Assessment of Chemistry

THE ASSOCIATION FOR INSTITUTIONAL RESEARCH

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FOREWORD

This volume is the fifth in a series sponsored by the Association for Institutional Research (AIR) focused on assessment in the disciplines. The first year was dedicated to employing assessment in the teaching of business, the second year to the teaching of mathematics and related fields, the third year to the best practices for assessment of engineering, and the fourth year to assessment of writing. The next volume will focus on assessment of arts- and design-related fields of study.

Each of the volumes in this series has reflected both the culture of the profession and the personalities of the authors and editors, as might be expected, and this one is certainly no exception. One can detect in the following pages some of the struggles of the chemistry professoriate as it has grappled with, for example, the difficulties of teaching both its own majors and large numbers of nonmajors such as engineering and premedical and other biology-related students in lower division courses. At the same time, one can also see some of the pedagogical solutions that have been adopted and proven to be successful through creative use of disciplinary and interdisciplinary adaptation.

Of special note in this volume should be the fact that the editors are from three divisions of one university: John Ryan, the lead editor, is an institutional researcher working in the assessment arena; Ted Clark is a chemist; and Alexis Collier is a psychologist. Likewise many of the chapters, though written by chemists or chemistry educators, have contributions from other learning experts also. This richness of interdisciplinary interaction among the contributors helps make this volume stand out from others in the field. As a result, the lessons learned from it can be applied immediately.

Thanks to the Publications Committee of AIR for its continued support of this series and for all of the staff in the Executive Office who have provided assistance in producing it. Volumes such as this are a large team effort; much of the team goes unrecognized.

John A. Muffo
John A. Muffo and Associates, Inc.

EDITORS' PROFILES

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and

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John Ryan is the Director of Assessment for the College of Education and Human Ecology at Ohio State University. His prior experience includes serving as an Assistant Provost and Associate Director of Institutional Research and Planning at Ohio State University as well as roles in student affairs and as a budget/policy analyst for the Ohio Legislative Budget Office. His publications and areas of interest focus on higher education policy and administration, student learning and persistence, and innovative approaches to improved data analysis and decision-support in colleges and universities. He also serves as a member of the Association for Institutional Research Publication Committee and as a member of the editorial board for the Enrollment Management Journal. He received his B.A. in political science with honors from Ohio State, his master's degree in political science from Ohio State, and his Ph.D. in higher education administration from the University of Nebraska-Lincoln.

Ted Clark is an Assistant Professor in the Chemistry Department at Ohio State University and Associate Director of the Ohio Consortium for Undergraduate Research-Research Experiences to Enhance Learning (OCUR-REEL) program. He earned his Ph.D. from the University of Michigan in the area of solid-state inorganic chemistry, completed a postdoctoral research position in the area of solid-state nuclear magnetic resonance spectroscopy at Ohio State, and has taught undergraduate general, analytical, and physical chemistry courses for more than a dozen years. Currently, he is involved in course and curricular development, environmental chemistry research, and the integration of technology in chemistry courses. An overarching theme of these interests is the inclusion of authentic in-class research experiences in undergraduate courses and an assessment of such experiences.

Alexis Collier is an Associate Provost and Associate Professor of Psychology at Ohio State University and has taught both graduate and undergraduate courses, including those designed to promote student development of independent research proposals and projects in integrative honors and laboratory courses. She coordinated the department's General Psychology 100 Instructional Program for 15 years and also received the OSU Department of Psychology Distinguished Teaching Award in 2000. Her research has been in the areas of learning, motivation, and memory with an integrating theme of age-dependent considerations in assessing cognitive and memorial processes. She has served as a grant review panel member for the National Institute of Mental Health and as consulting editor for the American Psychological Association's Journal Supplement Abstract Service. Dr. Collier served as a Provost Faculty Fellow in 1998–1999 and coordinated assessment across the Colleges of the Arts and Sciences during 2004–2007. She currently coordinates outcomes assessment activities university-wide as part of ongoing institutional initiatives to enhance the teaching and learning environment. She received her B.S. in psychology with distinction from Virginia Tech in 1973, and her Ph.D. in experimental psychology from the University of Washington in 1976, specializing in learning and motivation.

CHAPTER 1

ASSESSMENT AS A STRATEGY TO ENHANCE 21ST CENTURY CHEMISTRY EDUCATION

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In tandem with mathematics and other scientific fields of study, chemistry arguably represents one of the most challenging areas of study for students in higher education. In addition to its own inherent value as a discipline and a professional field, chemistry also serves as an important prerequisite to many "STEMM" (science, technology, engineering, mathematics, and medicine) programs and careers. The extent to which students have an interest in chemistry and are successful in developing the knowledge, skills, and affective dispositions and habits that lead to academic success in chemistry courses and programs, the greater both private and public returns on investments in chemistry education will be.

Beyond the provision of additional resources, innovations in chemistry teaching and learning are an essential component of a comprehensive strategy to enhance interest, skills, knowledge and performance in STEMM fields. Among these innovations, assessment represents one of the most important strategies that educators and postsecondary institutions can leverage to enhance the quality and quantity of chemistry knowledge and skills. The application of the scientific method, as well as action research and inquiry—skills that colleges and universities also seek to develop in their students—to the evaluation and assessment of instructional practices, experiences, and learning outcomes in chemistry provides a familiar approach for chemistry faculty, instructors, and programs. This approach to the assessment of student learning and success in chemistry can serve as a means to enhance student learning as well as program effectiveness and impact. In times of budget cuts and fiscal uncertainty, assessment and curricular innovations that address both learning and cost issues in delivering chemistry courses may possess an even stronger appeal for chemistry programs and their stakeholders.

Given the current economic and educational circumstances facing the United States, the contributions to this volume are apropos and timely. The authors, all faculty members and instructors in chemistry, provide a broad range of experiences, approaches, findings, and lessons learned—all from a disciplinary perspective. They also represent a diverse set of institutional contexts within which assessment must occur in order to improve student learning and academic achievement in chemistry. These contexts include public, private, two-year, four-year, research extensive, undergraduate-focused, and liberal arts-oriented colleges and universities.

Beyond the array of perspectives by institutional type, the chapters also represent programs and faculty at different stages of assessment development that reflect

different rationales for conducting assessment, including a recognition of poor student performance, high student attrition, and concern with access and opportunity among under-represented student populations. The chapters capture faculty and programs at various stages in the evolution of a culture of assessment and present diverse perspectives on topics such as the role of common, standardized assessments in chemistry, the role of locally developed instruments, issues of assessment research design, and the need to assess both content and affective dimensions of learning and development. In addition, they represent a range of perspectives and strategies employed based on student population, including a view of practices in high school chemistry assessment, a key component of the chemistry pipeline linking K-12 and postsecondary sectors.

In the midst of the diverse array of ideas and perspectives offered in this volume, all chapters are united by two primary motives—to enhance their students' learning and success in chemistry and, in turn, to share helpful insights and lessons with other chemistry faculty across the country that will assist them in doing the same. Each contributor supports the primary goal of this volume to provide detailed presentations and analyses of real cases that can be adapted in a variety of contexts to enhance the impact of chemistry instructors and faculty on their students' learning and to increase our collective understanding of how students "learn chemistry" and how assessment can be employed as a strategy to make substantive improvements in instruction and outcomes.

In Chapter 2, Ted Clark discusses important innovations taking place in an introductory chemistry instruction via research experiences at a large, public research university and in the Ohio Consortium for Undergraduate Research: Research Experiences to Enhance Learning (OCUR-REEL) program. Clark's experience with the program and his approach to assessing the impact of it have produced some important insights regarding how students view their chemistry learning experience as well as the impact of embedding research experiences within an introductory course. Based on the assessment evidence, developing and offering a research immersion experience earlier in a student's postsecondary chemistry experience rather than later may provide a fairly intuitive, "organic" strategy for enhancing student interest in chemistry, shatter myths about scientific inquiry and work, and encourage more students to continue their journey in chemistry education.

Roehrig, Kern, Wood, and Nyachwaya focus their attention on the use of an "equation drawing task" as a formative assessment of the depth of students' understanding of ideas and concepts in chemistry in Chapter 3. However, the population of interest is not college students. Their chapter shares what they have learned based on experiences with high school students—a critical segment of the STEMM pipeline whose current experiences and learning in chemistry will play a large role in shaping their future success and interest in these fields.

In Chapter 4, Kinder and Johnson share their experiences in developing course-based assessments for an introductory chemistry course at a regional campus that is part of a larger research university. The study focuses on supporting and improving student learning via evidence-based course redesign and instructor development. Four assessment tools were specifically developed to collect data and were designed

to be used inside the university's online course management system. The assessment tools, even as they continue to be enhanced and tested, have helped shed light on whether or not the course achieves established learning goals for its students. Their experiences and recommendations also provide an important perspective for those whose primary course audience comprises non-science majors.

Turning to the community college sector as another important part of the STEMM pipeline, in Chapter 5, Carver, Brothers, and Higgins describe the use of multiple assessments utilized during the STEM-ENGINES Undergraduate Research Collaborative, an NSF-funded Undergraduate Research Collaborative (URC) that focuses on the experiences of students at two-year community colleges. Students participated in research experiences during the academic year, with half of them continuing to do research at a four-year college or university during the summer. The authors describe the project and the use of assessment instruments that focus on student learning of chemistry content and process skills, emotional intelligence, and potential pursuit of STEM careers. In addition, the project evaluation design creates opportunities to gauge the impact of these experiences have on those who start their postsecondary education at a community college.

Hearne and her colleagues offer, in Chapter 6, an important perspective on chemistry assessment from the point of view of teaching at an institution that serves under-represented students. As part of the National Center of Academic Transformation's Course Redesign Initiative, the authors employed a "replacement model" to redesign a course where there was broad variation in the base knowledge of incoming students, a 55% student persistence rate into the second part of the freshman chemistry sequence, and a lack of coordination among the faculty members teaching the course, leading to course drift and inconsistent learning outcomes. Their redesign and assessment strategy provides some important ideas for others in the process of attempting comprehensive instructional reform with assessment as a key strategy to assess impact.

Turning to the impact of teaching strategies, in Chapter 7, Loertscher details an NSF-funded project to explore the impact of active learning techniques in biochemistry courses taught at a private university. Over time, the use of assessment as a tool to enhance learning and improve instruction has moved from a less formal approach to one that is more systematic and rigorous. Starting with data collected from student examinations and student self-reports, the project now is moving to a pretest/posttest design to assess impact. This experience could serve as a model to inform efforts at other institutions to enhance student learning in biochemistry, particularly when attempting to make a transition from initial assessment activity to the practice of a scholarship of teaching and learning

In Chapter 8, extending the range of study on active learning, O'Sullivan and Copper provide a case study from their experiences teaching general chemistry at one of the nation's military academies. They examined the performance of more than 5,000 students over five years, comparing group work and active learning exercises to lecture-based approaches to instruction. Using a number of metrics, their findings suggest a positive effect on students who were part of an active learning

environment in general chemistry. As the positive results became known to others in the department, more faculty members became interested in joining the project, offering important insights into how assessment strategies and innovations might be replicated and adopted throughout a department over time.

Pienta provides two case studies in Chapter 9 that represent different motivations for the desire to document or measure the knowledge, skills, and attitudes of chemistry students via changes at the course level and at the curriculum level in anticipation of reaccreditation and based on theory-driven plans and first principles, representing a phenomenological approach. The first example documents the process by which a traditional, large enrollment introductory-chemistry sequence underwent changes to address student dissatisfaction, unacceptable success levels, and demands from other programs that used these courses to fulfill their degree requirements. Demonstrating success required both qualitative and quantitative measures, the latter apropos to the discerning scrutiny of a faculty group made up of scientists. The outcome of the redesign was measureable, sustained, and transformative—student satisfaction and success increased as did the approval of constituencies who required the courses. The assessment plan for chemistry's undergraduate curriculum was motivated by an institutional reaccreditation, potential changes required for degree accreditation by chemistry's professional organization, and the turnover of a substantial number of faculty in the department. Each of those factors provided different timelines, motivation, and expectations. Originally skeptical of the need for a curricular assessment, the faculty eventually accepted its desirability. The success in the course redesign aided in the buy-in of the latter venture, and the faculty ultimately produced an exemplary model.

Kahle, Scantlebury, Woodruff, and Li discuss the evaluation of two large-scale projects to reform first- and second-year chemistry courses in Chapter 10. The projects, funded by the National Science Foundation under its Undergraduate Research Center program, focused on providing students with authentic research experiences in undergraduate chemistry courses with the goal of increasing both the number and the diversity of undergraduates electing to continue to study chemistry. Both projects chose to change the nature of their introductory courses through modules that included cutting-edge research and real-life applications of chemistry as well as multiple partners across a variety of institutions (research universities, two- and four-year colleges and universities, public and private institutions). The partnerships provided unique challenges (availability of equipment on some campuses, institutional support, timely reporting) as well as opportunities (replication of modules, cross-institutional research). Their findings suggest future directions for improving undergraduate chemistry courses as well as for evaluating large-scale, multisite projects, including implications for female students, students who planned on professional careers, and students of various ethnic/racial groups. The advantages of multisite projects are considered, and recommendations for more longitudinal designs are offered in chemistry outcomes assessment.

In the concluding chapter, Coppola shares his perspectives on his chemistry department's decision to eliminate the traditional two-semester general chemistry sequence and to allow students with some background in chemistry to take an organic

chemistry course. From the start, the development of this course was based on sound pedagogical principles and contemporary instructional strategies. Over 20 years and roughly 50,000 students, the department has continued to evolve the course in both content and method and has carried out substantive research on student learning that has informed practice. Coppola traces the development of the course and describes in detail three cases of alignment of explicitly identified learning goals, pedagogical approaches to achieving those goals, and the methods used to assess our outcomes, including higher level learning goals. Beyond quasi-experimental designs that attempt to identify group differences based on instructional interventions and student performance, Coppola brings us back to the discipline itself and the critical role faculty members must play in developing criterion-based assessments of student learning and progress that go beyond comparative, norm-referenced criteria.

Putting chemistry education into a larger context, the United States finds itself at a historic crossroads in STEMM disciplines and professions. Future economic growth, the capacity for innovation and new discovery, and global competitiveness will depend in no small part on the development of more highly skilled researchers and professionals in STEMM fields. In addition, the level of scientific literacy and understanding across the larger population must be enhanced to ensure a well-educated, informed society and citizenry. According to the Committee on Prospering in the Global Economy of the 21st Century: An Agenda for American Science and Technology (2007) in its report *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*:

> ... current trends in each of those criteria indicate that the United States may not fare as well in the future without government intervention. This nation must prepare with great urgency to preserve its strategic and economic security. Because other nations have, and probably will continue to have, the competitive advantage of a low wage structure, the United States must compete by optimizing its knowledge-based resources, particularly in science and technology, and by sustaining the most fertile environment for new and revitalized industries and the well-paying jobs they bring. We have already seen that capital, factories, and laboratories readily move wherever they are thought to have the greatest promise of return to investors. (p. 4)

In conclusion, we hope that the experiences and insights shared in this volume will prove to be a useful and valuable support as you seek to increase both the number of students who achieve academic success in chemistry as well as the level of knowledge and skills for the next generation of scholars, practitioners, and citizens. In this way, we hope to accelerate our collective progress in addressing the concerns and challenges identified by the scientific education community. The extent to which the challenges highlighted by national experts are addressed will depend in no small part on our ability to enhance student success in chemistry, both for those who will be directly employed in such fields as well as others whose understanding of chemistry will be essential to their individual quality of life and to the general well-being of our society.