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ABCS OF EDUCATION AND PROFESSIONAL DEVELOPMENT IN ANALYTICAL SCIENCE

A new resource to help instructors incorporate active learning into analytical chemistry courses

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Active learning involves instructional techniques that engage students in the learning process. In contrast to lecture-based classes and laboratory experiments where students are given specific recipes to follow, active learning usually involves small-group work on problems in the classroom and longer term projects in the lab where students work in teams to design and execute experiments.

There are many reasons why instructors should use an active learning approach. Findings from cognitive research on how people learn show that more is learned by doing something than simply watching or listening [1–6]. Studies on lecturing show that many people do not have the attributes needed to learn effectively in a lecture setting [7–9]. Other studies show that student achievement and retention improve when active learning is used [10–16]. There is great interest today in creating inclusive classroom environments where all students feel valued and perform to their potential. Engaging students with the material, their classmates, and their instructors has the potential to create more inclusive teaching environments [17–23]. Finally, active learning can promote learning outcomes that are more difficult to achieve with traditional instructional approaches, such as problem solving and critical thinking [7, 24].

We wish to describe a new book titled *Active Learning in the Analytical Chemistry Curriculum* that will help instructors implement the effective use of active learning in their courses [25]. The book is the outcome of a long-term curriculum project that first involved the development of active learning materials and then included a series of workshops aimed at promoting the use of active learning by instructors of analytical chemistry courses [26–28]. The book is designed to help overcome the barriers that inhibit many instructors from using active learning and to cultivate their creativity by providing a wide range of examples of active learning in analytical chemistry. Most of the authors are from US institutions, but the activities and methods used for facilitation and assessment are applicable worldwide. The table of contents of the book is provided in Table 1, and the text below illustrates some ways in which the book's contents may address common instructor concerns and challenges.

I've heard about the benefits of active learning, but I'm not sure how my students, my departmental colleagues, or my institution will respond.

The first chapter of the book discusses the reasons why instructors should use active learning in their courses, providing additional detail and references for the outcomes related to improved student learning, problem solving, and inclusivity as discussed above. This information is not only useful to instructors who may choose to adopt active learning, but also to share with students, colleagues, and administrators to generate buy-in. Chapter 16 further discusses strategies for helping instructors sustain their transformation to active pedagogies, which will be relevant to anyone interested in curricular reform in their own classes or planning professional development activities aimed at promoting the use of active learning by instructors.

I want to try active learning, but I don't know where to start.

One common barrier to the use of active learning has involved a dearth of classroom and laboratory materials to support such instructional approaches. The Active Learning site of the Analytical Sciences Digital Library (ASDL) has been built as a repository

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Table 1 Table of contents for *Active Learning in the Analytical Chemistry Curriculum*

Chapter	Title
1	Why Use Active Learning
2	Getting Started on Active Learning
3	Flipped Learning in the Analytical Chemistry Classroom
4	Active Learning at a Community College
5	Active Learning in Graduate Analytical Chemistry Courses
6	Analytical Chemistry in Context
7	Use of Primary Literature in the Classroom: Quantitative and Instrumental Analysis Topics
8	The Use of Simulations with Active Learning Exercises
9	Hands-on Class Activities as a Way of Enhancing Breadth of Instrumental Methods
10	Supporting Student Inquiry and Engagement in the Analytical Lab: Pilot Studies from Three Institutions
11	Active Learning Exercises Involving Building and Design
12	Field-based Analytical Chemistry Laboratory Experiences Performed in Collaboration with Government Agencies and in the Context of a Study Abroad Program
13	Multi-week Lab Projects Incorporate Breadth and Depth into Analytical Chemistry Laboratory Courses
14	Semester-long Projects in the Analytical Chemistry Laboratory Curriculum
15	Alternative Assessment of Active Learning
16	Sustaining the Adoption of Active Learning

for active learning materials developed specifically for teaching analytical chemistry [29]. These materials cover almost any topic that might be included in an undergraduate analytical chemistry course, including statistics and figures of merit, spectroscopy, separations, mass spectrometry, electrochemistry, and other techniques. Materials are freely available under the Creative Commons license and in editable form so instructors can use them as is or modify them to suit the specific needs of their courses. Many of the activities discussed in the book are available on the ASDL site.

A second common barrier is that many instructors do not have experience in effectively facilitating an active learning environment. Many students mistakenly believe that they learn better in a lecture than when they engage with the material [30], so students may respond negatively to ineffectively facilitated active learning. The book's second chapter discusses strategies for how to get started with active learning. This includes ways to increase student engagement in classes, research on how to best sort students into groups, how to effectively facilitate active learning to promote inclusion of all students, and aspects of how to assess active learning approaches. This chapter also includes a description of how an instructor used ASDL resources to facilitate the use of active learning in her courses. Other chapters in the volume also provide information on how to effectively facilitate the activities that are discussed.

I'm not sure active learning will work for me / my course / my students.

Throughout the book, readers will find information on the effective facilitation of active learning in a variety of classroom settings along with strategies for effective assessment. The book is authored by 39 instructors who share activities implemented at Ph.D.-granting, 4-year public and private, community college, historically Black, and Hispanic-serving institutions serving a wide range of student populations. Chapter 4 describes the use of active learning in the classroom and laboratory at a community college—community colleges in the USA offer 2-year associate degrees. Chapter 5 describes the use of active learning in graduate courses at three different Ph.D.-granting institutions. These involve courses on electrochemistry, mass spectrometry and microfluidics.

I've been teaching more with technology during the pandemic. How does educational technology fit into active learning?

Active learning doesn't have to be high tech. It might begin with simple activities like "think pair share" and guided worksheets. However, educational technology can provide important supports to active learning. For example, Chapter 3 in the book describes two authors' approaches to a "flipped" classroom, where students watch videos of lecture material prior to class and spend classroom time working in small groups on conceptual and quantitative problems. The discussion addresses key facets of video design as well as classroom activities and facilitation that are needed in a flipped approach. In addition to recorded video, lab simulations have become a more common educational tool during the pandemic and will continue to play a role in chemistry education even as we transition back to in-person laboratories. Simulations offer several advantages such as faster exploration of variables than possible with the actual method, multiple risk-free trials with instant feedback, and experience with the capabilities of an instrumental method unavailable in the laboratory portion of the course. Simulations can also better prepare students for upcoming laboratory experiments or reinforce concepts covered in the classroom. Chapter 8 describes four different approaches that achieve these goals using simulations of acid-base titrations, signal processing, cyclic voltammetry, and high-performance liquid chromatography.

How does active learning look in the laboratory? Aren't all lab activities active learning?

While students actively construct knowledge in the laboratory, more open-ended projects are better at developing students' higher order thinking skills than "cookbook" style labs that provide students with step-by-step instructions to follow [31–34]. That said, there are many ways to structure active learning laboratory activities, and five chapters focus on this topic. Chapter 10 describes a multi-institution approach to inquiry-based labs where many of the lab activities use paper microfluidic devices. Chapter 11 describes three different approaches involving design and building of various aspects of analytical science including 3D printed volumetric containers, spectrophotometers, and models of instrumentation that demonstrate underlying principles. Chapter 12 describes two approaches to the use of field-based work involving community partners. One involves collaborations with local federal or state governmental agencies and the other occurs in the context of a study abroad course that takes place in Costa Rica. Chapter 13 describes four different approaches that incorporate multi-week projects. Traditional experiments are used at the start of the term to help students build skills while a team-based project at the end of the term provides a more in-depth exploration and opportunities for students to develop problem solving and communication skills. General guidance on the implementation of multi-week projects is provided along with descriptions of projects utilizing a range of instrumental methods and quality control topics. Chapter 14 describes three different approaches to the use of semester-long laboratory projects. In one approach, students work in groups to develop methods for the analysis of different components of a common sample. Groups then circulate through the methods developed by others in the course. The second describes chromatography projects from an undergraduate separation science course. The third describes the implementation of a course-based undergraduate research experience on the analysis of phenolic compounds and antioxidants in plants. In the latter case, course projects have led to new avenues of inquiry in the author's research lab and resulted in one peer-reviewed research publication to date.

Some instructors worry that project-based laboratories may not expose students to as wide a range of instrumentation as the more traditional "technique of the week" format. However, the depth that students develop in a smaller number of techniques is itself a counterargument to this concern. Chapter 9 also describes two approaches where hands-on class activities are used to enhance the breadth of instrumental methods in courses where students conduct a single semester-long lab project.

I've been using some active learning methods, but I want to expand, update, and/or evaluate my classroom activities.

The book has several chapters on new activities that will interest even seasoned instructors. Chapter 6 describes four different approaches to teaching analytical chemistry in the context of real-world issues. Activities are incorporated into the classroom and/or laboratory of quantitative analysis, instrumental analysis, and advanced environmental chemistry courses. All activities incorporate the use of primary literature. Examples of activities include one that shows the presence of racial bias in pulse oximetry measurements, a series aimed at developing analytical method development skills, and the use of case studies to promote scientific literacy and communication. Chapter 7 describes two different approaches for incorporating primary literature into the classroom component of a course. One involves an advanced course on chemical equilibrium; the other is in an instrumental analysis course. Students read multiple articles over the semester, and each discussion is facilitated by a team of students who design an active learning worksheet.

One benefit of active learning is that this pedagogy helps students to develop important process skills, such as competence in problem solving, use of the chemical literature, written and oral communication, teamwork, and ethics. These skills have been identified as key outcomes by the American Chemical Society Guidelines for a certified bachelor's degree [35], but process skills tend to be harder to assess than content knowledge. While chapters 2-14 all include information about how the authors assess student learning, in Chapter 15, three authors focus on ways they assess problem solving, information processing, and critical thinking. Assessment of the process skills that are developed by active learning should involve strategies other than traditional exams and laboratory experiments. In Chapter 15, the authors describe several ways to do this through the use of a *Consumer Report*-like rating system for comparing analytical methods, the incorporation of a group component into exams, and specifications or mastery grading.

In summary, we hope this book provides information and resources to inspire instructors who do not yet use active learning methods to do so. We also believe it offers many examples and insights that will benefit instructors who are already practitioners of active learning. Readers are encouraged to contact chapter authors for additional insights about the use and facilitation of exercises that are described in the book.

Declarations

Conflict of interest The authors declare no competing interests.

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