



**RICHARD M. FELDER**

**REBECCA BRENT**

# TEACHING AND LEARNING STEM

**A PRACTICAL GUIDE**

FOREWORD BY BARBARA OAKLEY

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# Table of Contents

[Title Page](#)

[Copyright](#)

[The Authors](#)

[Dedication](#)

[Tables, Figures, and Exhibits](#)

[Foreword](#)

[Preface](#)

[Chapter 1: Introduction to College Teaching](#)

[1.0 Welcome to the University, There's Your Office,  
Good Luck](#)

[1.1 Making Learning Happen](#)

[1.2 Learner-Centered Teaching: Definition,  
Warning, and Reassurance](#)

[1.3 What's in This Book?](#)

[1.4 How to Use the Book](#)

[Part One: Designing Courses](#)

[Interlude. What Do They Need to Know?](#)

[Chapter 2: Learning Objectives: A Foundation of  
Effective Teaching](#)

[2.0 Introduction](#)

[2.1 Writing and Using Course Learning Objectives](#)

[2.2 Bloom's Taxonomy of Educational Objectives](#)

[2.3 Addressing Course Prerequisites and Program  
Outcomes](#)

[2.4 Ideas to Take Away](#)

[2.5 Try This in Your Course](#)

[Interlude. Good Cop/Bad Cop: Embracing Contraries in Teaching](#)

[Chapter 3: Planning Courses](#)

[3.0 Introduction](#)

[3.1 Three Steps to Disaster, or, How Not to Approach Course Preparation](#)

[3.2 A Rational Approach to Course Preparation and Redesign](#)

[3.3 Choosing a Course Text or Content Delivery System](#)

[3.4 Formulating a Course Grading Policy](#)

[3.5 Writing a Syllabus](#)

[3.6 The Critical First Week](#)

[3.7 Ideas to Take Away](#)

[3.8 Try This in Your Course](#)

[Interlude. How to Write Class Session Plans \(or Anything Else\)](#)

[Chapter 4: Planning Class Sessions](#)

[4.0 Introduction](#)

[4.1 Avoid Common Planning Errors](#)

[4.2 What's in a Class Session Plan?](#)

[4.3 Promote Long-Term Memory Storage, Retrieval, and Transfer](#)

[4.4 Two Cornerstones of Effective Class Sessions](#)

[4.5 Plan Good Questions and Activities](#)

[4.6 Don't Turn Classes into Slide Shows and Verbal Avalanches](#)

[4.7 Use Handouts with Gaps](#)

[4.8 Planning Undergraduate Laboratory Courses](#)

[4.9 Ideas to Take Away](#)

#### [4.10 Try This in Your Course](#)

### [Part Two: Teaching Courses](#)

#### [Chapter 5: Elements of Effective Instruction](#)

##### [5.0 Introduction](#)

##### [5.1 Make Class Sessions Effective](#)

##### [5.2 Make Pre-Class Assignments Effective](#)

##### [5.3 Don't Be a Slave to Your Session Plans](#)

##### [5.4 Keep Improving Your Teaching](#)

##### [5.5 Ideas to Take Away](#)

##### [5.6 Try This in Your Course](#)

#### [Interlude. Meet Your Students: Aisha and Rachel](#)

#### [Chapter 6: Active Learning](#)

##### [6.0 Introduction](#)

##### [6.1 What Is Active Learning?](#)

##### [6.2 Structures and Formats of Activities](#)

##### [6.3 How Well Does Active Learning Work? Why Does It Work?](#)

##### [6.4 Active Learning for Problem Solving](#)

##### [6.5 Common Active Learning Mistakes](#)

##### [6.6 Common Active Learning Concerns](#)

##### [6.7 Active Learning in Recitations and Flipped Classrooms](#)

##### [6.8 Ideas to Take Away](#)

##### [6.9 Try This in Your Course](#)

#### [Interlude. Is Technology a Friend or Foe of Learning?](#)

##### [Scenario 1](#)

##### [Scenario 2](#)

##### [Scenario 3](#)

#### [Chapter 7: Teaching with Technology](#)

## [7.0 Introduction](#)

### [7.1 Instructional Technology Tools](#)

### [7.2 Learning Benefits of Technology](#)

### [7.3 Setting Up Communications](#)

### [7.4 Integrating Technology into Instruction](#)

### [7.5 Blended Learning and Flipped Classrooms](#)

### [7.6 Online Courses](#)

### [7.7 Ideas to Take Away](#)

### [7.8 Try This in Your Course](#)

## [Interlude. Meet Your Students: Michelle, Ryan, and Alex](#)

## [Chapter 8: Evaluating Knowledge, Skills, and Understanding](#)

### [8.0 Introduction](#)

### [8.1 Multiple-Choice and Short-Answer Questions](#)

### [8.2 Evaluating and Promoting Conceptual Understanding](#)

### [8.3 Evaluating Problem-Solving Skills](#)

### [8.4 Evaluating Reports and Presentations](#)

### [8.5 Ideas to Take Away](#)

### [8.6 Try This in Your Course](#)

## [Part Three: Facilitating Skill Development](#)

## [Interlude. Meet Your Students: Stan and Nathan](#)

## [Chapter 9: Problem-Solving Skills](#)

### [9.0 Introduction](#)

### [9.1 The Long, Steep Path from Novice to Expert](#)

### [9.2 Strategies for Teaching Expert Problem-Solving Skills](#)

### [9.3 A Structure for Complex Problem Solving](#)



[9.4 Problem-Based Learning](#)

[9.5 Ideas to Take Away](#)

[9.6 Try This in Your Course](#)

[Appendix: Steps 4 and 5 of the Waste Treatment Problem Solution](#)

[Interlude. Meet Your Students: Dave, Megan, and Roberto](#)

[Chapter 10: Professional Skills](#)

[10.0 Introduction](#)

[10.1 How Can Professional Skills Be Developed](#)

[10.2 Communication Skills](#)

[10.3 Creative Thinking Skills](#)

[10.4 Critical Thinking Skills](#)

[10.5 Self-Directed Learning Skills](#)

[10.6 Project-Based Learning](#)

[10.7 Creating a Supportive Environment for Professional Skill Development](#)

[10.8 Ideas to Take Away](#)

[10.9 Try This in Your Course](#)

[Interlude. Sermons for Grumpy Campers](#)

[Chapter 11: Teamwork Skills](#)

[11.0 Introduction](#)

[11.1 Cooperative Learning](#)

[11.2 How Should Teams Be Formed?](#)

[11.3 What Can Teams Be Asked to Do?](#)

[11.4 Turning Student Groups into High-Performance Teams](#)

[11.5 Dealing with Difficulties](#)

[11.6 Ideas to Take Away](#)

[11.7 Try This in Your Course](#)

[Chapter 12: Learner-Centered Teaching Revisited](#)

[12.0 Introduction](#)

[12.1 Aspects of Student Diversity](#)

[12.2 Inductive Teaching and Learning](#)

[12.3 Learner-Centered Teaching Strategies](#)

[12.4 Last Words](#)

[References](#)

[Index](#)

[End User License Agreement](#)

## List of Illustrations

Chapter 1: Introduction to College Teaching

[Figure 1.3-1 Elements of Learner-Centered Teaching](#)

Part One: Designing Courses

[Figure I-1 Graphic Organizer of Part I](#)

Chapter 2: Learning Objectives: A Foundation of Effective Teaching

[Figure 2.2-1 Bloom's Taxonomy of Educational Objectives—Cognitive Domain](#)

[Figure 2.3-1 Course Design in Outcomes-Based Education](#)

Chapter 4: Planning Class Sessions

[Figure Exhibit 4.7-1 Excerpt from a Handout with Gaps](#)

Part Two: Teaching Courses

[Figure II-1 Graphic Organizer of Part II](#)

## Chapter 6: Active Learning

[Figure 6.3-1 Attentiveness versus Time in Lecture—No Activities](#)

[Figure 6.3-2 Attentiveness versus Time in Lecture—Activities Interspersed](#)

## Part Three: Facilitating Skill Development

[Figure III-1 Graphic Organizer of Part III](#)

## Chapter 9: Problem-Solving Skills

[Figure 9.3-1 McMaster Problem-Solving Structure](#)

[Figure 9.3-2 Definition Step of Waste Treatment Problem Solution](#)

# List of Tables

## Chapter 3: Planning Courses

[Table 3.3-1 Questions for Evaluating a Text or Content Delivery System](#)

[Table 3.4-1 Course Grading Policy Decisions](#)

[Table 3.6-1 Learning Students' Names](#)

[Table 3.6-2 Enhancing Communication with Students](#)

## Chapter 4: Planning Class Sessions

[Table 4.1-1 Common Planning Errors and How to Avoid Them](#)

[Table 4.8-1 Skills and Learning Objectives for Instructional Laboratories](#)

## Chapter 6: Active Learning

[Table 6.1-1 Active Learning Tasks](#)



[Table 6.2-1 Active Learning Structures That Address Specific Outcomes and Skills](#)

[Table 6.5-1 Six Common Active Learning Mistakes](#)

[Table 6.6-1 Five Common Concerns about Active Learning](#)

## Chapter 7: Teaching with Technology

[Table 7.1-1 Instructional Technology Tools](#)

[Table 7.2-1 Applications of Instructional Technology That Promote Learning](#)

## Chapter 8: Evaluating Knowledge, Skills, and Understanding

[Table Exhibit 8.4-1 Grading Checklist for Written Reports](#)

[Table Exhibit 8.4-2 Grading Rubric for Lab Reports](#)

[Table 8.4-1 Using Grading Forms to Teach Report-Writing Skills](#)

## Chapter 9: Problem-Solving Skills

[Table 9.1-1 Brainwave—Expert versus Novice Problem Solving](#)

[Table 9.3-1 Questions for Reflection](#)

## Chapter 10: Professional Skills

[Table 10.1-1 Activities and Assignments That Promote Professional Skill Development](#)

[Table 10.3-1 Illustrative Creative Thinking Exercises](#)

[Table 10.3-2 Illustrative Brainstorming and Brainwriting Exercises](#)

[Table 10.4-1 Illustrative Critical Thinking Exercises](#)

[Table 10.4-2 Structured Critical Reasoning](#)

[Table Exhibit 10.4-1 Grading Checklist for Critical Evaluation](#)

[Table 10.5-1 Assignments That Promote Self-Directed and Lifelong Learning](#)

## Chapter 11: Teamwork Skills

[Table 11.2-1 Criteria for Team Formation](#)

[Table 11.4-1 Possible Management Roles on CL Teams](#)

## Chapter 12: Learner-Centered Teaching Revisited

[Table 12.2-1 Inductive Teaching Methods](#)

[Table 12.3-1 Learner-Centered Teaching Attributes and Methods](#)

# **TEACHING AND LEARNING STEM**

## **A PRACTICAL GUIDE**

Richard M. Felder  
Rebecca Brent

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**Rebecca Brent, EdD**, is president of Education Designs, Inc., a consulting firm in Cary, North Carolina. She has more than 35 years of experience in education and specializes in STEM faculty development, precollege teacher preparation, and evaluation of educational programs at precollege and college levels, and she holds a certificate in evaluation practice from the Evaluators' Institute at George Washington University. She has authored or coauthored more than 60 papers on effective teaching and faculty development, and coordinated faculty development in the NSF-sponsored SUCCEED Coalition and new faculty orientation in the Colleges of Engineering and Sciences at North Carolina State University. Prior to



entering private consulting, Dr. Brent was an associate professor of education at East Carolina University, where she won an outstanding teacher award. In 2014, she was named a Fellow of the American Society for Engineering Education.

Separately and together, Drs. Felder and Brent have presented more than 450 workshops on effective teaching, course design, mentoring and supporting new faculty members, and STEM faculty development on campuses throughout the United States and abroad. They co-directed the American Society for Engineering Education National Effective Teaching Institute from 1991 to 2015.

*We dedicate this book to Charlotte and Wilson Brent, in  
loving memory of their lives well lived.*

# Tables, Figures, and Exhibits

## Chapter 1

[Figure 1.3-1 Elements of learner-centered teaching](#)

## Part One

[Figure I-1 Graphic organizer of part I](#)

## Chapter 2

[Table 2.1-1 Illustrative learning objectives](#)

[Table 2.1-2 Illustrative study guide 1](#)

[Table 2.1-3 Illustrative study guide 2](#)

[Figure 2.2-1 Bloom's taxonomy of educational objectives — cognitive domain](#)

[Table 2.2-1 Sample learning objectives at different Bloom levels](#)

[Figure 2.3-1 Course design in outcomes-based education](#)

## Chapter 3

[Table 3.3-1 Questions for evaluating a text or content delivery system](#)

[Table 3.4-1 Course grading policy decisions](#)

[Table 3.6-1 Learning students' names](#)

[Table 3.6-2 Enhancing communication with students](#)

## Chapter 4

[Table 4.1-1 Common planning errors and how to avoid them](#)

[Exhibit 4.7-1 Excerpt from a handout with gaps](#)

[Table 4.8-1 Skills and learning objectives for instructional laboratories](#)

## **Part Two**

[Figure II-1 Graphic organizer of part II](#)

## **Chapter 6**

[Table 6.1-1 Active learning tasks](#)

[Table 6.2-1 Active learning structures that address specific outcomes and skills](#)

[Figure 6.3-1 Attentiveness versus time in lecture— no activities](#)

[Figure 6.3-2 Attentiveness versus time in lecture— activities interspersed](#)

[Table 6.5-1 Six common active learning mistakes](#)

[Table 6.6-1 Five common concerns about active learning](#)

## **Chapter 7**

[Table 7.1-1 Instructional technology tools](#)

[Table 7.2-1 Applications of instructional technology that promote learning](#)

## **Chapter 8**

[Exhibit 8.4-1 Grading checklist for written reports](#)

[Exhibit 8.4-2 Grading rubric for lab reports](#)

[Table 8.4-1 Using grading forms to teach report-writing skills](#)

## **Part Three**

[Figure III-1 Graphic organizer of part III](#)

## **Chapter 9**

[Table 9.1-1 Brainwave— expert versus novice problem solving](#)

[Figure 9.3-1 McMaster problem-solving structure](#)

[Figure 9.3-2 Definition step of waste treatment problem solution](#)

[Table 9.3-1 Questions for reflection](#)

## **Chapter 10**

[Table 10.1-1 Activities and assignments that promote professional skill development](#)

[Table 10.3-1 Illustrative creative thinking exercises](#)

[Table 10.3-2 Illustrative brainstorming and brainwriting exercises](#)

[Table 10.4-1 Illustrative critical thinking exercises](#)

[Table 10.4-2 Structured critical reasoning](#)

[Exhibit 10.4-1 Grading checklist for critical evaluation](#)

[Table 10.5-1 Assignments that promote self-directed and lifelong learning](#)

## **Chapter 11**

[Table 11.2-1 Criteria for team formation](#)

[Table 11.4-1 Possible management roles on CL teams](#)

## **Chapter 12**

[Table 12.2-1 Inductive teaching methods](#)

[Table 12.3-1 Learner-centered teaching attributes and methods](#)

## Foreword

For many university professors, teaching is like being handed the keys to a car without being taught how to drive. The result? Even experienced professors can wind up driving with their pedagogical parking brakes on. They steer forward clumsily, unaware that there's an easier way, and ignoring the smoke emerging from the tailpipe.

This book is hands-down the best instruction manual for professors in science, technology, engineering, and mathematics that you can find. Husband-and-wife team Richard Felder and Rebecca Brent write in an exceptionally clear, non-stuffy voice that makes this a book you can read even at the end of a busy day. A simple glance at the table of contents or index will rapidly take you to what you might need to find at the moment—either before or after you've read the whole book.

The book is packed with special features, which include brief interlude essays that give you a sense of what your students are thinking, succinct summaries of key practical insights from neuroscience, and concrete suggestions based on solid research and decades of experience. Everything is backed with loads of references, so you can easily explore as deeply as you choose.

Books on teaching in the STEM disciplines often center on one discipline—physics, say, or engineering. Few comprehensively encompass teaching in STEM fields ranging from biology and chemistry to theoretical mathematics. This book takes a broad-ranging approach that enables readers to pluck the best insights from a wide variety of STEM disciplines.



And it's a great thing—there's never been a stronger need for a book that lays out the foundations of good teaching at university levels in the STEM disciplines. Worldwide, STEM jobs are like mushrooms—popping up at far higher rates than many other types of jobs, yet not enough candidates for these jobs are graduating from our STEM programs. In fact, often only a small percentage of high school seniors are interested in pursuing STEM careers. Many of those students fall by the wayside as they bump against the challenges of STEM studies.

But as Richard Felder and Rebecca Brent lay out in this remarkably engaging book, there are ways to work smarter as instructors—ways to help improve students' desire and ability to master tough material. This book can help you open important career opportunities for your students, even as you help improve and increase their skills that address profound national and international needs. You will also find that releasing the parking brake of less-than-adequate teaching will make your life as a professor more fulfilling and enjoyable.

Learner-centered approaches go all the way back to the Greeks, the Buddha, and various traditions of the Far East, and have recently been taken up again in the STEM disciplines by expert teachers and researchers such as mathematician Robert Lee Moore and physicists Eric Mazur and Carl Wieman. There is a reason for the continued popularity of learner-centered teaching techniques by the best and most famous teachers—such approaches do much to stimulate student success. This book contains up-to-date practical information about how to apply these techniques in the STEM disciplines.

On a personal note, I first met Rich and Rebecca at the very beginning of my teaching career and was lucky enough to attend a workshop they taught on learner-centered

teaching, which is the pedagogical framework of their book. That workshop changed the whole focus of my teaching and enabled me to understand learning in a whole new, deeper way. You'll find that your own understanding of learning will be greatly enriched as you read this extraordinary book.

—Barbara Oakley, PhD, PE  
Professor of Engineering, Oakland University, Rochester,  
Michigan  
Visiting Scholar, University of California, San Diego

Author of *New York Times* best-selling book *A Mind for Numbers: How to Excel in Math and Science (Even If You Flunked Algebra)*, and co-instructor of *Learning How to Learn: Powerful Mental Tools to Help You Master Tough Subjects*, one of the world's largest massive open online courses, for Coursera-UC San Diego.

## Preface

Why another “how-to-teach” book, and why us as the authors? Our answers are in our stories.

(Rich's story) *When I started my academic career in chemical engineering at NC State back in prehistoric times, I had the same training in teaching that most college professors get: none. Not knowing that there were alternatives, I fell back on the only teaching model I had, which was how my professors had taught me.*

*Unfortunately, no one ever taught them how to teach either, and so for the first fifteen years of my career I did what all my colleagues did—gave nonstop lectures and tests that were always too long and drastically curved course grades so I wouldn't end up failing most of the class.*

*You could take my lecture notes to the bank. The derivations were complete and correct, my delivery was clear and occasionally entertaining, and most students left the lectures thinking they understood everything. The result was that I got high ratings and won some awards. There were just two minor hitches. After the lectures the students struggled for hours to complete assignments that involved problems similar to the ones I worked in class, and many of their exam grades were pitiful. Most who failed blamed themselves, figuring that if they couldn't do well with a teacher as clear as I was, they obviously lacked what it takes to be an engineer.*

*Most of them were wrong—a lot of the blame for their failure was mine. When I was developing and polishing those lecture notes—finding clear ways to express difficult concepts, coming up with good examples of every method I was teaching—I was really learning that stuff! The problem*

*was that I was then feeding my students predigested food. They didn't have to go through the intellectual labor of working some of it out for themselves, which meant that they never really understood it, no matter how clear it may have seemed in the lectures.*

*Most STEM professors never read education literature, and I was no exception. It was years before I learned that excellent research has been done on alternative teaching methods, some of which have been found to promote learning much better than traditional methods do. I started trying some of those alternatives and found that they worked beautifully in my courses, and I subsequently met some pedagogical experts who helped me sharpen my understanding. One of them became my professional colleague and the coauthor of this book and my wife—Rebecca Brent. (Who says educational research doesn't pay off?)*

*(Rebecca's story) I've been a teacher since my earliest preschool days spent "teaching" a neighbor child her letters, and early on I made education the focus of my career. I loved learning about how people learn and creative ways to facilitate learning. I began my professional life as an elementary school teacher, and then got my doctorate and became a teacher educator at East Carolina University. It was fascinating for me to watch my students as they first began to teach and put all the education theory I had taught them into practice on a daily basis. I also worked on a faculty team to develop training programs for people in non-academic professions who wanted to change careers and become teachers. It was then that I realized that passing along a few, well-chosen techniques could go a long way toward helping people to become effective instructors. When Rich and I began to give workshops to university STEM faculty, I found that the approach held up. We could help people understand something about how*

*their students learn, get them to think carefully about what they wanted their students to be able to do and how they could evaluate the students' ability to do it, and offer some simple ways to get students engaged in class, no matter how many of them were in the room. Some workshop attendees tried a few of our suggestions and started to see effects on their students' learning, some made major transformative changes in their courses and saw correspondingly significant impacts, and a few now give excellent teaching workshops themselves, which delights us.*

*In our workshops, we review teaching methods that have been proven effective by solid replicated research, most of which are relatively easy to implement. Our goal in this book is to share those methods and some of the supporting research with you.*

The first chapter of the book contains a short introduction to some of what educational research has revealed about effective teaching and learning, a preview of the book's contents, and some suggestions for how to use the book. The chapter is a quick read and introduces ideas we will return to periodically in the rest of the book. Following that are chapters that deal with methods for designing and implementing effective courses and helping students acquire and improve their skills at problem solving, communications, creative and critical thinking, high-performance teamwork, and self-directed learning.

There are several things we don't intend the book to be. One is a compendium of everything anyone knows about teaching. Writing something like that would take more time than we have and reading it would take more time than you have. It's also not a scholarly treatise on the theories behind the methods we have chosen to cover. Plenty of books out there review the theories and we will point you

to some of them, but our emphasis will be on nuts and bolts of the practice—what the methods are, how to implement them, and pitfalls to avoid when doing so. We'll also share findings from modern cognitive science that provide good clues about why the methods consistently work as well as they do.

The book draws extensively on journal articles we have authored or coauthored. Most notably, the interludes between chapters are almost all based on our “Random Thoughts” columns that have appeared in the quarterly journal *Chemical Engineering Education* since 1988. We are grateful to Managing Editor Lynn Heasley for granting us permission to modify and reprint the columns.

We have not been shy about asking for help, and so we have a long list of colleagues who previewed and critiqued chapter drafts, shared course materials, and provided invaluable encouragement. Rather than elaborating on what most of them did and making this preface longer than some of the chapters, we will simply express our deep thanks to David Brightman, Lisa Bullard, Jo-Ann Cohen, Marc Cubeta, Jackie Dietz, John Falconer, Stephanie Farrell, Elena Felder, Gary Felder, Kenny Felder, Mary Felder, Cindy Furse, Susan Geraghty, Jeff Joines, Milo Koretsky, Susan Lord, Misty Loughry, Nicki Monahan, Michael Moys, Mike Prince, Julie Sharp, Kimberly Tanner, Dan Teague, John Tolle, Thomas Wentworth, and Carl Zorowski.

We will, however, single out two individuals, without whom this book would not exist. From the moment she learned that we were planning a book more years ago than we care to contemplate, the superb author and educator Barbara Oakley functioned as our principal cheerleader, critic, and nudge, repeatedly and good-naturedly assuring us that the world desperately needed this book when we doubted



ourselves, red-inking our occasionally pedantic and hyperbolic prose, and gently prodding us back into action when not much from us was showing up in her in-box. Eventually things reached a point where we had to keep pushing on—we couldn't have lived with the guilt we would have felt over disappointing Barb. Words can't begin to convey our gratitude.

And words are equally inadequate to thank our editor, Maryellen Weimer, the long-time guru of *The Teaching Professor* newsletter and author of *Learner-Centered Teaching*. Having a professional icon like Maryellen working with us was somewhat intimidating—it was as if we had set out to compose a symphony and learned that Mozart would be advising us. Fortunately, besides being one of the top authorities on higher education in the world, Maryellen is also one of the finest editors and nicest human beings. She gave us a steady stream of impeccably good advice, without ever trying to impose her views or her voice on our writing, and Rich has even forgiven her for siding with Rebecca every single time the coauthors disagreed about something.

And finally, we want to thank Kenny, Joyce, Elena, Leonicia, Gary, Rosemary, Mary, Ben, Jack, Shannon, Johnny, James, and Cecelia for putting up with our frequent disappearances in the final stages of writing this book. At the top of our very long list headed by “*When we finish this &#^\*%& book, we will...*” is “*be more reliable parents and grandparents.*” We hope that by the time the thirteen of you are reading this, we will have started to keep that resolution.

Richard Felder  
Rebecca Brent

# **Chapter 1**

## **Introduction to College Teaching**

### **1.0 Welcome to the University, There's Your Office, Good Luck**

As everyone knows, skilled professionals routinely receive training before being certified to practice independently. Electricians, machinists, and chefs get preliminary instruction and then serve for months or years as apprentices. Accountants, psychologists, physicists, and physicians spend years earning degrees in their fields, and the physicians spend additional years in supervised internships and residencies. It would be unthinkable to allow people to practice a skilled profession without first being trained for it, especially if their mistakes could cause harm to others ... unless they are college faculty members.

The standard preparation for a faculty career is taking undergraduate and graduate courses in your discipline and completing a research project on a topic someone else has defined. Once you join a faculty, your orientation may consist of nothing but the heading of this section, and perhaps a half-day or a day on such things as health and retirement benefits and the importance of laboratory safety. The unstated assumption is that if you have a degree in a subject, you must know how to teach it at the college level.

Anyone who has ever been a college student knows how bad that assumption can be. What student has never had a professor who taught at a level ridiculously above anything the students had a chance of understanding, or put entire classes to sleep by droning monotonously for 50- or 75-minute stretches with no apparent awareness that there

were students in the room, or flashed PowerPoint slides at a rate no human brain could possibly keep up with?

Instructors like these unfortunately abound on college faculties. If you teach like any of them, no matter how much you know and how accurately you present it, you probably won't enjoy looking at your students' test scores or your end-of-class student ratings. Being an excellent or even just a competent teacher requires knowing many things graduate school doesn't teach, such as how to design courses and deliver them effectively; write assignments and exams that are both rigorous and fair; and deal with classroom management, advising problems, cheating, and an uncountable number of other headaches teachers routinely encounter. Figuring out all those things on your own is not trivial. Although there is something to be said for trial-and-error learning, it's not efficient—and in the case of teaching, the ones making the errors are not the ones suffering the consequences. Many new faculty members take years to learn how to teach well, and others never learn.

It doesn't have to be that way. Proven methods for teaching effectively—that is, motivating students to learn and helping them acquire the knowledge, skills, and values they will need to succeed in college and their professions—are well known. Many of those methods are not particularly hard—you can just learn what they are and then start using them. That doesn't mean they make teaching simple: teaching a course—especially for the first time—is and always will be a challenging and time-consuming task. The point is that teaching well does not have to be harder than teaching poorly. The purpose of this book is to help you learn how to teach well.

## **1.1 Making Learning Happen**

## Brainwave: What Goes on in Our Brains When We Learn?

*Learning* is shorthand for encoding and storing information in long-term memory, from which it can later be retrieved and used. According to a widely-used model of this process, new information comes in through the senses, is held for a fraction of a second in a sensory register, and is then either passed on to working memory or lost. Once in working memory, the information is processed, and after a fraction of a minute (or longer if the information is repeated), it is then either stored in long-term memory or lost.

The chances of a new sensory input getting into long-term memory vary dramatically from one input to another. The inputs most likely to make it relate to (1) *threats* to the learner's survival or well-being. In descending order, the next most likely inputs to be stored are those with (2) *strong emotional associations* for the learner; (3) *meaning* (relationship to the learner's interests, goals, prior knowledge, and past experiences); and (4) *sense* (comprehensibility).

It follows that if teachers present information irrelevant to anything students know and care about and it makes little sense to them, there should be no surprise if the students later act as if they never heard it. It never made it into their long-term memory, so for all practical purposes they *didn't* hear it. Moreover, even if information makes it into long-term memory, unless it is reinforced by rehearsal (conscious repetition), the clusters of nerve cells that collectively contain it are weakly connected and the information may not be easily retrieved.