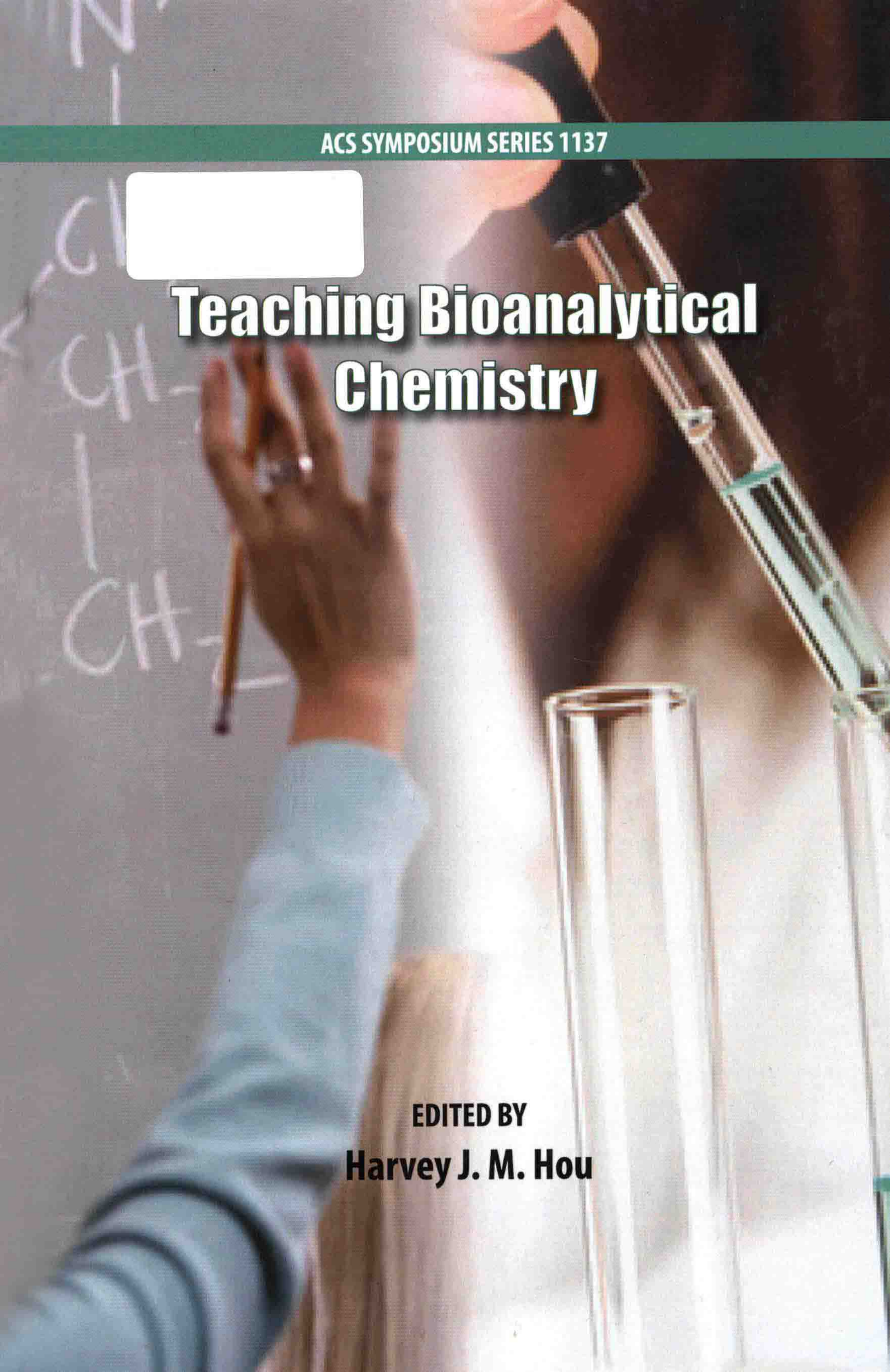

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Teaching Bioanalytical Chemistry

EDITED BY

Harvey J. M. Hou

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Teaching Bioanalytical Chemistry

Foreword

The ACS Symposium Series was first published in 1974 to provide a mechanism for publishing symposia quickly in book form. The purpose of the series is to publish timely, comprehensive books developed from the ACS sponsored symposia based on current scientific research. Occasionally, books are developed from symposia sponsored by other organizations when the topic is of keen interest to the chemistry audience.

Before agreeing to publish a book, the proposed table of contents is reviewed for appropriate and comprehensive coverage and for interest to the audience. Some papers may be excluded to better focus the book; others may be added to provide comprehensiveness. When appropriate, overview or introductory chapters are added. Drafts of chapters are peer-reviewed prior to final acceptance or rejection, and manuscripts are prepared in camera-ready format.

As a rule, only original research papers and original review papers are included in the volumes. Verbatim reproductions of previous published papers are not accepted.

ACS Books Department

Preface

It is evident that the focus of analytical chemistry in academia and industry is increasingly on the analysis of biological activity and detection of biological molecules. Bioanalytical chemistry has been becoming one of the most promising enhancements in chemical education. The purpose of this book is to present the recent progresses in terms of novel strategy and pedagogy of teaching bioanalytical chemistry in the classroom and laboratory. The effective and efficient ways are the incorporation of specific bioanalytical chemistry experiments in an existing chemistry class. In addition, brand new bioanalytical chemistry courses at undergraduate and graduate levels may be created and implemented into the chemistry curriculum. At least three layers of bioanalytical chemistry content may be developed and implemented in chemistry education: (1) introduction to bioanalytical chemistry, (2) (intermediate) bioanalytical chemistry, and (3) advanced topics in bioanalytical chemistry.

A grand challenge of bioanalytical chemistry is to build upon the explosively growing knowledge learned from quantitative and instrumental analysis, to integrate it into the extremely demanding chemistry curriculum, and to facilitate student learning by making connection between a variety of subdisciplines in science and technology. It is an honor and privilege for me to have organized four symposia on teaching bioanalytical chemistry in the biennial conference in chemical education (BCCE) in the past six years. The symposia have provided a great forum for sharing and stimulating the novel ideas of implementing the bioanalytical chemistry components into the existing chemistry classes or developing complete bioanalytical chemistry courses to enhance student learning. The authors are selected from the presenters in these symposia as well as invited experts in teaching bioanalytical chemistry at college and universities in the United States.

Because of the exceedingly rapid development and multidisciplinary nature of bioanalytical chemistry, it made educators to teach bioanalytical chemistry in classroom and laboratory tremendously challenging and demanding. The chemistry educators suffered drastically from the relatively limited textbook and confirmed teaching resources. In this ACS symposium book we present the recent advances in teaching bioanalytical chemistry, which are written in thirteen chapters by twenty-eight dedicated experts in the field of bioanalytical chemistry education in colleges and universities. These teaching innovations have been completely tested in the chemistry classroom and laboratory. The organization of the book provides a list of unconventional and effective teaching approaches to address most of the typical bioanalytical techniques. However, due to the restricted time and capability, it is impossible to present the complete advances in methodologies and applications of bioanalytical chemistry. It is not our intension to present a comprehensive textbook. The topics of new development in bioanalysis including, not limited to, immobilization of biomolecules, X-ray crystallography, and nuclear magnetic resonance, are beyond the scope of this book. We hope that this ACS symposium book may provide valuable information and practical innovations in teaching bioanalytical chemistry and enrich the chemistry curriculum for educators of the two-year community colleges, four-year colleges and universities at undergraduate and graduate level.

Due to the extremely limited time frame for collecting manuscripts and the strict deadline for publishing the book, the authors of this book stand for an incomplete list to represent the teaching community of bioanalytical chemistry. Some of the outstanding educators, who have presented their verified ideas and innovations in the BCCE symposia and initially decided to write book chapters for sharing their excitement and teaching experience in teaching bioanalytical chemistry in classroom and laboratory, are unfortunately unable to contribute to the book. As a result, the content of this book will be a snapshot in bioanalytical chemistry education presented in the BCCE symposia. The book introduces a head start to express and exchange new thoughts and innovations in teaching bioanalytical chemistry. I am looking forward to launching a more comprehensive book in teaching bioanalytical chemistry in the future.

I would like to take this opportunity to acknowledge the authors for writing the excellent book chapters and for being supportive and cooperative when the manuscripts were reviewed and revised. I would also like to thank the external reviewers for their timely contribution and effort in judging the value of the manuscript and delivering the constructive comments, which undoubtedly improve the quality and readability of the book. I am very grateful to Tim Marney, Arlene Furman, and Aimee Greene of the ACS Books Editorial Office for their insightful advice and meaningful assistance during the entire book project. I would like to thank the ACS Division of Chemical Education for sponsoring the BCCE symposia, which provide an exceptional venue for bringing the bioanalytical educators together and for making this book project possible. Finally, I would like to thank my wife, Du Liao for providing continuous support in all my endeavors.

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Chapter 1

Introduction: Bioanalytical Chemistry Education

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This book is written by twenty eight experienced bioanalytical educators and provides specific examples including experiments and courses in bioanalytical chemistry education. Bioanalytical chemistry is broadly defined in this book as analytical applications in the chemical and biological sciences using a variety of experimental methodologies. In this chapter, I will briefly present current statues of bioanalytical chemistry education, summarize the innovative pedagogy and approach in teaching bioanalytical chemistry, discuss the novel bioanalytical laboratory experiments, and review the new bioanalytical chemistry courses presently taught in the chemistry curriculum. I will also share my experience in teaching bioanalytical chemistry, and my views on the potential problems and possible solutions in bioanalytical chemistry education.

Bioanalytical chemistry has been becoming one of the most promising enhancements in chemical education because the focus of analytical chemistry in academia and industry is increasing on the analysis of biological activity and detection of biological molecules. During 2006-2012, teaching bioanalytical chemistry and laboratory has been one of the symposia in the biennial conference on chemical education (BCCE) sponsored by American chemical Society Division of Chemical Education. The symposia have provided an exceptional venue for bioanalytical chemistry educator to sharing and stimulating the novel ideas and pedagogies in their teaching practice.

This ACS symposium book is written by twenty-eight authors from fourteen institutions including the liberal art colleges and the national research universities and offers specific samples including experiments and courses in bioanalytical chemical education. Bioanalytical chemistry is traditionally classified as one subdiscipline of the field of analytical chemistry, which includes the qualitative and quantitative analysis of biomolecules using chemical, biochemical, and instrumental techniques. The typical analytical methodologies are spectroscopy, electrochemistry, chromatography, and mass spectrometry. In this book, a broad definition of bioanalytical chemistry is used and includes all the analytical applications of experimental methodologies in the chemical and biological sciences. It will cover the biophysical chemistry, biochemistry, environmental chemistry, green chemistry, nanotechnology, and forensic science, in addition to the traditional bioanalytical chemistry.

It seems that much of forensic analysis and environmental science is not performed on biological samples and is based on physical methods unrelated to plants or animals. However, forensic analysis involves the analysis of illicit drugs and their metabolites (*1*). DNA profiling of biological fluids is widely used in forensic science and enriches the content of bioanalytical chemistry. In particular, microbial forensics is an emerging field of forensic science and dedicated to the detection, characterization, and interpretation of evidence from the scene of acts of bioterrorism or biocrimes (*2*, *3*). The evidences include bacteria, fungal pathogen, plant toxins, influenza viruses, and other dangerous species and belong to the context of bioanalytical chemistry. Environmental science may be associated with the detection of contamination due to the bacteria, viruses, and toxins, and can be an important component in bioanalytical chemistry.

Although bioanalytical chemistry defined in this book may overlap significantly with biochemistry laboratory, it is different from each other in two aspects. 1) Bioanalytical chemistry focuses on the sample analysis and not the purification of proteins or the molecular cloning of genes, which are the key components in biochemistry laboratory. 2) Bioanalytical chemistry includes all the applied sciences using approaches in physics and chemistry, which include biophysical chemistry, environmental science, green chemistry, material science, nanotechnology, and forensic science. These topics are not main concerns in biochemistry laboratory.

1. New Pedagogy and Approach in Bioanalytical Chemistry Education

Active learning is the key in higher education and has been applied in college classrooms and laboratories duing the past several decades. The previous ACS syposium book, "Active Learning," summarizes the innovative approaches and the active learning methods in the mode of delivery of analytical chemistry (*4*). Due to the extremely rapid growth in applcation and multidisciplinary nature of bioanalytical chemistry, it is unbelievably challenging and demending for chemical educators to teach bioanalytical chemistry in classroom and laboratory with a limited course time and vast course content. Instead of using the traditional "expository instruction," the unconventional pedagogy and strategy must be exployed to integrate development into the curriculum, to facilate student learning by connecting the variety of subdisciplinery in science and technology.

Teaching bioanalytical chemistry may be instructor-directed (maximum guided) and student-driven (minimum guided). Based on the literature and my own experience in chemistry education, student learn the course material more by doing the activities via the hand-on experience. When it is possible, I always offer the hand-on experience or laboratory experiment in my class. Active learning is the key for students to understand the concepts and master the scientific skills. To enhancing the student learning, the active learning modules have been increasingly used in teaching bioanalytical chemistry in classroom and laboratory, which include inquiry-based approach, problem-based method, cooperative-based learning, role playing strategy, discover-based learning, research-based curriculum, context-based case studies (CBCS), small mobile instruments for laboratory enhancement (SMILE), and project-based learning. These active-learning approaches are dicussed in several chapters in this book (*5–9*).

Barne and Sander reviewed the nontraditional methods for teaching a specific area of analytical chemistry: spectroscopic techniques in bioanalysis (*6*). The readers may get a flavor for the different way and types of experiments that can be used to teach spectroscopic techniques in bioanalysis. The most widely used non-traditional approaches are process oriented guided inquiry learning (POGIL) and peer-led team learning (PLTL). POGIL uses strict structured student roles in group settings with well designed questions for the students to answer. In contrast, PLTL focuses on peer leaders who have been taught through separate training program for the course. These leaders work together to guide students to find solutions of the designed problems provided by faculty and become the active and coherent part of the teaching team. These innovative teaching strategies have improved student learning outcomes in the skills of higher-order thinking, problem-solving, conceptual understanding, teamwork, and communication.

2. New Bioanalytical Laboratory Experiments

Typically chemistry curriculum is incredibly difficult and demanding for undergraduates in colleges and universities. In many cases, it includes one year of general chemistry, one year of organic chemistry, one year of physical chemistry, one year of analytical chemistry (quantitative analysis and instrumental analysis), one year biochemistry, and one year inorganic chemistry (descriptive and advanced topic). Addition of a new bioanalytical chemistry might be problematic in the curriculum without deleting one existing chemistry course. The effective and efficient way is to integrate the lab component in the existing chemistry curriculum. The new experiment design should target on enhancement of the student learning, skills, competency, and enthusiasm in bioanalytical chemistry.

I have implement three experiments in the existing chemistry classes, "Procedures of Chemical Analysis" and "Chemical Biology and Technology," at UMass Dartmouth. These experiments are the determination of secondary protein structure using Fourier transform infrared spectroscopy (FTIR), forensic analysis of illicit drugs using bioanalytical techniques, and chlorophyll fluorenscence evaluation of American cranberry plant under diverse conditions.

The objectives of the first experiment, "Protein secondary structure determined by Fourier transform infrared spectroscopy," are the understanding of the principle of infrared spectroscopy and the development of the ability to determine the secondary structures of the native and denatured proteins including myoblobin, cytochrome c, and trypsinogen (*10*). With minimized help from the instructor and extensive discussion between the peers, students are required to generate experimental procedures, prepare protein solutions, to record the infrared spectra, fit the infrared peak, calculate the secondary protein structures, and write lab report.

Forensic science is the application of scientific principles to criminal and civil laws within a criminal justice system (*1*). It involves the examination of items of evidence by analyzing alcohol, carbon monoxide, and drugs in body fluids as well as substances such as glass, soil, hair, ink, bullets, and gunpowder. To meet the increasing need of students who are interested in forensic science, another experiment "Forensic analysis of illicit drugs in uring and saliva samples" is offered. Two objectives of the experiment are 1) understand the principle of immunoassay of forensic drugs including alcohol, cocaine, and marijuana, and 2) identify the forensic drugs in urine and saliva samples using test kits including One Site Alcohol Test Kit and One Step Urine Test Cassette.

The third experiment in the chemistry course "Chemical Biology and Technology" invovles the evaluation of the photosynthetic performance in the leaves of American cranberry under diverse conditions using chlorophyll fluorescence kinetics (*11*). Three objectives of the experiment are to conprehend the principle of the chlorophyll fluorimeter, to determine the photosynthetic activity of plant tissue samples, and to examine the effects of two environmental factors including pH and temperatures. The experiment include one lecture and one lab period. The lecture provide the background of the methodogy and its application in plant biology. During the lab period, students in groups are required to devise their own experimental procedures, to conduct the experiments, and to write a lab report to summarize the experimental results.

Ho describes an outstanding lab experiment using protein conformational studies as theme to engage students in active learning (*8*). The protein conformation is probed by a variety of spectroscopic methods including UV-vis absorption, fluorescence, FTIR, and mass spectrometry. Through the well-designed course, students will learn not only the concepts and theory of the protein conformational changes, but also the principle and application of the instrumentation by collaborative learning and science writing heuristic. The emphasis is place on the critical thinking and problem solving skills. The chapter provides an effective way for instructors to turn passive cookbook lab learning into active inquiry-base activities.

Akinbo implements multiple laboratory component in analytical chemistry courses: 5 project modules in quantitative analysis and 4 project modules instrumental analysis, including one environmental and one bioanalysis project (*5*). Chohan and Sykes use SMILE initiative to transform the traditional analytical experiment into discovery project-based labs. (*7*). It fills the need to involve students in troubleshooting instruments and to understand what goes on "inside the box." For example, students are required to design, construct, optimize and troubleshoots SMILE. Gilfilen, Lavender, Clinger, and Clinger describes a nice overiew of experiments and suggests improvement on a numbers of experiments in instrumental analysis and biochemistry to engage the pre-professional student in relevant laboratory activities (*12*). Gross, Clevenger, Neuville, and Parker develop one distinctive experiment using paper microfluidics for the undergraduate analytical chemistry laboratory (*13*). Microfluidic devices allow the analysis of tiny volume of fluids in microscale channels and wells. Research within the world of microfluidic devices, whether paper or another substrate, is currently quite common and constantly growing. Through the experiment students learn the fabrication of paper-based microfluidic devices and analysis of glucose and protein in the "unknown" synthetic using samples in the setting of clinical laboratory.

3. New Bioanalytical Chemistry Courses

A Bioanalytical chemistry course can be a laboratory-intensive or a purely lecture-based course. These courses can be offered in three levels in chemical curriculum, 1) introductory level (100 or 200 level), 2) intermediate level (300 and 400 level), and 3) advanced topics (400 and graduate-level). I have developed and implement an introductory bioanalytical chemistry and bioanalytical chemistry.

To enhance the chemical education, a new sophomore introductory bioanalytical chemistry course has been designed and implemented in chemistry curriculum at Gonzaga University in 2005. The introductory bioanalytical chemistry course is a three (3)-credit class includes three (3) hour lecture and three (3) hour laboratory component per week. The lectures covers the topics including acid-base chemistry, spectrometry, chromatography, electrochemistry, chemical kinetics, and thermodynamics.

The laboratorys focus on the applications of selected analytical methods to biological problems. Acid-base titration involves the titration of amino acid solution. Spectrometry experiment is designed to determine the chlorophyll a and chlorophyll b in spinach samples. Infrared spectroscopy is used to monitor the secondary protein conformational structures in protein samples. Inductively coupled plasma is used to quantify the content of manganese and calcium in chloroplasts. Instead of using pH electrode in traditional analytical chemistry, an oxygen electrode is utilized to obtain the oxygen evolution activity of photosynthetic electron transport in chloroplasts. An experiment using differential scanning calorimetry to assess the enthalpy change of protein denature process is developped. Additional three experiments including the separation using column chromatography, identification of proteins by electrophoresis, and chemical kinetics of enzymes are implemented.

A bioanalytical chemistry course covering the fundamental techniques in protein and DNA analysis using enquire-based approach is developped at UMass Dartmouth. The focus is placed on the methodologies to probe the structure and function relationship of membrane proteins. The topics include spectroscopic analysis of total biomolecules, enzymes, immunoassays, electrophoresis, cnetrifugation, electrochemistry, chromatography, mass spectrometry, and other techniques in bioanalytical chemistry. The class requires two laboratory reports to assess the written skills of students, which must follow the guideline and format of a chemistry journal. There are two hourly exams to assess the student learning of principles and theories of analytical methods. Two oral presentations on the published paper with critiques in the field of bioanalytical chemistry. The same teaching strategies

Dovichi describes an excellent undergraduate course in bioinstrumental analysis which has been taught for six years between 2005 and 2010 at the University of Washington (*14*). The course covers essential bioanalytical/ bioinstrumental techniques and provides undergraduate a well-designed platform for learning bioanalysis. It is developed upon a graduate-level bioanalysis course developed by the author. The course consists of 18 lectures and eight laboratory experiments. The first half of semester focuses on the nucleic acid analysis including DNA electrophoresis, sequencing, hybridiation, PCR, and real-time PCR. The second half deals with protein analysis including protein electrophoresis, chromatography, mass spectrometry, bioinformatics, enzyme chemistry, receptors, antibody, flow cytometry, and fluorescence microscopy.

Witter and Arnold represents an unique interdisciplinary bioanalytical course for upper-level undergraduates in the field of ecological and analytical sciences (*15*). The course is designed as an advanced traning program. It is research-intensive and centers at the investigation of the ecological roles of natural products in mediating plant-insect interaction using modern analytical chemistry by team-teaching of a chemical ecologist and an analytical chemist. The lectures are designed to ensure student learning in concepts and theories in the field of ecology. The lab experiments reiterate the principles taught in classroom and allow students to perform the analyses of samples in the field and laboratory.

Ronkainen describes an exceptional advanced elective course for undergraduates, Bioanalytical Chemistry and Chemistry Sensors, and reflects in detail about the course content, learning format, and performance assessment (*9*). In particular, the course involves an emphasis on primary literature. Specifically, the focus of course is placed on problem solving, data interpretation, oral communication, and critical analysis of literature. The chapter provides detailed account of rational for the pedagogical approach, course structure, course content, learn outcomes, and course assessment instrument. It offers a well-defined idea of how to develop a similar course.

Beussman describes a lab-intensive bioanalytical chemistry course to prepare students for research in STEM field (*16*). The course have been successfully been offered several times at St. Olaf College. In the course 1) relatively common instrumentation including 1-D gel electrophoresis, UV-vis spectrometers, and HPLC systems and 2) exotic and expensive instruments including 2-D gel systems, capillary electrophoresis systems, and mass spectrometers are utilized to the topics including bimolecular structures, protein fingerprint, peptide sequencing, post-translational modification, bacteria identification, and clinical applications.

Guo, Young, and Yan describes a course design of a graduate-level bioanalytical chemistry class, "Biophysical Spectroscopy," offered at Yale University (*17*). The course is designed to teach a survey of biophysical spectroscopic methods using guided inquiry and project-based teaching strategies. Students will learn the basic principles of biophysical spectroscopy and address fundamental questions in the field of biology at the molecular level and gain the problem solving and critical thinking skills. Nguyen, Arceo, Weber, Springer and Hanrahan applied undergraduate research activities to enhance student learning in the Bioanalytical Chemsitry curriculum (*18*). The teaching activities aim to increase high-impact practices and reveal the importance of computer based projects in analytical chemistry curriculum. Specifically they describes a research-based acitivity and focused on experiential learning in classroom and laboratory.

4. Concluding Remarks

As the methodologies and applications of analytical chemistry in biological and medical sciences are increasingly developed and established, content of bioanalytical chemistry must be taught in the chemistry curriculum for the next generation of work force and world leaders. Teaching bioanalytical chemistry has been becoming one of the most important components in enhancing chemistry eduction. However, due to the fast growing knowledge and novel technology in bioanalytical chemistry, it is difficult to cover the advance and progress of bioanalytical chemistry in a single one-semester course. In addition, the arrangment of chemistry curriculum is extremely tight, it make it more difficult to have additional bioanalytical chemistry course. This is the challenging problem and dilemma we must address in current chemistry education.

As described in this ACS symposium book, the most straightforward and effective way to implement bioanalytical chemistry content is to introduce bioanalytical chemistry laboratory experiments in the existing chemistry classes. Alternatively, novel bioanalytical chemistry may replace one of the quantitative analysis or instrumental analysis class. Advanced topic classes are very feasible in graduate level chemistry classes. These novel courses include introductory bioanalytical chemistry, lab-intensed bioanalytical chemistry, biosensor, biophysical spectroscopy, and bioinstrumental analysis. Due the nature of the multidisciplinary and applied science to real world problem, the novel teaching pedagogy and strategy in the bioanalytical chemistry education must be and have been utilized, which include POGIL and PLCL as well as the inquire-based, research-based, and problem-based learning methodologies.

This ACS symposium book is to provide real stories of implementation of bioanalytical chemistry in college and university and to serve a capstone in teaching bioanalytical chemistry for chemistry educator. I intend to continuously organize the BCCE symposia on teaching bioanalytical chemistry in the years to come and encourage the participants to exchange and share new ideas and innovative experiences in teaching bioanalytical chemistry in classroom and laboratory. I believe that by working together we are able to make a difference in bioanalytical chemistry education and enhance student learning. In such a way, we are able to prepare the students better to enter the work force and become the competitive world leader in the STEM field.

Acknowledgments

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