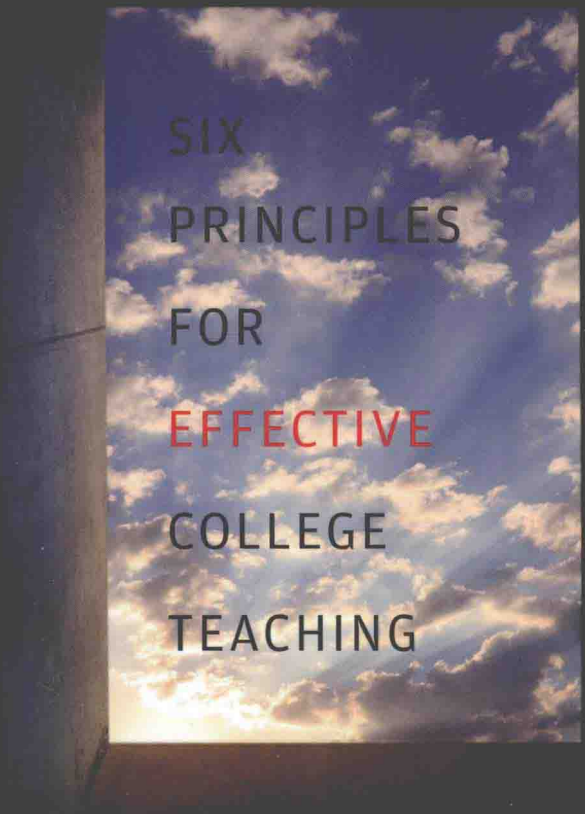
Making Scientists



Gregory Light Marina Micari

MAKING SCIENTISTS

SIX PRINCIPLES FOR EFFECTIVE COLLEGE TEACHING

Gregory Light

Marina Micari

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MAKING SCIENTISTS

To our families, colleagues, and friends
who have supported us in this project.

MAKING SCIENTISTS

Contents

	Introduction	1
1	The Gateway Science Workshop Program	9
2	Learning Deeply	36
3	Engaging Problems	60
4	Connecting Peers	92
5	Mentoring Learning	126
6	Creating Community	156
7	Doing Research	186
8	Creating Lasting Change in the STEM Classroom	214
	Epilogue	247

Notes 253
Index 283

Introduction

LIKE SCIENCE ITSELF, this book is the result of the cumulative work and research of many people over many years. From its early beginnings until the present day, the ongoing Gateway Science Workshop (GSW) and the Science Research Workshop (SRW) programs,[1] which this book describes and draws upon, have involved thousands of students, hundreds of student mentors, many dozens of science faculty, and over twenty-five program directors, coordinators, and educational researchers. And every year that number increases. Except for a number of students who became our colleagues through their dedication and work over several years, we are unable to mention by name the thousands of student participants. Nevertheless, these students constitute the very heart of this book. Their ideas, thoughts, insights, and comments resonate in its pages. They are the book.

We do at the very outset want to mention a number of people by name. They are our "coauthors." Their published and unpublished work contributes to the substance of this book, and their intellectual influence is apparent in every chapter. Without the day-to-day conversations and research collaborations we shared with them at the Searle Center, this book could not have been written. We will

inevitably leave out many critical contributions for which we apologize in advance. We are focusing here on those who provided seminal ideas and sustained long-term contributions to the project.

In the first instance we must mention the work of Larry Pinto, whose concerns and questions as a biology professor reflecting on important issues of student learning in the classroom provided the initial impetus for this program. Not only was Larry instrumental in starting and championing the program in its first years, but he has remained with the program every year—advising, advocating, and critiquing—as it expanded well beyond his own discipline. We also are indebted to Wendy Born, Ken Bain, and Dan Linzer, who worked with Larry in the early years. Wendy's doctoral work first carefully examined the program and its impact on students. In this capacity she was the first coordinator and evaluator of the program. Ken's leadership was instrumental in moving the program forward early on, and Dan has been an ever-present source of support as chair, dean, and provost.

At the risk of leaving out many colleagues who should clearly be named here, we want to acknowledge a number of key faculty who have made substantial contributions to the program over the years, both as formal and informal advisers. In addition to Ron Braeutigam, Eugene Lowe, and Steve Fisher, who have chaired our Advisory Board for more years than they want to remember, they include Martina Bode and Mike Stein in math; Debbie Brown, David Buchholz, and David Taylor in physics; Rick Gaber and John Mordacq in biology; Franz Geiger, SonBinh Nguyen, and Mark Ratner in chemistry; Steve Carr and Joe Holtgreive in engineering; and Bruce Sherin in education. Particular thanks are due to Penny Hirsch, Rick Gaber, and SonBinh Nguyen for their support in the

development and implementation of the SRW program. We would especially like to thank our three external advisers on this project: Richard Light (Harvard), Uri Treisman (Texas-Austin), and Claude Steele (Stanford). Their advice, ideas, and gentle guidance provided us with a constant source of inspiration and support.

Over the last decade the program has profited from a series of exceptional program coordinators and assistants, young professionals with a deep passion for science, education, and young people. In smooth succession, Su Swarat, Bettina Chow, Annette Munkeby, Cynthia Pederson, Carol Smith, Amy Gould, Louie Lainez, Sara Woods, and Casey Prouty have been the backbone of the program. They not only performed as the program's mission control, ensuring the day-to-day quality of nearly a hundred workshops per week, they were also at the center of the ongoing cycles of innovation and expansion for which the program became known.

Working closely with the coordinators over the years, three colleagues deserve special mention for their sustained contributions to the study of the program. Bernhard Streitwieser, Su Swarat, and Pilar Pazos have all served as leaders and lead researchers on the GSW and SRW programs. All three have spent many years at the Searle Center contributing to the development, writing, and implementation of the major projects, research grants, and research publications that underpin this book. Their work with SRW has also sparked several other innovative science education programs.

In addition we want to mention our Searle Center colleague Susanna Calkins. Her research has also contributed to this book, and her editorial input helped bring life to the decade of GSW stories. We also wish to thank Stanley Lo for his editorial suggestions and

his support in the planned expansion of the program into introductory lab sections.

Finally, we cannot overstate the exceptional contributions to the content and nature of this book by our colleague Denise Drane. Denise has been a central member of our study of the program since she was first lured into conducting "a couple of statistical analyses" during the winter holidays of 2000. As a lead researcher on the project for over ten years, she has contributed in thought, word, and deed to almost all of the innovations and studies reported in the book and has been the major force behind the assessment of the program's impact on student achievement, persistence, and experience. Her influence has been immense.

This book would not be what it is without their input.

OVERVIEW OF THE BOOK

This book presents six learning principles that have been critical to the success of the GSW program:

1. Learning Deeply
2. Engaging Problems
3. Connecting Peers
4. Mentoring Learning
5. Creating Community
6. Doing Research

These principles characterize the environments in which the best science is conducted. The book offers discussion and guidance in two related areas: (1) how to use these principles to design courses to help students learn well in STEM fields (science, technology,

engineering, and mathematics) and (2) how to develop educational STEM innovations, large or small. The book begins with an overview of the GSW program, focusing on its rationale, structure, and goals as well as its growth and resilience over the past dozen years. In this first chapter we also look at the program's extensive evaluation and the strong positive outcomes found for both grades and retention of participants. Each principle is then addressed in a single chapter, drawn from GSW program experience and supported by educational research and theory.

Chapter 2 addresses the nature of meaningful learning. We contrast "deep" with "surface" learning approaches and the ways in which students can be encouraged to move toward deep approaches. We also share GSW research project findings to shed light on the motivations and anxieties that STEM students bring to their work, and how these influence their studying. In that study students fell into one of three categories of learning, which we termed *reliance, engagement,* and *independence.* Together these categories describe a kind of journey toward thinking scientifically, from rote memorization to wanting to make sense of new ideas and concepts to a desire to map them out within the wider scientific landscape.

In Chapter 3 we focus on using problems effectively in teaching. We contrast problem-oriented approaches to teaching with more traditional approaches, with a particular focus on the structure of the problems. We share our own students' evaluation of the problems used in the GSW—and the insights those evaluations gave us into the nature of a good group problem. In their evaluations students tended to address one of three characteristics of the problem: how well it promoted their knowledge of key science concepts; how well it fostered conceptual understanding; or how well it facilitated

discussion. For each of these three characteristics, we enumerate more specific qualities that promote learning. We also highlight the importance of designing problems that challenge students to work beyond their current understanding. We end with guidelines for constructing problems.

Chapter 4 focuses on peer learning. Just as scientists work and learn collaboratively, students, we argue, should be working and learning together. We outline the characteristics of a productive learning group, and we review our own research into group dynamics in the GSW, which shows that groups with greater levels of collaboration and deeper engagement with concepts had better learning outcomes. We discuss the key features of effective learning groups, including clear goals, appropriate material, adequate support, and solid leadership. We end with a set of strategies about how to establish a group-learning program.

We focus on mentoring in Chapter 5. We review the nature of the mentoring relationship within a peer-led program, and we share a mentoring model we developed based on our research with GSW students and their peer facilitators, paying particular attention to the cognitive, behavioral, and interpersonal components of mentoring. We then describe our approach to training mentors, which takes the form of a year-long education course required of all peer facilitators in which they gain knowledge of key issues in STEM education and engage in their own group educational research project. We also present what we have learned about how peer mentors develop through the experience of mentoring, with benefits to their academic abilities, leadership skills, and career preparedness.

Chapter 6 addresses learning communities. We introduce a model of participation in which learners are considered active members