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Active Learning in College Science

The Case for Evidence-Based Practice

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Preface

> If a new antibiotic is being tested for effectiveness, its effectiveness at curing patients is compared with the best current antibiotics, and not with treatment by bloodletting. However, in undergraduate STEM education, we have the curious situation that, although more effective teaching methods have been overwhelmingly demonstrated, most STEM courses are still taught by lectures—the pedagogical equivalent of bloodletting. (Wieman 2014)

Nobel prize-winning Physicist and Stanford University Professor Carl E. Wieman succinctly summarizes the findings from a recent meta-analysis of over 200 studies that compared active learning approaches to standard lectures in college-level science courses (Freeman et al. 2014). Those studies found substantially *enhanced learning* and significantly *less failure* in courses that encourage "asking rather than telling" and "doing rather than sitting." The most successful practices were those that asked students to apply their knowledge rather than merely to absorb it. And yet in an age of instantly accessible knowledge, the majority of college science faculty continue to rely on teaching methods perfected in a medieval academy where the written word was the coveted possession of the fortunate few and where crumbs of insight were selectively dispensed to the masses in carefully measured doses.

This book is dedicated to an exploration of evidence-based practice in college science teaching. It is grounded in disciplinary education research by practicing scientists who have chosen to take Wieman's challenge seriously and to investigate claims about the efficacy of alternative strategies in college science teaching. In editing this book, we have chosen to showcase outstanding cases of exemplary practice supported by solid evidence and to give wider voice to practitioners who offer models of teaching and learning that meet the high standards of the scientific disciplines. Our intention is to let these scientists speak for themselves and to offer authentic guidance to those who seek models of excellence. Our primary audience is made up of the thousands of dedicated faculty and graduate students who teach undergraduate science at community and technical colleges, 4- year liberal arts institutions, comprehensive regional campuses, and flagship research universities.

In keeping with Wieman's challenge, our primary focus has been to uncover classroom practices that encourage and support meaningful learning and conceptual understanding in the natural sciences. Our own review of published work in the field suggests a useful way of classifying these classroom practices which provides a structural framework for this book. Following an *introduction* based on constructivist learning theory (Part I), the practices we explore are *Eliciting Ideas and Encouraging Reflection* (Part II), *Using Clickers to Engage Students* (Part III), *Supporting Peer Interaction with Small Group Activities* (Part IV); *Restructuring Curriculum and Instruction* (Part V), *Rethinking the Physical Environment* (Part VI), *Enhancing Understanding with Technology* (Part VII), and *Assessing Understanding* (Part VIII). The final part (IX) of the book is devoted to *professional issues* facing college and university faculty who choose to adopt active learning in their courses.

The common feature underlying all of the strategies described in this book is their emphasis on actively engaging students who seek to make sense of natural objects and events. Many of the strategies we highlight emerge from a constructivist view of learning that has gained widespread acceptance in recent years (Mintzes et al. 2005a, b). To constructivists, learners make sense of the world by forging connections between new ideas and those that are part of their existing knowledge base. For most students, that knowledge base is riddled with a host of naïve ideas, misconceptions, and alternative conceptions they have acquired throughout their lives. In large part, the job of the teacher is to elicit these ideas, to help students understand how their ideas differ from the scientifically accepted view, to assist as students restructure and reconcile their newly acquired knowledge, and to provide opportunities for students to evaluate what they have learned and apply it in novel circumstances. Clearly, this prescription demands far more than most college and university scientists have been prepared for.

The authors of this book are a diverse group of scientists who have experienced frustration with conventional practices and in turn have chosen to implement active learning strategies in their classrooms on an experimental basis. Many of them have extensive preparation in their discipline (e.g., biology, chemistry, earth and space sciences, physics) but little formal training in pedagogy or learning theory beyond the traditional graduate teaching assistantship. Here, they share the hard-won insights they have gained through daily practice and the results of well-designed studies to document their effectiveness. The chapters they write are authentic, first-hand accounts of instructional and curricular innovation supported by thousands of studies published in a range of widely read sources, including *Journal of College Science Teaching*, *CBE—Life Sciences Education*, *Journal of Chemical Education*, *Journal of Geoscience Education*, *American Journal of Physics*, and others.

But why would a college or university scientist read this book? Although many college and university faculty claim familiarity with one or more active learning strategies (e.g., clickers), few are conversant with the wide range of potential techniques, and fewer yet have implemented even one. Many reasons have been given for this failure (e.g., "I am a great lecturer. Why should I change?"), but one enduring obstacle is that adopting active learning strategies involves *risk*: risk of losing control, risk from lacking the needed skills to succeed, risk of being out of step with colleagues, and risk that students will reject the approach or fail to perform at expected levels. This book provides models of innovation by credible colleagues from a wide range of scientific disciplines who offer advice, support, and tangible evidence that active learning works and that it can be implemented with reasonable success and acceptable risk.

In this book, we bring together in one place the best advice by the most authoritative voices in this rapidly emerging enterprise. For the first time, this book offers strong, evidence-based work on active learning practices from across disparate scientific disciplines in a single volume that speaks to the common concerns of all college science faculty. We purposefully eschew much educational jargon and complex statistical treatment (which obfuscate rather than illuminate) in favor of a common sense-scientific approach that appeals to a skeptical but open-minded reader. Our hope is that the readers will choose to try some of the strategies described in these pages and to investigate their effectiveness. We invite and encourage the readers to share their experiences with us (*sciencelearningassociates@gmail.com; ewalter@csufresno.edu*).

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30 Active Learning Concepts

This list defines several commonly used concepts encountered in the discussion of active learning in college science. It is followed by a figure that guides the reader to specific chapters addressing each of these concepts within several scientific disciplines.

Active Learning: A model of instruction that encourages meaningful learning and knowledge construction through collaborative activities that support thinking and doing; "hands-on, minds-on teaching"

Assessment: Tools or methods used to evaluate, measure, and document the outcomes of instruction; may be formative (low stakes, in-course) or summative (high stakes, end-of-course)

Augmented Reality: An interactive computer-enhanced depiction of real-world objects or events which may include pictures, sounds, or texts; superimposing or overlaying real objects with digital information

Clicker: A hand-held device used by students to respond to questions posed by an instructor; responses are recorded and tallied by a combination of software and hardware to display visual feedback

Collaborative Learning: A generic umbrella term to describe any of a number of instructional approaches in which small groups of students work together to solve a problem, complete a task, or create a product

Concept Mapping: A technique for creating two-dimensional, hierarchical, node-link diagrams depicting the most important concepts and relationships in a knowledge domain

Constructivism: An epistemological position based on the idea that learning is a product of "mental construction"; learners construct their own understanding by relating new knowledge with what they already know; may include radical, cognitive, and/or social elements

Cooperative Learning: A form of collaborative learning in which teams are composed of students of heterogeneous ability; an instructor typically assigns a structured activity, and individuals are accountable for their own work and that of the group as a whole

CURE (course-based undergraduate research experiences)**:** Laboratory-based investigations that engage a whole class of students in addressing a research question of interest to the scientific community through asking and answering scientific questions, analyzing relevant data, and making and defending arguments.

Engagement: The extent to which students express interest, curiosity, attention, and/or passion when involved in a learning episode

Error Discovery Learning: A Web-based active learning method that engages students in solving fast challenge problems through their own thinking and then assessing competing conceptual arguments and identifying specific conceptual errors

Evidence-Based Practices: Instructional practices that are guided by research findings, as opposed to intuition, unsubstantiated beliefs, common experience, or personal preference

Flipped Instruction: An instructional strategy that reverses the traditional classroom environment by introducing concepts outside of the classroom in the form of readings, videos, and/or computer-enhanced methods and moving traditional homework into the classroom often engaging collaborative activities

Gamification: An instructional approach that seeks to motivate students by using video game design and game elements in learning environments with the goal to engage learners by capturing their interest and inspiring them to continue learning

Meaningful vs. Rote Learning: In meaningful learning, new concepts are linked to existing concepts in the learner's knowledge structure, whereas in rote learning, new concepts are stored in a verbatim, non-substantive, and arbitrary way in cognitive structure (D.P. Ausubel); understanding vs. memorizing

Metacognition: Awareness, understanding, and control of one's own thinking or learning processes; executive control; thinking about thinking, learning about learning

MOOC (massive open online course)**:** A Web-based course with unlimited participation that is openly accessible to all who wish to enroll and often tuition-free

Online Learning: Instruction that is mediated by the Internet; interactions between students and instructor may be synchronous (live) or asynchronous (recorded) and may be enhanced with a wide range of instructional materials

Peer-Led Team Learning: A complement to the lecture and an alternative to the traditional recitation section, replacing it with a *team* of students who collaborate to develop their problem-solving skills and conceptual understanding by working on faculty-developed exercises and featuring an undergraduate leader who is strategically trained for his or her role

Problem-Based Learning: An instructional strategy in which small teams of students attempt to understand a messy, real-life, authentic problem, activating prior knowledge, generating and testing hypotheses, defining learning objectives, researching necessary information or data, finding solutions, reporting, and reflecting on their own learning

Project-Based Learning: Similar to problem-based learning but students working as a team are given a "driving question" to answer and are then directed to create an artifact to present their knowledge. Artifacts may include a variety of media such as writings, art, drawings, three-dimensional representations, videos, photography, or technology-based presentations.

Reflective Writing: A metacognitive strategy in which students consciously think about and analyze a concept and record the changes in their thinking about it. It may involve critically evaluating an experience and linking it with what has been learned from coursework.

Resistance: Refusal to accept or comply with a novel instructional approach; opposition or aversion to the instructor's efforts

Self-Efficacy: Beliefs about one's ability to perform a task or engage in a process; self-confidence

Social Media: Types of Internet-based communication in which the users create online communities to share information, ideas, personal messages, and other content; examples are Facebook, Twitter, and blogs

Studio Classrooms: Flexible learning spaces that replace conventional lecture halls and teaching laboratories that are equipped with multiple projection screens, white boards, one or more overhead projectors, round tables that seat small groups of student collaborators, and technology and scientific equipment available for student use

Team-Based Learning: A structured system of collaborative engagement characterized by individual pre-work, readiness testing, clarification sessions, application exercises, and peer evaluation

3D Printing: The process of making a physical object from a three-dimensional digital model, typically by laying down many thin layers of a material in succession

Video Vignettes: Web-based assignments that combine online video with video analysis and interactivity, each addressing a known learning difficulty informed by discipline-based education research; invites students to make predictions, perform observations, and draw conclusions about a single phenomenon

Virtual Learning: Enhancements that offer Web-based presentation of resources, activities, and interactions within a course structure and provide for different stages of assessment and/or report on participation; may have some integration with other instructional components