *change,* which occurs as a result of *experience* and increases th potential for improved performance and future learning (adapted from Mayer, 2002). There are thre critical components to this definition:

1. Learning is a *process,* not a product. However, because this process takes place in the mind, w

can only infer that it has occurred from students' products or performances.

2. Learning involves *change* in knowledge, beliefs, behaviors, or attitudes. This change unfol over time; it is not fleeting but rather has a lasting impact on how students think and act.
3. Learning is not something done to students, but rather something students themselves do. It the direct result of how students interpret and respond to their *experiences*—conscious ar unconscious, past and present.

OUR PRINCIPLES OF LEARNING

Our seven principles of learning come from a perspective that is developmental and holistic. In oth words, we begin with the recognition that (a) learning is a developmental process that intersects wi other developmental processes in a student's life, and (b) students enter our classrooms not only wi skills, knowledge, and abilities, but also with social and emotional experiences that influence wh they value, how they perceive themselves and others, and how they will engage in the learnir process. Consistent with this holistic perspective, readers should understand that, although we addre each principle individually to highlight particular issues pertaining to student learning, they are all work in real learning situations and are functionally inseparable.

In the paragraphs below, we briefly summarize each of the principles in the order in which they a discussed in the book.

Students' prior knowledge can help or hinder learning.

Students come into our courses with knowledge, beliefs, and attitudes gained in other courses ar through daily life. As students bring this knowledge to bear in our classrooms, it influences how th filter and interpret what they are learning. If students' prior knowledge is robust and accurate ar activated at the appropriate time, it provides a strong foundation for building new knowledg However, when knowledge is inert, insufficient for the task, activated inappropriately, or inaccurate, can interfere with or impede new learning.

How students organize knowledge influences how they learn and apply what they know.

Students naturally make connections between pieces of knowledge. When those connections for knowledge structures that are accurately and meaningfully organized, students are better able retrieve and apply their knowledge effectively and efficiently. In contrast, when knowledge connected in inaccurate or random ways, students can fail to retrieve or apply it appropriately.

Students' motivation determines, directs, and sustains what they do to learn.

As students enter college and gain greater autonomy over what, when, and how they study and lear motivation plays a critical role in guiding the direction, intensity, persistence, and quality of th learning behaviors in which they engage. When students find positive value in a learning goal activity, expect to successfully achieve a desired learning outcome, and perceive support from the environment, they are likely to be strongly motivated to learn.

To develop mastery, students must acquire component skills, practice integrating them, and know when to apply what they have learned.

Students must develop not only the component skills and knowledge necessary to perform comple tasks, they must also practice combining and integrating them to develop greater fluency ar automaticity. Finally, students must learn when and how to apply the skills and knowledge they lear As instructors, it is important that we develop conscious awareness of these elements of mastery so to help our students learn more effectively.

Coal-directed practice coupled With targeted feedback enhances the quality of students' learning.

Learning and performance are best fostered when students engage in practice that focuses on specific goal or criterion, targets an appropriate level of challenge, and is of sufficient quantity ar frequency to meet the performance criteria. Practice must be coupled with feedback that explicit

communicates about some aspect(s) of students' performance relative to specific target criteri provides information to help students progress in meeting those criteria, and is given at a time an frequency that allows it to be useful.

Students' current level of development interacts with the social, emotional, and intellectual climate of the course to impact learning.

Students are not only intellectual but also social and emotional beings, and they are still developin the full range of intellectual, social, and emotional skills. While we cannot control the development process, we can shape the intellectual, social, emotional, and physical aspects of the classroo climate in developmentally appropriate ways. In fact, many studies have shown that the climate w create has implications for our students. A negative climate may impede learning and performanc but a positive climate can energize students' learning.

To become self-directed learners, students must learn to monitor and adjust their approache to learning.

Learners may engage in a variety of metacognitive processes to monitor and control their learnin —assessing the task at hand, evaluating their own strengths and weaknesses, planning their approac applying and monitoring various strategies, and reflecting on the degree to which their curre approach is working. Unfortunately, students tend not to engage in these processes naturally. Whe students develop the skills to engage these processes, they gain intellectual habits that not on improve their performance but also their effectiveness as learners.

WHAT MAKES THESE PRINCIPLES POWERFUL?

The principal strength of these seven principles is that they are based directly on research, drawing o literature from cognitive, developmental, and social psychology, anthropology, education, an diversity studies, and research targeting not only higher education but also K-12 education. Althoug of course, this is not an exhaustive review and any summary of research necessarily simplifies a ho of complexities for the sake of accessibility, we believe that our discussions of the researc underlying each principle are faithful to the scholarship and describe features of learning about whic there is widespread agreement. Indeed, several of our principles converge with those that others hav delineated (Pittsburgh Science of Learning Center, 2009; American Psychological Society, 2008), convergence that we believe attests to their salience.

Not only are these principles research-based, but as we have shared them with colleagues over th years, we have found that they are

- *Domain-independent:* They apply equally well across all subject areas, from biology to desig to history to robotics; the fundamental factors that impact the way students learn transcen disciplinary differences.
- *Experience-independent.* The principles apply to all educational levels and pedagogic situations. In other words, although the pedagogical implications of a principle will b somewhat different for first-year undergraduate students in a lab environment as opposed graduate students in a studio environment, the principle still applies.
- *Cross-culturally relevant:* Although the research we identified has been conducted primarily the Western world, faculty colleagues in other countries have resonated with the principle finding them relevant to their own classes and students. However, it is important to bear mind that culture can and does influence how the principles should be applied as instructo design and teach their courses.

INTENDED AUDIENCES

This book is intended for anyone interested in understanding more about how students learn and applying that information to improve instruction. This includes—but is not limited to—fac—ul members, graduate students, faculty developers, instructional designers, and librarians. It als

includes K-12 educators. In addition, the principles outlined here are valuable for instructors at a experience levels. They can help new and inexperienced instructors understand the components effective course design and classroom pedagogy. They can help experienced instructors troublesho problems or adapt effective strategies to suit new courses or student populations. They can also he highly successful and experienced instructors reflect on what makes their approaches and metho effective. Finally, these principles can enable faculty members to better support student learnir without having to rely on outside experts (a benefit that is particularly valuable for faculty campuses without teaching and learning centers).

HOW TO READ THIS BOOK

Each chapter in this book begins with stories that represent teaching situations that we hope will stri readers as familiar. Although the instructors described in these stories are fictional, the scenarios a authentic, representing composites of real problems we have encountered over many years consulting with faculty. We analyze these stories to identify the core problems or issues involved ar use them to introduce the learning principle relevant to those problems. Then we discuss the princip in relation to the research that underlies it. Finally, we provide a set of strategies to help instructo design instruction with that principle in mind.

Because all of these principles combine to influence learning, no one principle stands alon Consequently, the chapters can be read in any order. Moreover, the book can be read in conjunctio with our Web site, which provides additional strategies, applications, sample materials, and resource The URL is http://www.cmu.edu/teaching.

NOTE

1 Herb Simon was a university professor at Carnegie Mellon University and had joint appointments i the departments of psychology and computer science. While at Carnegie Mellon, Herb played a majo role in the development of the Graduate School of Industrial Administration (renamed the Tepper School of Business in 2004), the Department of Psychology, the School of Computer Science, and the College of Humanities and Social Sciences. He was one of the founding fathers of the fields of cognitive psychology and artificial intelligence, and won the Nobel Prize in Economics in 1978 and the National Medal of Science in 1986. For many years (until his death), Herb served as a member of the Advisory Committee to the Eberly Center for Teaching Excellence. He was often heard paraphrasing this quote from Elliott Dunlap Smith, a past president of Carnegie Mellon University.

CHAPTER 1
How Does Students' Prior Knowledge Affect Their Learning?

But They Said They Knew This!

I recently taught Research Methods in Decision Sciences for the first time. On the first day class, I asked my students what kinds of statistical tests they had learned in the introducto statistics course that is a prerequisite for may course. They generated fairly standard list th included T-tests, chi-square, and ANOVA. Given what they told me, I was pretty confident th my first assignment was pitched at the appropriate level; it simply required that students take data set that I provided, select and apply the appropriate statistical test from those they ha already learned, analyze the data, and interpret the results. It seemed pretty basic, but I w shocked at what they handed tin. Some students chose a completely inappropriate test whi others chose the right test but did not have the foggiest idea how to apply it. Still others cou not interpret the results. What I can't figure out is why they told me they knew this stuffwh it's clear from their work that most of them don't have a clue.

Professor Soo Yon Won

Why Is This So Hard for The to Understand?

Every year in my introductory psychology class I teach my students about classic learni theory, particularly the concepts of positive and negative reinforcement. I know that these c be tough concepts for students to grasp, so I spell out very clearly that *reinforcement* alwa refers to increasing a behavior and *punishment* always refers to decreasing a behavior. I al emphasize that, contrary to what they might assume, *negative reinforcement* does not mea punishment; it means removing something aversive to increase a desired behavior. I al provide a number of concrete examples to illustrate what Mean. But it seems that no matt how much I explain the concept, students continue to think of negative reinforcement punishment. In fact, when I asked about negative reinforcement on a recent exam, almost 6 percent of the class got it wrong. Why is this so hard for students to understand?

Professor Anatole Dione

WHAT IS GOING ON IN THESE STORIES ?

The instructors in these stories seem to be doing all the right things. Professor Won takes the time gauge students' knowledge of statistical tests so that she can pitch her own instruction at th appropriate level. Professor Dione carefully explains a dif ficult concept, provides concrete example and even gives an explicit warning about a common misconception. Yet neither instructor's strategy having the desired effect on students' learning and performance. To understand why, it is helpful consider the effect of students' prior knowledge on new learning.

Professor Won assumes that students have learned and retained basic statistical skills in the prerequisite course, an assumption that is confirmed by the students' self-report. In actuality, althoug students have some knowledge—they are able to identify and describe a variety of statistical tests— may not be sufficient for Professor Won's assignment, which requires them to determine whe particular tests are appropriate, apply the right test for the problem, and then interpret the results. He Professor Won's predicament stems from a mismatch between the knowledge students have and th knowledge their instructor expects and needs them to have to function effectively in her course.

In Professor Dione's case it is not what students do *not* know that hurts them but rather what the *do* know. His students, like many of us, have come to associate positive with "good" and negative wi "bad," an association that is appropriate in many contexts, but not in this one. When students a introduced to the concept of negative reinforcement in relation to classic learning theory, their pri understanding of "negative" may interfere with their ability to absorb the technical definition. Instea of grasping that the "negative" in negative reinforcement involves removing something to get

positive change (an example would be a mother who promises to quit nagging if her son will clean h room), students interpret the word "negative" to imply a negative response, or punishment. In oth words, their prior knowledge triggers an inappropriate association that ultimately intrudes on ar distorts the incoming knowledge.

WHAT PRINCIPLE OF LEARNING IS AT WORK HERE?

As we teach, we often try to enhance our students' understanding of the course content by connectin it to their knowledge and experiences from earlier in the same course, from previous courses, or fro everyday life. But sometimes—like Professor Won—we overestimate students' prior knowledge an thus build new knowledge on a shaky foundation. Or we find—like Professor Dione—that our studen are bringing prior knowledge to bear that is not appropriate to the context and which is distorting the comprehension. Similarly, we may uncover misconceptions and inaccuracies in students' prio knowledge that are actively interfering with their ability to learn the new material.

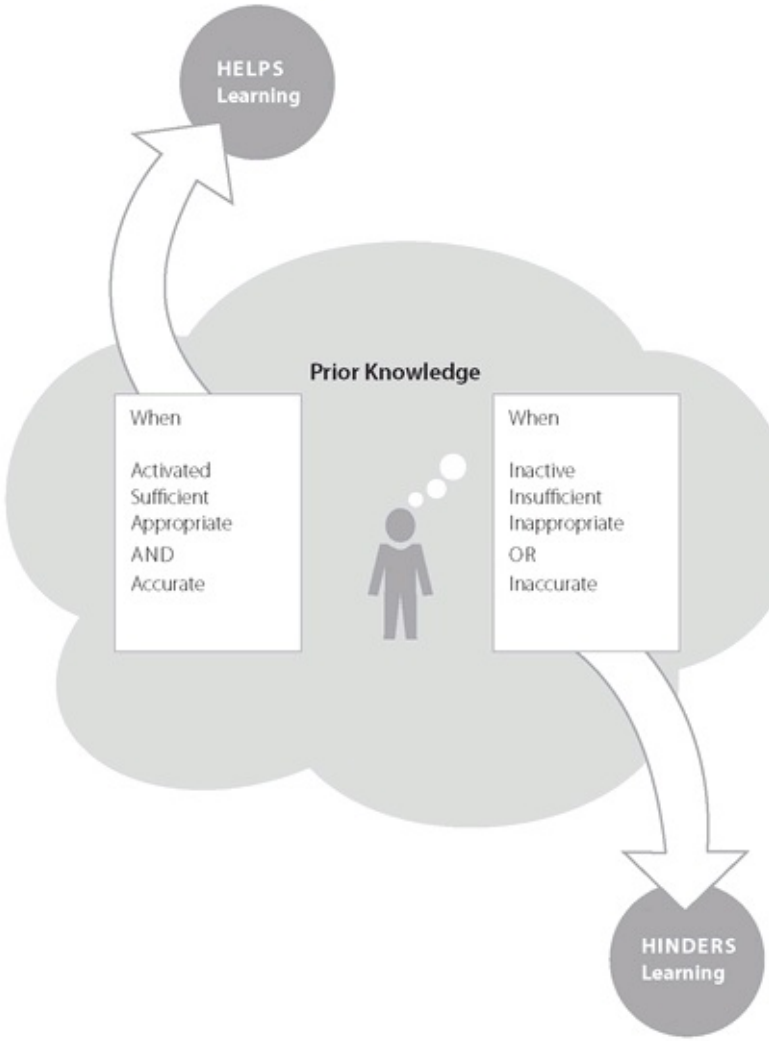
Although, as instructors, we can and should build on students' prior knowledge, it is also importa to recognize that not all prior knowledge provides an equally solid foundation for new learning.

Principle: *Students' prior knowledge can help or hinder learning.*

Students do not come into our courses as blank slates, but rather with knowledge gained in oth courses and through daily life. This knowledge consists of an amalgam of facts, concepts, model perceptions, beliefs, values, and attitudes, some of which are accurate, complete, and appropriate f the context, some of which are inaccurate, insufficient for the learning requirements of the course, simply inappropriate for the context. As students bring this knowledge to bear in our classrooms, influences how they filter and interpret incoming information.

Ideally, students build on a foundation of robust and accurate prior knowledge, forging link between previously acquired and new knowledge that help them construct increasingly complex an robust knowledge structures (see Chapter Two). However, students may not make connections t relevant prior knowledge spontaneously. If they do not draw on relevant prior knowledge—in oth words, if that knowledge is *inactive*—it may not facilitate the integration of new knowledg Moreover, if students' prior knowledge is *insufficient* for a task or learning situation, it may fail t support new knowledge, whereas if it is inappropriate for the context or *inaccurate*, it may active distort or impede new learning. This is illustrated in Figure 1.1.

Figure 1.1. Qualities of Prior Knowledge That Help or Hinder Learning



Understanding what students know—or think they know—coming into our courses can help u design our instruction more appropriately. It allows us not only to leverage their accurate knowledg more effectively to promote learning, but also to identify and fill gaps, recognize when students a applying what they know inappropriately, and actively work to correct misconceptions.

WHAT DOES THE RESEARCH TELL US ABOUT PRIOR KNOWLEDGE?

Students connect what they learn to what they already know, interpreting incoming information, an even sensory perception, through the lens of their existing knowledge, beliefs, and assumptio (Vygotsky, 1978; National Research Council, 2000). In fact, there is widespread agreement amon researchers that students *must* connect new knowledge to previous knowledge in order to lea (Bransford & Johnson, 1972; Resnick, 1983). However, the extent to which students are able to dra on prior knowledge to *effectively* construct new knowledge depends on the nature of their pri knowledge, as well as the instructor's ability to harness it. In the following sections, we discu research that investigates the effects of various kinds of prior knowledge on student learning an explore its implications for teaching.

Activating Prior Knowledge

When students can connect what they are learning to accurate and relevant prior knowledge, they lea and retain more. In essence, new knowledge "sticks" better when it has prior knowledge to stick to. one study focused on recall, for example, participants with variable knowledge of soccer we presented with scores from different soccer matches and their recall was tested. People with mo prior knowledge of soccer recalled more scores (Morris et al., 1981). Similarly, research conducted b Kole and Healy (2007) showed that college students who were presented with unfamiliar facts abo well-known individuals demonstrated twice the capacity to learn and retain those facts as studen who were presented with the same number of facts about unfamiliar individuals. Both these studi

illustrate how prior knowledge of a topic can help students integrate new information.

However, students may not spontaneously bring their prior knowledge to bear on new learnin situations (see the discussion of transfer in Chapter Four). Thus, it is important to help studen activate prior knowledge so they can build on it productively. Indeed, research suggests that eve small instructional interventions can activate students' relevant prior knowledge to positive effect. F instance, in one famous study by Gick and Holyoak (1980), college students were presented with tw problems that required them to apply the concept of convergence. The researchers found that eve when the students knew the solution to the first problem, the vast majority did not think to apply a analogous solution to the second problem. However, when the instructor suggested to students th they think about the second problem in relation to the first, 80 percent of the student participants we able to solve it. In other words, with minor prompts and simple reminders, instructors can activa relevant prior knowledge so that students draw on it more effectively (Bransford & Johnson, 197 Dooling & Lachman, 1971).

Research also suggests that asking students questions specifically designed to trigger recall can he them use prior knowledge to aid the integration and retention of new information (Woloshyn, Paivi & Pressley, 1994). For example, Martin and Pressley (1991) asked Canadian adults to read abo events that had occurred in various Canadian provinces. Prior to any instructional intervention, th researchers found that study participants often failed to use their relevant prior knowledge to logical situate events in the provinces where they occurred, and thus had difficulty remembering specif facts. However, when the researchers asked a set of "why" questions (for example, "Why woul Ontario have been the first place baseball was played?"), participants were forced to draw on the prior knowledge of Canadian history and relate it logically to the new information. The researche found that this intervention, which they called *elaborative interrogation*, improved learning an retention significantly.

Researchers have also found that if students are asked to generate relevant knowledge fro previous courses or their own lives, it can help to facilitate their integration of new material (Peec Van Den Bosch, & Kruepeling, 1982). For example, Garfield and her colleagues (Garfield, Del Mas, Chance, 2007) designed an instructional study in a college statistics course that focused on the conce of variability—a notoriously difficult concept to grasp. The instructors first collected baseline data o students' understanding of variability at the end of a traditionally taught course. The followin semester, they redesigned the course so that students were asked to generate examples of activities f their own lives that had either high or low variability, to represent them graphically, and draw on the as they reasoned about various aspects of variability. While both groups of students continued struggle with the concept, post-tests showed that students who had generated relevant prior knowledg outperformed students in the baseline class two to one.

Exercises to generate prior knowledge can be a double-edged sword, however, if the knowledg students generate is inaccurate or inappropriate for the context (Alvermann, Smith, & Readanc 1985). Problems involving inaccurate and inappropriate prior knowledge will be addressed in the ne two sections.

Implications of This Research Students learn more readily when they can connect what they a learning to what they already know. However, instructors should not assume that students wi immediately or naturally draw on relevant prior knowledge. Instead, they should deliberately activa students' prior knowledge to help them forge robust links to new knowledge.

Accurate but Insufficient Prior Knowledge

Even when students' prior knowledge is accurate and activated, it may not be sufficient to suppo subsequent learning or a desired level of performance. Indeed, when students possess some releva knowledge, it can lead both students and instructors to assume that students are better prepared tha