CURRICULAR DEVELOPMENTS IN THE ANALYTICAL SCIENCES

A Report from the Workshops

October 28-30, 1996
Leesburg, VA

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September 10, 1997

Dr. Theodore Kuwana
Department of Chemistry
University of Kansas
Lawrence, KS 66045

Dear Ted,

The National Science Foundation's (NSF) Division of Undergraduate Education (DUE) is pleased to be co-sponsoring these two workshops addressing the education and training of the Analytical Sciences workforce. I have read with great interest the interim reports for Workshops I and II. You have made significant progress. The issues and challenges identified – Learning Partnerships, Course Content and Learning Modes, Learning Technologies, Faculty Development, Dissemination, and Assessment and Evaluation — are universal across the disciplines. It is the universality of the issues to be addressed and the inherently multidisciplinary nature of the analytical sciences that implies broad and immediate applicability of the results of your deliberations.

The common objective of your activities is the presentation of educational material in an engaging manner, employing effective pedagogy and instructional technology to attract and retain students in engineering, mathematics, and the sciences. Additionally, your recommendations will inform us on how to prepare all graduates — majors as well as non-majors —for entry into the workforce, rewarding careers, and a desire to continue learning throughout their lives. In particular, you have laid a foundation for consideration of such implementation issues as interdisciplinary approaches; attention to diversity; systemic reform of undergraduate education; and the preparation of future K - 12 teachers.

Your efforts are appreciated and commended.

Sincerely,

Norman L. Fortenberry

Norman L. Fortenberry
Director, Division of
Undergraduate Education

NATIONAL SCIENCE FOUNDATION
4201 WILSON BOULEVARD
ARLINGTON, VIRGINIA 22230

September 12, 1997

Dr. Theodore Kuwana
Department of Chemistry
University of Kansas
Lawrence, KS 66045

Dear Ted,

The NSF's Division of Chemistry has primary responsibility for research and education at the graduate level in the field of chemistry. Significant investment in undergraduate education occurs primarily through the Research Experience for Undergraduates (REU) Program, in which the Division invests approximately $2.5 million annually.

The quality of graduate education is circumscribed and the cost of graduate education is increased by inadequate preparation of incoming students. Graduate students in chemistry come from all types of schools and have distressingly varied preparation for their graduate careers, with respect to both broad knowledge of the field and the ability to attack problems. The quality of these students as they begin graduate school can be improved through systematic improvement in the undergraduate learning experience. The subdiscipline of analytical chemistry presents an ideal model and vehicle for that improvement, as it deals with solving problems across a broad range of science and technology by using an equally broad range of tools.

A further, although less direct concern of the Division, is that the central science of chemistry plays an appropriate role in the fields of science and engineering that rely on the concepts and tools of chemistry. In most cases those responsible for moving the project of interest forward have knowledge of and skill in chemistry at the undergraduate level. This background must be adequate for the proper formulation of a problem, proper selection and use of tools, and the search for more sophisticated help when necessary. Analytical measurements are ubiquitous in laboratory science today. Solid grounding of undergraduates in analytical science thus has the potential to enable progress in science and technology across a broad front.

The Division is pleased to have had the opportunity to sponsor these workshops and by so doing to have raised both the consciousness and expectations of the participants. It is hoped that this report will extend to a broader audience an ongoing discussion of curricular reform.

Sincerely,

Janet G. Osteryoung
Director, Division of Chemistry

CONTENTS

The current exploration of Mars is a dramatic example of the multidisciplinary nature of analytical science.

Analytical science provides information on the chemical composition and structure of materials that are important not only to chemistry, but also to a broad range of disciplines such as materials science, biology and biotechnology, forensic science, and the earth sciences. In the Martian project, geologists, paleobiologists, astronomers, astrophysicists, and chemists work together. Analyses of meteorites found in Antarctica, as well as information from the early Viking and current Pathfinders missions, have been provided by a broad range of techniques. These techniques include mass spectrometry, scanning electron microscopy, microprob two-laser microscopy, and alpha proton x-ray (APX) spectrometry. This work also illustrates the importance of remote sampling and hyphenated (integrated) techniques. Such sampling and analysis techniques are quite a contrast to the classical wet analysis of geological samples brought to conventional laboratories.

This report addresses the education and training of those who enter the work force in areas dealing with the analytical sciences. It is the result of two workshops funded jointly by the NSF Division of Undergraduate Education and the Division of Chemistry.

Its recommendations are directed to the development of course and laboratory curricula in two- and four-year colleges and in undergraduate education in graduate-level institutions, as well as to areas of cooperation among academics, industry, and government. The recommendations indicate that reform involves not only content but also the other elements of the learning environment: strategy, evaluation, and delivery of content. Analytical science involves problem solving, thus problem-based learning is a logical and appropriate educational strategy. Furthermore, this reform should occur in two directions: the inclusion of applications from other disciplines in analytical chemistry courses and the incorporation of analytical techniques in courses and curricula of other disciplines.

The Martian exploration is an unique example of the key role analytical science plays in providing information for industry and government in many critical areas including quality assurance, development of new products, environmental regulation, and health care. The goals, content, practitioners, and consumers of the analytical sciences continue to change.

This report describes the current status of and trends in analytical science and makes recommendations for improving the education and training of undergraduate students in this dynamic environment.

Frank Settle
Program Director
Division of Undergraduate Education

Fred Hawkridge
Program Director
Division of Chemistry

BACKGROUND

A grant co-funded by the National Science Foundation's Division of Undergraduate Education and Division of Chemistry supported these two workshops. Our goal was to develop a set of recommendations and implementation modes for curricular improvements in the education and training of future analytical scientists. The first workshop was held Oct. 28-30, 1996, at the conference facility of the Xerox Documentation University in Leesburg, Va. The second workshop was held March 13-15, 1997, at the Regency Suites Hotel in Atlanta, Ga.

The workshops focused on the NSF goal to catalyze pivotal changes in the education and training of undergraduates in science, mathematics, engineering, and technology (SME&T). In its 1996 report, Shaping the Future, NSF identified several areas of concern regarding America's SME&T competency. It specifically addressed the growing need in our country for a technically skilled work force and sounded the alarm that current SME&T education did not fully address that need. It called for a nationwide action by government, industry, and the higher education community to address and strengthen the current weaknesses in SME&T undergraduate education.

The workshops served as a forum for the analytical community-in partnership with NSF-to address these concerns and to define and consider issues that impact future work-force competency. The participants represented two- and four-year colleges, graduate-level institutions, industrial companies, and government agencies and laboratories.

WORKSHOP FORMAT

The program format allowed ample time for discussion among participants and offered input from several speakers who shared perspectives from industry and academe. The technique known as Linkage Analysis Planning (LAP) expedited the process to identify and prioritize issues. This method is used widely by organizations involved in planning because it allows stakeholders to share, communicate, and prioritize their vision.

At the onset, participants generally agreed that improvements in science, mathematics, and engineering education are central to shaping America's scientific and technological future. This need extends from K-12 through postdoctoral studies. Finding agreement on what needs to be improved or changed, how to implement and pay for such improvements, and how to build better linkages between academe and industry are challenges.

GENERAL AGREEMENT

Regarding analytical curricula, participants generally agreed that measurement, problem solving, and hands-on techniques were central to educational content. But how do educators bring real-world problems and problem-solving skills into the curriculum? What measurement skills do they need to teach? What is the balance between fundamentals and what is thought of as "skills"? Which techniques are to be emphasized or de-emphasized? How are interdisciplinary areas brought into the analytical curriculum and how is analytical chemistry transported to other disciplines?

Most participants thought that better interactions between faculty and industry would bring about a cross-pollination of ideas and resources. Many in the group focused on analytical chemistry, but most agreed that chemistry-based programs must create stronger ties to related disciplines, both on campus and within industry. But how do undergraduate programs educate and train those chemistry students-many of whom will enter the work force in analytical areas--to meet the diverse and ever-changing needs of other science and engineering disciplines? Industry representatives and educators lamented the fact that students also needed to improve their skills in communication, teamwork, and problem-solving.

THIS REPORT

In Section I, these issues are put in context by looking at the undergraduate analytical curriculum. Work-force issues are among the drivers of educational reforms, so Section II offers industry perspectives on the issues that affect education and work-force competency. In Section III, we identify the six issues that emerged as the workshops' priority issues: 1) course content and learning modes; 2) core technologies for undergraduate labs; 3) faculty development; 4) learning partnerships with industry; 5) the impact of technology; and 6) follow-up and dissemination. Section III also recaps the participants' recommendations and their suggestions for their implementation.

Follow-up and dissemination, as well as the assessment and evaluation of the initiatives triggered by the recommendations will be on-going activities. I look for your many ideas and suggestions, such as those that will increase the interaction between academics, industry, and government regarding curricular improvements.

ACKNOWLEDGEMENTS

Finally, I wish to acknowledge the contributions of the steering committee in helping to organize the workshops; the workshop participants for their enthusiasm and willingness to present ideas and discuss issues; the key presenters and speakers for stimulating our thinking about curricular changes; and the NSF for its financial and pro-active support.

You are invited to be challenged and stimulated by the commentaries and best practices offered by several participants, as included in Appendices A and B of this report.

Ted Kuwana
Chair

I. LOOKING AT UNDERGRADUATE ANALYTICAL CURRICULUMS: A BROAD VIEW

> ***"Today, students with diverse backgrounds are seeking an education that will prepare them for careers in a global society with science and technology as a common currency. Because undergraduate education is central to the preparation of tomorrow's knowledge workers and affect such a large, diverse, and growing segment of the population its reform has potentially widespread application and benefits.***
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> – *Synergy*, July I996

Analytical science increasingly is an integral part of all science and engineering disciplines, and it also plays an important role in broader societal concerns. So analytical science education must reach beyond students' undergraduate analytical chemistry courses. But how do we educate and train undergraduates who will meet this country's diverse and growing need for people in the science-based and engineering disciplines? How do we shape the undergraduate curriculum so that it can prepare students for jobs in the industries that hire analytical scientists? The questions have no simple, all-encompassing answers. The workshop participants did not agree on all the desirable attributes of an undergraduate curriculum, but they did agree on these four:

- A broad education with significant emphasis on the liberal arts is still a desirable goal for most students.
- The traditional approach to undergraduate education in analytical chemistry requires significant changes and improvements.
- As part of these changes, the curriculum must introduce the scientific method in introductory courses and must include a thorough understanding of the analytical process.
- It must offer a context-based education that includes problem-based learning. This approach challenges students to think critically and gives them the best preparation for careers in and outside of the sciences.

A liberal arts education remains an integral part of most four-year, undergraduate programs that offer degrees in the sciences and in engineering. A core of liberal arts courses can also be found in most two-year programs. Those endorsing a liberal arts education assume that courses in the humanities, social sciences, and natural sciences will expose students to a variety of life-enriching disciplines. They also assume that the liberal arts will hone students' critical thinking skills as well as their ability to write and speak effectively.

Industry representatives, however, expressed concern that younger employees with college degrees lack these solid communication skills. Surprisingly, new science graduates also seem to have little understanding of the scientific method and limited experience with the analytical process and its rigors of sampling, sample preparation, measurement, data analysis, and interpretation. Clearly the industry representatives see gaps in the education and training of undergraduates entering the analytical work force.

Although industry needs should be given serious consideration when looking at curricular reforms, undergraduate science education is not solely a training mill for industry. One participant made a case for industry assuming more responsibility for skill development in its new hires. (See Layloff, Appendix A)

For decades new graduates in the sciences have consistently divided their post-graduation pursuits almost equally between industry, the professional schools, and graduate schools. A significant percentage of master- and doctoral-level students eventually find careers in industry. So, long-term, industry does absorb a large number of chemistry undergraduates.

The industry percentage also increases when those with associate degrees are included in the totals. A good percentage of graduates from two-year, technical programs immediately enter the technical work force. Many take jobs with companies that have a recruiting presence on campus or with those companies who work with the community college to develop specific training programs.

Just as not all undergraduates go on to industry, not all students in introductory science courses are science majors. Many chemistry students are majors, but many also take chemistry to fulfill a liberal arts requirement. Do traditional curricula meet the learning needs of these non-majors? Could revised curricula attract more majors? Another factor is that a great deal of introductory chemistry is completed at the two-year, community college and not at four-year institutions. Can curricular revisions be made without specifically addressing the needs of students in two-year schools?

These workshops examined two- and four-year college programs, but participants acknowledged that any national movement to revise science curricula must also include K-12 students and teachers. (See Smalley, Appendix A.) As one participant noted, “Science is for everyone, K-16, it’s not just for those who want to become scientists.” If science, however, was taught as if it was relevant to everyone, then perhaps more elementary, high school, and freshmen college students might choose to become scientists.

Any suggestions for curricular reform then must consider the diversity of the students and of those who teach or who hire students. Curricular reform speaks to the needs of industry and graduate schools. It affects both science majors and non-majors, and K-12 students. It also must address the two-year curricula that assist not only industry, but also the students who are headed for four-year institutions and who take their first introductory chemistry course at a two-year college. (See McMillan, Appendix A.)

TRADITIONAL APPROACH

A central goal drove these workshops and the discussions and recommendations they generated: To steer the undergraduate analytical curriculum in a new direction. The direction clearly is away from the traditional approach, which some believe has not encouraged or developed the scientific and technical work force the nation needs.

Analytical chemistry is essential to many of the nation’s science and engineering initiatives. So to ensure that the nation’s technical needs will be met, the undergraduate analytical curriculum needs to better prepare students to become problem solvers. In turn, this preparation will give students a broader range of career opportunities. If the learning is exciting and relevant, analytical courses also may attract more young people into the sciences.

Those calling for change, both at the workshops and in national arenas, bemoan the lack of relevancy and excitement in many traditional courses. They want to eliminate the “plug-and-chug,” cookbook approach to college laboratories. They want to change the 50-minute lecture blocks that start with abstract concepts and principles and end with examples that often are detached from experience. Too often, they say, course content is neither relevant to students nor related to problems and issues in the real world.

In their essay, “The Power of Problem-Based Learning in Teaching Introductory Science Courses,” (See Appendix C.) authors Deborah Allen, Barbara Duch, and Susan Groh note that “. ..the structure of traditional science courses erects numerous roadblocks to dents becoming actively involved in their own learning." The undergraduate science experience, they say, is often too closely related to traditional approaches to teaching and learning where students listen to a teacher, work standard problems, and memorize facts for exams. College students spend little time understanding the concepts behind the material. They work alone, and their achievement is based on routine paperwork: exams and exercises. In the end, students may not retain new information long enough to apply it to the next course in the sequence.

A content-based approach, in which the emphasis is on covering as many analytical techniques and methods as possible, creates difficulty for the instructor. The proliferation of methods and their variants makes it impossible for the student to become versed in all of them. Rapid changes in certain areas can make knowledge that is learned today obsolete in a few years. The content of the analytical curriculum will continue to evolve, but the analytical method and the way in which analytical scientists go about examining and devising solutions to problems will remain the same. It is essential that students learn general problem-solving skills to solve open-ended problems. It is also essential that students learn how to work in teams to solve these problems.

Traditional college science courses have a difficult time meeting the criteria for good courses as defined by the National Research Council (NRC). In its 1996 report, "Analysis to Action," (See Appendix C.) the council listed characteristics of good courses. These courses

- are problem-driven
- emphasize critical thinking
- provide hands-on experience
- are relevant to topics students find in life
- offer both the process and concepts of a discipline
- show links between related disciplines
- place the subject in a broader personal, historical, cultural, social, or political context
- provide intellectual tools needed to explore new areas

In her workshop comments, Barbara Duch called for a course approach in which science is taught as science is practiced at its best--through discovery, active involvement, and team efforts. For Duch and many others, the method of problem-based or inquiry-based learning offers a viable alternative to more traditional approaches. It also incorporates the characteristics of good courses as defined by the NRC report.

PROBLEM-BASED LEARNING

> ***"The goal of education in analytical science is to develop problem-solving skills based upon scientific inquiry. This would include team-based approaches to problem identification, application of multiple analytical techniques, effective communications of experimental results, and development of the ability to learn new techniques and concepts."*** **-Workshop II**

What is problem-based learning (PBL)? Though not new, problem-based learning has attracted a great deal of attention, especially in the natural sciences. PBL is learning that is driven by a problem, not by an abstract concept. Ideally the problem can be found in real life, and it has no quick, easy solution. Students not only have to solve the problem, but they also have to find the information and other resources they will need. They work in groups; they share information; they teach each other.

They are engaged in active learning to develop and test their hypothesis so they can arrive at solutions to problems. The principles and concepts they learn along the way are an integral part of the problem they struggle with. The knowledge they gather is connected to the course at hand, and they can integrate what they learn into other courses. Their grades are based not only on what they remember, but also on what they can do.

PBL teaches students how to learn and how to ask the questions that lead them to solutions. What information do I need? Where can I find it? How can I organize the data so that they are meaningful to me and to others? How can I communicate the information to others? These questions and the steps needed to solve a problem and discover an answer or solution can be applied again and again on the job or in graduate school.

PBL captures students' attention and presents them with real-life situations that involve more than one discipline and certainly more than one set of standard problems. In life, problems are not exclusively related to chemistry, or to biology, or to microbiology. Environmental pollution, for example, may involve the gathering and exchange of information across all those disciplines and more. In life, learning and problem-solving are not detached and separated by topic.

In the laboratory, PBL means students are active participants in experiments. They are told less about how to do the experiments and are expected to make their own decisions. In the analytical curriculum, PBL means students undertake the complete process of performing measurements--from identifying the problem to collecting samples; from doing appropriate sample workup and pretreatment to undertaking the measurement; and from analyzing to validating the results. Such an approach means that students participate in fewer experiments and that the emphasis is on the depth of problem solving rather than on the breadth of analytical techniques.

PBL then addresses the real concerns of industry and graduate schools:

- that students come prepared with problem-solving skills
- that they can use relevant measurement methods
- that they can think across the disciplines
- that they can effectively communicate what they know
- that they can work with others to solve a problem

PBL, however, requires that faculty be creative, flexible, and willing to relinquish some control over and responsibility for the students' learning. PBL also sparks concerns about how faculty are to assign individual grades. Those who are concerned about scoring student achievement might look to industry for guidance. On the job, people's competency and contributions are evaluated in any number of ways, including portfolios, peer reviews, self-assessments, and final product. Grades can include evaluation of individual contribution as well as the results of a team effort.

BENEFITS OF PBL

In spite of the adjustments that come with adopting this teaching approach, PBL offers some striking benefits:

- It may help to reverse the recent trend of reducing the amount of laboratory time in all undergraduate science courses, or it may at least bring greater learning to shortened lab periods, or encourage students to learn outside of their labs.
- It lends itself to research experiences where undergraduates may be part of a team that includes other undergraduates, graduate students, and faculty.
- It can be used in K-12, making it possible for undergraduate programs to create or connect with science outreach programs in the community.
- It stresses communication skills, teamwork, and problem solving. These skills are needed in all the sciences, not just analytical science, and they also are essential on the job.
- It adapts well to an interdisciplinary approach. In fact, the discovery method that is an integral part of PBL almost guarantees students will be learning across the curriculum.
- It often requires that students use several techniques and a variety of equipment.

PBL thus addresses the needs of analytical students regardless of their specific disciplines. It also promotes the goals of the National Science Foundation:

- to promote student learning
- to prepare students for rewarding careers
- to increase awareness and appreciation of SME&T issues
- to develop inter-disciplinary SME&T curricula
- to prepare students for technical and instructional careers
- to promote scientific literacy in the public

CHALLENGES

This whole-hearted endorsement of problem-based learning also comes with more than a casual nod to the challenges it brings. Curricular changes are difficult to usher through departments and university administrations. The task of steering analytical curricula in a new direction must be undertaken by faculties who already carry heavy teaching and research loads.

Concerns about time must be added to concerns about equipment costs for new instruments, hardware and software, and Internet access. Where will faculty find the textbooks and materials that support and complement problem-based learning? How can two- and four-year programs prepare students when textbooks and laboratory instruments lag behind current practice? Any endorsement for widespread curricular changes also must recognize that textbook publishers and academic curricular committees move too slowly to keep pace with today's rapid technological advances.

Perhaps some helpful suggestions can be found in the comments of Larry Suter, (See Appendix C.) who oversaw the research contained in a report funded by the NSF: *A Splintered Vision: An Investigation of U.S. Science and Mathematics Education*. Concerned with K-12 education, the report has application to the teaching of undergraduates.

"U.S. science and math teaching," writes the NSF's Suter, "is a mile wide and an inch deep, when compared to our international competitors." Suter notes that U.S. teachers have less time to prepare lessons than teachers in other countries. Plus, no coherent approach guides U.S. K-12 science and math curricula, with schools covering different topics in different sequences.

The report refers to a study led by William H. Schmidt of Michigan State University that attempts to explain why international students consistently out-perform U.S. students in math and science. These stronger students may come from countries with a more uniform approach to the teaching of topics collectively deemed important. Using inquiry-based, hands-on learning, teachers give important topics in-depth treatment, and fewer topics are crammed into each school term. Students have time to explore and understand the important concepts.

In the report, NSF Director Neal Lane says "...America needs a scientifically and technologically literate work force in order to compete in the global marketplace, and all American students need a sound education in science and mathematics in order to compete in an increasingly demanding work place." A copy of the report, *A Splintered Vision,* is available on the World Wide Web: http://ustimss.msu.edu.

The goal of these workshops–to drive analytical curricula in a new direction–may also include a push to establish a greater consensus on what students need to know and what they must know well. What basic concepts and skills must students acquire to succeed in the work place? What approaches must we offer them so they find science and technology not only relevant and exciting, but also within the capability of any student who is willing to study and become involved in his or her own learning?

Participants may have disagreed, for example, on which techniques to drop and add in an analytical chemistry curriculum. Give the boot to gravimetric analysis and titrimetry? Focus more on spectroscopy or capillary electrophoresis? They wanted more time to consider other questions as well: How to balance the fundamentals with the specifics? Which disciplines to import into an interdisciplinary approach? How to transport analytical chemistry into other disciplines?

But they also found consensus. Undergraduates need to understand the fundamental concepts of the scientific method and analytical measurement. They must know how to select the appropriate analytical method and how to evaluate the data. Most likely problem-based learning will offer more students the greatest learning opportunities.

So, analytical science courses must teach students how to think about measurement, about method, about data, and about the evaluation of that data. These courses must be designed to teach all students-those who will find jobs analyzing and generating the data, those whose job it will be to use the data and seek solutions, and those who will become part of a public educated about and interested in science and technology.

In the end, analytical science must become part of the larger national push to improve science, mathematics, engineering, and technology education in the United States. This need extends from K-12 classrooms through undergraduate and into advanced educational levels and is central to shaping America’s scientific and technological future.

II. EDUCATING TOMORROW'S TECHNICAL WORK FORCE: A NATIONAL CONCERN

WHERE ARE THE SCIENTISTS AND TECHNICIANS?

Too few people choose analytical science as their career. The shrinking number of those with useable skills in science, math, engineering, and technology (SME&T) concerns not only industry, but also the National Science Foundation. The NSF wants to catalyze pivotal changes in SME&T education and training of undergraduates. In its 1996 report, Shaping the Future, (See Appendix C.) NSF specifically addresses the country's growing need for a technically skilled work force and sounds the alarm that current SME&T education does not fully address that need.

The U.S. industries that hire analytical scientists and technicians face two dilemmas: a declining number of new-hires and lower-than-expected skill levels among those entering industry.

In their article in the Journal of Chemical Education, (See Appendix C.) Richard DePalma and Alan Ullman note that undergraduate science majors do not naturally assume they will have careers in science. In large part, they dismiss going on for advanced degrees and using their education within industry because they know little about what scientists in industry do.

WHAT EXACTLY IS INDUSTRY LOOKING FOR IN ITS EMPLOYEES?

Those graduates who do go into industry, however, spark the second dilemma. A growing number of new-hires lack the technical and personal skills industry needs. Those industry representatives who spoke at the workshops said their companies need people who can write and speak clearly and who can work effectively as part of a team. Their employees must be able to define a problem, gather and analyze samples, and suggest solutions based on the data. They must be able to apply these skills to real-world problems, in complex and challenging environments, and to pay attention to quality assurance, controls, external and internal standards, and validation.

Many undergraduates do not even consider a science major, feeling the subject is beyond their grasp or interests.

In general, the minimum personal and professional skills employers need are different than the skills many students receive during their analytical education. New-hires in industry must be organized, methodical, and flexible. They must follow instructions, ask questions, show initiative, communicate effectively, and pay attention to detail.

New-hires with good professional skills solve problems, think critically, have a good knowledge of chemistry and good lab practices, and can work alone or as part of a team. They understand the results, have good manual dexterity, and can operate a computer. At a technical minimum, new-hires must be able to do separations and spectroscopy and to manage a great deal of information.

Workshop participants representing higher education and industry agreed that undergraduate analytical curricula do not consistently produce graduates with minimum skills.

Workshop participants representing higher education and industry strongly supported a curricular shift to PBL and the use of real-life problems in undergraduate labs. Industry people and faculty agreed that PBL offers the best opportunity to create an environment that develops the skills industry needs and that sparks excitement about the measurement sciences and careers in those fields. At its most basic, they note, PBL teaches students how to think and how to solve problems. In industry--where the problems may change, but the problem-solving method does not--employees who can think their way to solutions are a valuable commodity.

Most faculty viewed industry as an ally. Help us, many said. Help us stay current with the technology and instrumentation industry uses, and help us buy or share equipment. In the Information Age, help us retrieve and manage the wealth of information important to you, to us, and to our students. Give our students a taste of what a science-related career is like. Come to our campuses and invite us to your places of business. Use your business clout and leadership in our communities and region to generate real-dollar support for higher education.

Without hesitation, the industry representatives said they knew their companies were willing to form partnerships with higher education. In fact, many already involve themselves in SME&T undergraduate education, and some have developed outreach programs that reach students in K-12.

Through internships, in-house summer research programs, and on-campus visits and talks, industries have helped many undergraduates to become excited about research and to develop needed skills. Industry programs have given students a broader perspective of career opportunities, experiences with real-world problem solving, and information about industry expectations for what new-hires should be able to do on the job. See Boutilier and Sabo in Appendix B for some strong examples of industry involvement in education.

Most faculty viewed industry as an ally in the effort to bring about curricular changes.

The workshop recommendations reflect the hope that more partnerships for such things as on-site courses and hands-on learning, equipment purchases and shared resources, faculty development and sabbatical opportunities, and internships and undergraduate research assignments will ensue between academe and industry.

But within the academic community, some are notably nervous about what these partnerships may mean. Most everyone supports ideas such as the creation of the Senior Analytical Corps and its promise of campus visits and expertise from retired industry people. Faculty certainly encouraged industry people to clearly communicate the job-related skills they need and want to see in future employees and to suggest the kind of preparation students should get at the undergraduate level.

Not everyone, however, wants to see industry representatives sitting down at faculty meetings to discuss curricular changes. The university, some note, is much more than a training camp for industry; students have more educational needs than the development of job-related skills.

Before industry and the academic community can find mutually satisfying solutions to the educational problems they have identified, they must find new and creative ways to interact. They must keep alive the discussions begun at these workshops and maintain the enthusiasm for change and mutual support they found in each other.

The direction and guidelines for a joint educational venture remain to be found. But clearly industry and the academic community see themselves as united in a common effort to improve undergraduate analytical curricula and to increase the number of students who study for careers in industry.

III. SUMMARY OF RECOMMENDATIONS AND IMPLEMENTATION MODES

The recommendations that follow are designed to provide a variety of resources to instructors that will encourage experimentation and facilitate implementation of classroom and laboratory educational strategies. It is important that the implementation of these recommendations involve a partnership among the major players in this matter: college and university faculty and administrators; representatives of those industries who are major employers of students with skills in the science-based and engineering disciplines; and the federal agencies that support research and educational activities in the analytical sciences.

1. COURSE CONTENT AND LEARNING MODES

Undergraduate analytical curricula need to better prepare students to solve future problems and to pursue analytical science careers.

RECOMMENDATION: That the academic community develop context-based curricula that incorporate problem-based learning (PBL).

PBL and the use of real-life samples and contextual examples will help undergraduates apply what they learn on campus to careers within industry or to graduate study. To be effective, however, a problem-solving approach must encompass the complete analytical process-sampling, sample preparation or separation, measurement, and data analysis and interpretation-rather than focus on just a single analytical step or methodology.

In general, the participants agreed that all analytical students, regardless of their specific disciplines, must know how to use the scientific method and the analytical process. (For more on this, see Pardue, Appendix C.) They must write and speak effectively and must know how to work as teams and participate in strategic planning. They must be computer literate and familiar with the instrumentation used in their discipline.

The generic components of an analytical problem-solving approach should include the following:

- defining the problem
- dealing with sampling
- separating the analyte from interfering substances
- performing the measurement
- interpreting the data
- assessing and validating the results

The development of such analytical problem-solving skills in classroom and laboratory activities will, by necessity, involve mastery of analytical methods that include separation science, optical spectroscopy, electrochemistry, mass spectrometry, surface analysis, and other techniques. It is important that the emphasis be shifted from superficial coverage of methods to the utilization of selected methods in the context of problem-solving. The laboratory portion of the course should consist of relevant experiments. When possible, these experiments should address real, contemporary problems.

We realize that we must be realistic about how much can be included in the usual introductory college course, but we believe a reassessment of course content and teaching methods will make it possible for these skills and approaches to be included.

To those ends, we recommend the following:

Develop appropriate and supportive learning materials: Texts, laboratory manuals, and other materials should be developed that support a context-based, problem-solving approach to the study of analytical science.

Develop lab modules that emphasize and test all aspects of the analytical process: A great need exists for laboratory modules that motivate faculty and that interest students. These materials may include multi-week, inquiry-based, real-world examples and, when possible, the analysis of real samples.

Distribution of examples of the best practices being used within the academic analytical community will help others develop and implement best practices in their departments. (See Appendix B for Best Practice examples.)

The establishment of partnerships between analytical scientists in industry and in academia will help guide the development of new laboratory modules on specific topics.

RECOMMENDATION: That teaching styles accommodate students' different learning needs.

The National Science Foundation (NSF), other governmental agencies, and industry are trying to entice a more diverse group of people into the scientific and technical work force. This nationwide push to build the technical work force can succeed if there is acknowledgment that not all students learn science in the same ways and that teaching approaches must address a variety of learning styles. For a good discussion on teaching styles, see Chapter 8, "Getting to Know Your Students," in *Science Teaching Reconsidered: A Handbook,* published in 1997 by the National Academy Press.

The traditional lecture format or cookbook laboratory often fails to entice students into science courses or fails to help those already enrolled to succeed. Success in introductory science courses will encourage students to re-create that success in other courses and even in a science-based career.

To those ends, we recommend that the following be implemented:

Analytical faculties expand their teaching methods: Effective instruction in the analytical sciences should incorporate some of the following methods. When possible, these methods should emphasize the development of oral and written communication skills:

- Small-group learning
- Cooperative learning
- Project-centered classes
- Investigative-oriented labs and lectures
- Case studies
- Emerging technologies
- Assessment tools of context-based learning

RECOMMENDATION: That more students be offered hands-on learning opportunities.

For many students, an introductory chemistry course is their only formal exposure to analytical chemistry. Those who go beyond first-level courses may not be challenged in ways that excite them to pursue analytical science as a career.

To those ends, we recommend that the following be implemented:

Bring context-based learning to introductory courses: Context-based educational principles should be used in the introductory chemistry labs that involve analytical measurements. These measurements should include topics related to quantitation by “wet” analytical methods, such as titrimetry and gravimetry. Introducing these measurements at the introductory level will allow more time within the analytical curriculum to teach the skills and problem-solving approaches mentioned earlier.

Provide undergraduates research opportunities with faculty members: Undergraduate research develops familiarity and comfort with the scientific method and the analytical process and builds skills in problem solving and critical thinking.

Scale up best practices: Scaling up best practices to accommodate larger classes requires some special attention. Technology, such as interactive multi-media, can ease some problems of teacher-to-student ratio.

RECOMMENDATION: That universities form partnerships with community schools to enrich the K-12 science experience.

Many of the principles of analytical science are particularly well-suited to the K-12 classroom. Through outreach to K-12 teachers, two- and four-year institutions and research universities have an opportunity to strengthen science education in younger students and to stimulate their excitement in the sciences.

RECOMMENDATION: That the American Chemical Society (ACS) take a more active role in promoting curricular improvements in the education and teaching of analytical chemistry.

To those ends, we recommend the following:

The ACS Examination Committee keep the analytical examinations current: Exams can promote the learning of the analytical process by including questions about sampling, sample preparation and separation, measurement, data acquisition, and interpretation.

The Committee of Professional Training assist in the move toward curricular reform. The committee can consider ways to promulgate “best practices” of problem-based learning and to develop recommendations on technology standards. (See Core Technologies under Section 2.)

2. CORE TECHNOLOGIES FOR UNDERGRADUATE LABS

Anyone trying to equip an undergraduate laboratory or classroom faces a seemingly endless list of choices for such things as equipment, software, online services and world wide web access, and data acquisition tools.

RECOMMENDATION: That the analytical community develop a list of appropriate and well-developed technologies that faculty may consider for their classes and laboratories.

The Institute of Electrical Engineers developed such a list. It examined the appropriate use of technology in the classroom and set recommendations for technology standards. The analytical chemistry community could do the same.

A list of core technologies would help faculty and departments in the acquisition of instrumentation. A follow-up group from these workshops will meet and forward its list of recommended core technologies to professional societies for dissemination to the wider educational community.

To those ends of developing core technologies, we recommend the following:

Pursue continuing education: Faculty must actively upgrade their technological skills and knowledge through continuing education opportunities. ACS- or industry-sponsored short courses, virtual conferences and web courses, and training opportunities offered by manufacturers and vendors can help keep faculty current. (See Evans, Appendix A, for examples of how technology can be used with student researchers.)

Encourage vendors to serve the education market: Members of the analytical community should identify, recognize, and support those companies that serve the educational market and that develop or offer products and equipment of high quality and at reasonable costs.

Broaden definition of technology: By broadening the definition of technology to include more than what might be found in analytical chemistry, faculty will gain an appreciation for how technology enhances and supports work in other disciplines or other professions.

A technology symposium that brings together people from other disciplines could broaden our appreciation for technology and its uses and encourage us to use it more broadly and with greater innovation.

RECOMMENDATION: That faculty and their departments strive to incorporate today's technology into classrooms and laboratories and to use technology as an access to real-world learning.

In addition to learning about technology, faculty must also make technology an integral part of today's undergraduate classroom and laboratory. They must find ways to use various technologies as tools for learning.

To those ends, we recommend that the following be implemented:

Use technology to link classrooms and to enhance learning: Through the Internet, the web, video-teleconferencing, and virtual classrooms and laboratories, technology can link K-12 classrooms with colleges and research universities, and institutions of higher learning with each other and with other local, state, and federal agencies. These communication technologies will also enable industry to interact with classrooms nationwide, creating virtual internships and bringing outside expertise to campus.

Iowa offers an excellent example of just such a learning network. The state has invested more than $240 million in the Iowa Communications Network (ICN). This optical fiber network currently links every community college, every four-year state school, and many private colleges and K-12 institutions. Each of the state's 99 counties also has at least one site. When completed, ICN will have 600 sites.

Some faculty are cautious about the widespread use of virtual learning and research simulations. Fears and concerns about virtual-learning opportunities can be mitigated if educators acknowledge that virtual learning enhances, but cannot replace, hands-on learning. It can supplement, but cannot supplant, real-world experiences.

3. FACULTY DEVELOPMENT

Analytical faculty are essential to the education and training of undergraduates who seek science-related careers. To prepare and encourage students, faculty must stay current with technology and with the skills industry seeks. Faculty also must be encouraged to drive the curricular reforms in undergraduate education that will support U.S. research efforts and foster growth in the scientific and technical work force.

RECOMMENDATION: That faculty in the analytical areas broaden their technical skills and industry awareness by seeking non-academic resources and learning opportunities.

Just as the participants call industry to a greater involvement in the education and training of faculty and students, they also call faculty to take an active role in their own continuing education.

To those ends, we recommend that faculty implement the following:

Invite non-academics to campus: Through short courses, classroom speaker programs, lectures, and one-on-one relationships between faculty and members of industry and government, faculty can connect with and learn from those who can bring a work-world perspective to the academic setting.

This outreach can include an invitation to join departments in discussions about curriculum. Local and regional industrial and governmental representatives can deepen the academic world's knowledge of the work place and suggest ways in which the curriculum can support industry and government needs for skilled workers.

Seek sources for real-world problems: Through contacts with local and regional industries, faculty can find sources for real-world problems and even samples that can be used in the classroom and laboratory.

Develop exchange and visitation programs: Continuing education happens on and off campus and in short and long periods of time. Non-academics can come to campus, and faculty can make on-site visits to industry and government.

Although travel distances, time, and costs will determine the types of exchanges, faculty are encouraged to consider a broad range of possibilities. Options can include exchanges for a day, a year, a summer, spring and winter breaks, or exchanges on an intermittent but ongoing basis.

Establish a non-academic advisory board: Non-academic advisory boards can help with a multitude of needs. Board members are sources for real-world problems and samples, resources for continuing education and exchange programs, contacts for donations of equipment and supplies, resources for donor development, avenues to internships and mentoring programs, and support for research opportunities.

Support development of the Senior Analytical Corps: Industry is encouraged to develop a Senior Analytical Corps and share the experience and knowledge of its retired scientists and technicians with academics. This corps of retired industrial experts will be an educational resource and help mentor students and faculty through on-campus short courses and lectures. These activities will help faculty and students keep current with industry needs and viewpoints.

For their part, educators can work with industry, can encourage the development of such a corps in their area, and can find ways to tap the expertise of retirees who join the corps.

RECOMMENDATION: That analytical faculty drive the revisions to undergraduate analytical curricula and help spread the word about the need for these revisions.

Ultimately, curricular reforms must come from within the academic community. Academic administrations must also want and support these changes. Many faculty and their institutions are unaware or unconcerned that their analytical curricula have not kept pace with technology or work force needs. They would, however, support changes if they understood the issues, the growing need for reform, and funding agencies' interest in supporting these reforms.

To those ends, we recommend that faculty implement the following:

Create opportunities for curricular changes: Visits from non-academics and industry sponsored short courses, lectures, and exchange programs can offer opportunities to educate. Interactions between non-academics and academic administrators, department heads, and other faculty can create awareness of the work force and research needs of industry and government and show the vital role of curriculum in meeting those needs.

Work within academics to generate support for change: Faculty have made a career of educating and encouraging their students. In the area of curricular reform, faculty must now teach each other about the needs and benefits of reform and encourage support for such reform. Those who support change can bring others to support it as well. They can

- Share problem-based learning materials and other curricular information
- Urge colleagues to attend presentations and short courses by non-academics
- Serve as liaisons between industry and government and the campus
- Share information about NSF and other outside funding sources that support curricular reform and growth in the technical and scientific work force
- Disseminate information on best practices

More faculty may support problem-based learning and the use of real-world problems and samples if they see success elsewhere. Success stories can be shared if

- Information about best practices is distributed to faculty nationwide
- Fellowships are funded that enable faculty to visit Best Practice sites
- A clearinghouse is established to gather and distribute materials used in Best Practice courses

4. LEARNING PARTNERSHIPS WITH INDUSTRY

Calling upon industry for such things as instrumentation, financial support, real-life expertise, and learning opportunities can help educational institutions prepare future analytical scientists for the work force.

RECOMMENDATION: That industries form learning partnerships with educators in the analytical sciences.

Partnerships between those who hire analytical scientists and technicians and those who educate and train them will enhance the educational opportunities for two- and four-year students. These partnerships will also increase the number of students who are likely to choose a career in the analytical sciences and will prepare more students for real-world work.

Through their campus visits, industry people can bridge the work world and academic world by bringing an awareness of real-world problems and problem-solving approaches to classrooms and laboratories.

By reaching out to a broad spectrum of students and faculty, on- and off-campus partnerships will encourage diversity in the work force and multi-disciplinary approaches and reflect the global opportunities present within industry today.

Through innovation and shared resources, these partnerships will help America build a technically and scientifically skilled work force.

To those ends, we recommend that the following be implemented:

Create learning opportunities for faculty and students: Industry can offer more on-site short courses, summer internships, fieldwork opportunities, and other short-term, cooperative employment. It can sponsor and assist in developing undergraduate research projects and in creating mentoring programs for new faculty. It can also co-sponsor symposia or professional meetings and can work with faculty to develop research programs of mutual interest to industries and universities. In exchange, research faculty can develop on-site short courses for industry.

The NSF GOALI-Grant Opportunities for Academic Liaison with Industry-initiative provides grant opportunities to implement many of these industry-university partnerships. These opportunities are especially helpful in fostering exchanges between faculty and industrial scientists and in the joint training of graduate and postdoctoral students.

Share knowledge and resources: Industry can donate used equipment, help with the purchase of new equipment, or share equipment. These approaches enable industry to play an important role in keeping academic laboratories current and in helping students and faculty become familiar with on-the-job instrumentation.

Industry can take a leadership role in bringing web and video conferences to campuses nationwide. Remote analysis of real-world samples, virtual laboratory experiences, and simultaneously transmitted lectures or conferences can provide relevant data and teach information-gathering skills through the use of advanced technologies.

Build regional alliances: Industry can help build alliances between industry, government, educators, and communities--everyone with a stake in a technically skilled work force. These alliances will encourage multi-disciplinary efforts and the sharing of human and financial resources.

Participate in curricular development: Industry can take a non-traditional approach and help in the development of curricula that address not only a solid foundation in analytical principles, but also the application of those principles to the real-world needs of industry.

5. TECHNOLOGY

The rapid growth, ongoing upgrades, and costs inherent in modern technology can overwhelm and surpass the ability of faculty and institutions to keep current. Technology, however, drives and supports both research and industry. Students seeking science- and technology-related jobs learn needed skills from course work and in laboratories that keep pace with technological change.

RECOMMENDATION: That the community of analytical educators take an active role in the design, assessment, and purchase of technology as it applies to education and in their own continuing education.

Up-to-date instrumentation and equipment, faculty and student access to computers, links to the web, virtual learning experiences, knowledge about available technology, and the skill to work effectively in spite of rapid technological change were among the issues the participants considered.

All felt the pressure to be on the cutting edge of technology, even as they faced budget constraints and limitations of time and access to information. In spite of the pressure to be technologically advanced, the participants agreed that economic and commercial factors cannot drive the choices of which instruments, hardware and software, and equipment to purchase for laboratories and classrooms. Rather, faculty and their institutions must determine what is an appropriate use of technology in the classroom. They must also have realistic expectations about its use and benefits to students and researchers.

To those ends, we recommend that the following be implemented:

Help faculty stay current on technology: Faculty want to keep up with current technologies, but many have trouble finding the time and resources to stay abreast of developments. Some are overwhelmed by the task of finding and then studying the wealth of information. Governmental agencies, publishers, and professional societies can help faculty focus on relevant information about technology and its uses in the classroom and laboratory.

The creation of a web site devoted to new forms of technology, an Internet listserve about technology, or a clearinghouse that could receive and distribute information would increase faculty access to relevant news about technology and its innovations.

Symposia at professional gatherings, such as PITTCON, can also help faculty stay current and share information about what has worked in other classrooms and laboratories nationwide.

The American Chemical Society can distribute information on best practices, as they apply to the use and applications of technology for undergraduates and cooperate with other scientific and professional societies to distribute information. We also support the NSF's interest in developing a national library for technology that will be organized, kept current, and disseminated electronically.

6. FOLLOW-UP AND DISSEMINATION

Keeping people informed and in touch about curricular issues and the research and work force needs of industry and government is critical to encouraging, implementing, and finding support for change.

RECOMMENDATION: That everyone involved in undergraduate education look for ways to share information about curricular reform.

Before curricula and laboratory practices can be reformed, those in chemistry must have a basic understanding of problem-based learning, best practices in teaching, current technology, grant support for curricular reform, industry and government work force needs, and the national push to increase the technical and scientific labor pool.

Those in academia, industry, and government must hear about this reform movement. They must be kept current on what others are accomplishing and what remains to be done.

To those ends, we recommend that all who helped shape this report and those who read and support its recommendations implement the following:

Share information through professional organizations: Professional journals can provide features on such topics as best practices, workshops on curriculum and sponsored programs, and editorials that address curricular reform. Members of professional organizations can encourage editors at publications like the *Journal of Chemistry Education* or *Analytical Chemistry* to find writers for these stories.

Some professional organizations have their own web sites where information can be posted or where links to additional information are provided.

Participants agreed that the discussions and information from these workshops be shared widely and presented at professional meetings of industry and academia.

Professional organizations and instrument vendors might also prepare and distribute teaching materials to their membership. Having materials and ideas in hand will help faculty maintain the process of curricular reform.

Encourage industry to speak out for reform: Through its connections, industry can help educate state, regional, and federal agencies, other industries, the academic community, and K-12 institutions about the need to develop an educated analytical work force.

Within industry, groups like the Directors of the Industrial Research Analytical Group (DIRAG) or ALMA (Association of Laboratory Managers) can be encouraged to make recommendations on curricular reform and to help disseminate information.

Offer workshops at national and biennial meetings: At their local, regional, and national meetings--such as PITTCON--professional organizations can offer workshops on topics related to curricular reform, including funding opportunities.

Develop a newsletter for analytical faculty: A national newsletter can keep faculty at two- and four-year colleges and at research universities in touch and encourage reform as a continuing process and goal.

At present, faculties from these various institutions generally do not connect with each other. All, however, are involved in the education and training of tomorrow's scientists, technicians, and academic researchers. A newsletter offers a common point of contact to those who share a common mission.

Form information links with existing initiatives: Existing initiatives like the NSF's KDI Initiative or the ACS' initiative Vision 2020 to support work force development can help distribute information.

RECOMMENDATION: That everyone who is involved in analytical undergraduate education or who benefits from it look for ways to fund curricular reform.

To this end, we recommend that all who helped shape this report and those who read and support its recommendations implement the following:

Encourage industry to generate funds for reform: Industry can help leverage financial support for reforms that will improve undergraduate analytical education and that will increase the numbers of those employed in the analytical sciences.

Seek grant support for curricular reform: NSF has indicated that programs are in place for the ongoing work of reform and for programs that result from the ideas and efforts generated by these workshops.

The Division of Undergraduate Education has funded several of the best practices found in Appendix B. More opportunities for education projects with a multi-disciplinary focus exist in current and new programs.

JERRY A. BELL
AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE
WASHINGTON, DC

INDUSTRY-SPONSORED EDUCATIONAL PROGRAMS: AN EXAMPLE FROM MERCK AND THE AAAS

Industry is investing in the improvement of science education from kindergarten through the baccalaureate. One such program is the Merck/AAAS Undergraduate Science Research Program, a collaborative effort administered by the American Association for the Advancement of Science (AAAS) and funded by The Merck Company Foundation.

This program, with its explicit goals and criteria, is open to all eligible institutions located in one of twelve northeastern and mid-Atlantic states.

Grants from the Merck/AAAS Undergraduate Science Research Program--$20,000 annually for up to three years--enhance undergraduate science education in the areas of biology and chemistry. They specifically encourage programs that foster an understanding of the interrelationship between biology and chemistry and that help to bridge these disciplines. Grant-supported undergraduate research experiences emphasize the relationships between biology and chemistry, encourage students to pursue graduate education in these sciences, and develop student interest in careers that combine these sciences.

The grants also facilitate interactions between the pharmaceutical industry and academic institutions. For example, the Merck Lecture Series, funded through this program, provides an opportunity for Merck scientists, among others, to interact with students and faculty at the grantee institutions.

At AAAS, we believe that by encouraging more interdisciplinary programs in biology and chemistry at the grantee institutions, the program may change the “culture” of the sciences. Those at Merck believe the program’s focus on interdisciplinary research and interaction with Merck scientists will help attract students to biomedical research.

After years of involvement with industry-sponsored education programs, those of us at AAAS also offer some brief guidelines for anyone interested in developing business- and industry-sponsored programs at colleges and universities.

These programs should

- focus more on systemic approaches and less on discrete, scattershot projects
- support more sustained projects and fewer one-shot, short-term projects
- support more programs based on a shared vision and fewer without clear goals
- create more partnerships that support mutual interests and fewer that support only corporate self-interest
- offer more support that leverages institutional funds
- take a more active involvement in attaining goals and less in maintaining a distance from the institution
- provide for more visits from scientists who can target program goals and fewer random, unfocused visits

The Merck/AAAS Undergraduate Science Research Program follows these guidelines. With annual funding of almost $300,000, the Merck Company Foundation has made a long-term commitment to this program. The guidelines above are good benchmarks against which to judge the effectiveness of industry-sponsored programs at colleges and universities.

Jerry A. Bell is the AAAS’ Director of the Science, Mathematics and Technology Programs.

CHARLES A. EVANS
CHARLES EVANS ASSOCIATES
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THE USE OF TECHNOLOGY IN A TEACHING ENVIRONMENT FOR SURFACE ANALYSIS

We have begun several initiatives using technology for the education of students and other scientists. The first is the writing of a computer-aided, instruction software package that contains two components. One is a tutorial on the four most common surface analytical techniques: ESCA, Auger, Dynamic SIMS, and Rutherford Backscattering Spectrometry (RBS). The second is an experimental data acquisition simulation package that allows the student to design a sample and then to submit it for analysis to any of the four techniques.

The ultimate goal is to be able to perform analyses at a great distance from the student, who will be present via the video conference.

Depending on the sample and the analyst's request, the software can generate spectra as well as depth profiles. The data can also be manipulated to provide different types of presentation to the students. The tutorial is available on the web page of Charles Evans & Associates at http://www.cea.com. At present, the experiment simulation software is not operable from the web page. However, when a diskette of the software is obtained, both components are available to the user. In addition, the tutorial acts as a help system during the operation of the experimental simulation software.

Our other use of technology involves video conferencing with a capability we call remote presence or tele-analysis. This experiment is being done in conjunction with the Center for Materials Research at Stanford University. The goal is to use video conferencing located at Stanford University and Charles Evans & Associates to provide a variety of capabilities to assist students in their use of surface and microanalysis for their theses.

The student first has a video conference with an analyst or analysts. This can be set up on fairly short notice. The nature of the analytical requirement is discussed over the video link, and then the student submits his or her sample for analysis by mail or by courier. The analysis is again performed via video conference so that the student can see the actual analysis taking place. The value of such a system eventually would come from students being able to send samples from their research site to another university or to a commercial analytical lab where the analysis is done. They will also be able to participate in the analysis, even though travel costs prohibit their physical presence during the analysis. Enhancements that we are working on include simplifying the transmission of images to remove the need for a dedicated video conferencing system. We have transmitted repetitive, still images from a video camera via the internet from our site to a desktop computer accessing the internet. Updates every few seconds seem to be quite possible. To provide the presence under such conditions, the analyst and the student or customer would be connected by normal phone line operating with a speaker phone or hands-free mode so the data can be discussed.

The real challenge that remains is how to fax a sample!

We also are attempting to transmit data via traditional phone line directly to a printer without having to have a dedicated computer on the receiving end. It may also be possible to transmit the data via the internet to the remote printer. In this way, an updating, still image of the laboratory is seen, real-time presence is provided by a standard telephone line, and data transmission could be to a color printer or some other appropriate output device at the customer or student's site. Although these approaches may seem rather uninspiring, we believe we are limited only by today's technology and our imaginations.

Charles Evans is the principal owner of Charles Evans Associates.

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THE TRAINING OF ANALYTICAL CHEMISTS: A MERCK SURVEY

Questions as to how teachers can best educate and train analytical chemists for technical careers certainly were central to these workshops. Voices from industry, academics, and National Science Foundation were all heard during the discussions on how and if analytical science curricula adequately prepare today's students for the work force.

At the second workshop, K.C. Kwan from the Merck Research Laboratories shared data from an informal survey sent to more than 200 practicing analytical chemists. Most of them worked at Merck & Co., but some also worked with the Drug Metabolism Unit at Rhone Poulenc Roher in Collegeville, Penn. Kwan's survey results offer relevant information about the training of analytical chemists as revealed by the chemists themselves.

Basic laboratory skills should include weighing, measuring, pipetting, the preparation of standard solutions, and an understanding of the concepts of accuracy, precision, and specificity.

Kwan said the survey was undertaken for two reasons. First, discussions at the first workshop made it clear that data about job-related skills either didn't exist or wasn't available. "Second," he said, "I wanted a reality check on an impression that my colleagues and I have formed over the years: Recruits coming directly from undergraduate or graduate programs generally need 6 to 12 months to become productive analytical chemists in industry." Kwan said the fact that a large majority of the responders acquired their analytical skills on the job was consistent with his impression.

Kwan shared the overall impressions that could be gleaned from the 55 survey responses. Of those who replied, 22 had undergraduate degrees, 11 had master's, 10 had Ph.D.s, and another 10 had post-doctoral work. The following is a summation of their comments:

(1) An understanding of the basic principles of chemistry is essential to success on the job. This basic knowledge should include general chemistry, as well as organic, analytical, physical, and inorganic. In addition, undergraduates should have a basic understanding of math, physics, and biochemistry. Chemistry graduates felt their formal training gave them an adequate foundation.

(2) About half of the responders said they acquired their analytical skills as undergraduates; a similar number obtained theirs as graduate students. Forty of the responders also cited on-the-job training, especially for their skills with modern instruments and problem solving.

Summer internships and cooperative study programs are valuable adjuncts in undergraduate training.

(3) Most thought basic analytical techniques should be taught as early as possible in high school and undergraduate courses. Laboratory courses in qualitative and quantitative analysis are essential. Responders cited spectroscopy, separation science, electrochemistry, experimental design and statistics, and electronics for chemists as important ingredients in the undergraduate curriculum. A laboratory course in instrumental analysis was cited wishfully with the caveat that undergraduates don't have access to modern analytical instruments even in schools that have these instruments.

(4) Courses within the liberal arts, but outside of chemistry, are needed to develop interpersonal, communication, organizational, and computer skills. The chemists also noted that students should be helped to understand Federal regulations and should learn how to keep records, how to plan and organize experiments, and how to manage time.

Kwan noted people should be careful not to over-interpret the results from such a small sample size. However, those who replied represented almost the entire range of analytical chemists within Merck, so their responses offer a valuable perspective.

Judith Galas, a free-lance writer, attended the workshops and interviewed Dr. Kwan for this commentary.

KENNETH HUGHES
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TIME AND QUALITY INSTRUCTION: KEY INGREDIENTB IN UNDERGRADUATE EDUCATION

Academic institutions and industry want to modify the traditional lecture and laboratory curriculum in analytical chemistry. Most often, there is a desire to incorporate real-world chemical systems of increasing complexity, multimedia, and computer technology. How does one generate real situations and experiences for students using this technology?

Unfortunately there is no right answer, but there are several issues. The most important, however, is time. Time spent in the laboratory is critical to the learning process and to student progress in areas of problem solving and communication. The current trend is to decrease the time spent in the laboratory so that more students can take the lab. But two- and three-hour laboratories do not adequately educate or train students headed for the work force.

Students must have time to observe, re-work experiments, and discover solutions to problems and their own mistakes.

Labtime is only one issue; the other is the teaching quality in labs. At many research-level institutions, graduate students work as teaching assistants (TAs) or research assistants (RAs). TAs more often are the youngest and least experienced graduate students. In many cases, the majority of first-year graduate students serve as TAs, and this experience gives these beginning students an opportunity to review the materials needed during their graduate careers.

As RAs senior graduate students are valued as students who provide maximum return to faculty researcher's dollars. In return, RAs get paid to focus on their research. In the past two decades, the job of RA has been elevated, and it now carries with it much higher esteem. The RA status motivates students to do a better job in the research laboratory.

An unforeseen drawback, however, is the decline in the quality of instruction in undergraduate labs. Here the TA attitude more than aptitude sets the tone and quality of instruction. Older TAs often resent the time teaching drains from their own research time, and often are single-minded in their efforts to become RAs again.

Older TAs o/ten have poor attitudes ing their responsibilities to assist in the training and education of undergraduates.

One possible solution to this growing problem is to split the teaching requirement for a graduate degree into two parts: one teaching requirement to be completed in the first year and the other during the semester just before graduation.

The advantage is that newer graduate students get to teach in the laboratory earlier, while their enthusiasm is high and their research still unfocused. This split approach may also help senior graduate students relay the excitement of research to undergraduates and to newer TAs. It may also prepare them for their on-the-job interactions with bachelor-level technicians, with engineers, with scientists outside their field, and with people in the marketing and legal departments. Finally, a senior graduate student provides more competent support for many courses and clearly assists the faculty member teaching the course.

Kenneth Hughes is an Assistant Professor of Chemistry

CYNTHIA K. LARIVE
UNIVERSITY OF KANSAS
LAWRENCE, KS

INSTRUMENTAL METHODS OF ANALYSIS LABORATORY: A MOVE TO MODERNIZE COURSES AT THE UNIVERSITY OF KANSAS

The analytical faculty at the University of Kansas have been active for some time in efforts to modernize our undergraduate courses. Until recently, however, most of these changes have been relatively minor, incremental improvements such as replacing a cookbook lab with one that is more relevant to the students. Even with these improvements, our courses have followed the same general format that has been used for decades.

An assigned, semester-long analytical problem challenged the student teams.

These NSF workshops on the analytical chemistry curriculum have demonstrated possibilities we had not imagined. They have stimulated us to critically examine our curriculum and methods of instruction and have provided the motivation for change.

The most dramatic change that took place this year was in the Instrumental Methods of Analysis laboratory. Previously, the first part of the lab had consisted of a series of experiments designed to familiarize the students with a variety of analytical instruments. The focus of these laboratories was almost entirely on the mechanics of the instrument.

During the last one-third of the semester, the students worked on a special project. For this they incorporated one or more of the instruments they'd used earlier in the course to solve a problem of their own choosing. The students worked much harder on their special projects than they did during the first part of the course; and, not surprisingly, they reported that they learned more. They were not simply completing exercises.

This spring Professor Craig Lunte revised the Instrumental Analysis Laboratory course to focus entirely on analytical problem-solving. On the first day students filled out job applications and were assigned to a team of analytical chemists in one of three "companies": a start-up pharmaceutical company, a micro-brewery consulting firm, and the Environmental Protection Agency (EPA). Each team had a problem to solve. The problems were open-ended and solvable over the course of the semester.

The course now includes a new focus on communication.

The biotech team had to develop analytical methods for analysis of a chiral small drug and its major metabolites that would be derived from a genetically engineered organism. Through analysis of the fish, water, and sediment samples, the EPA was to determine the cause of a fish kill in a local river. The micro-brewery consulting firm had to find the source of a skunky smell in a product from a local brewery.

The students had to determine how to effectively solve their problem, so they made extensive use of the library early in the semester. To select an appropriate analytical method, they also had to be familiar with the capabilities of each of the available instruments. A key component of the course was several opportunities to make oral presentations and written reports to middle management, which was Lunte and the teaching assistants; and to upper management, which was the other analytical chemistry faculty.

We feel this approach worked, and we will be integrating a similar problem-based learning strategy into our other undergraduate and graduate analytical chemistry courses.

Cynthia Larive is an Assistant Professor of Chemistry

THOMAS LAYLOFF
FOOD AND DRUG ADMINISTRATION
ST. LOUIS, MO

EMPLOYERS, NOT UNIVERSITIES, CREATE SKILLED EMPLOYEES

Only an incompetent manager would assign a task to an individual without knowing if the person had the knowledge and skills required to satisfactorily perform it. And the corollary: Only an incompetent manager would allow an incompetent analyst to work in the laboratory.

College chemistry curricula are being questioned because employers are unwilling or unable to ensure that their employees possess the required knowledge and skills needed to perform their assigned tasks. Specialized chemical technologies have increased remarkably, while the amount of time spent in undergraduate chemical education has remained constant or has declined.

I estimate that in my FDA laboratories it takes two to three years of full-time experience for a competent person to become productive at the journeyman level.

I, for one, do not believe the university can deliver an immediately employable product who has all of the skills any employer could want. For example, the competency skills I need in my lab include such things as knowledge of applicable safety, chemical hygiene, and quality assurance principles, maintenance of sample integrity, and knowledge of the routine application of one or two separation techniques.

The traditional chemistry program delivers to employers someone who possesses a basic, general knowledge of the nomenclature and of inorganic chemistry, organic chemistry, and physical chemistry; a cursory knowledge of computer applications; and often a brief exposure to separation science.

All of this education and training happens in approximately four months of full-time study. It is extraordinary that so much is accomplished in so little time, even if we also assume that the students are expected to spend more time out of the classroom acquiring this knowledge.

It is impossible for students, even through the graduate programs, to acquire competence in the diverse skills required in the technical job market. Given this limitation of time and the broad range of employment opportunities and employer needs, what should one expect from graduates?

For sure, there should be a good knowledge of basic laboratory skills and the ability to read reagent bottles. Beyond that an educated science student also should have at least a cursory knowledge of the current technical breakthroughs reported in the press such as DNA testing or the cloning of sheep--just as a part of being educated.

The curriculum should also serve to launch a love of learning and, if possible, a deep desire to participate in the orderly pursuit of the unknown. This sensitization to learning and the pursuit of knowledge should be built into all aspects of the curriculum, but the best opportunities come within the sciences.

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JAMES LEARY
JAMES MADISON UNIVERSITY
HARRISONBURG, VA

TODAY'S STUDENT AND THE ACADEMIC ENVIRONMENT

Any curricular workshop must first and foremost address curricular matters, and this report indicates we have done that enthusiastically. However, we should acknowledge that a good, solid curriculum is only one of a number of necessary conditions for success, and that by itself no curriculum ensures success.

Focusing exclusively on the curriculum may be counterproductive.

We should not naively delude ourselves, or the recipients of our report, into believing that simply by improving any curriculum our students will be better prepared for the challenges they will face in graduate schools, professional schools, or industry. We may even contribute to the illusion that the curriculum is the problem, and that its improvement will result in better prepared students.

Let's also consider two of the many barriers to higher education that often play a larger role than the curriculum in students' academic success: student study habits and university resources. For the moment let us assume that classes and labs revolve around wonderful, real-world problems that students accept as relevant. To succeed, students will still need to study and attend class. Is it realistic to assume that the average undergraduate will actually make the time commitment required for success?

Remember, contemporary student life often revolves around social activities, part-time jobs, and intercollegiate sports. One might claim little has changed on campuses in 50 years, but have universities always provided cable TV in the dorms? Are the elaborate, campuswide computer facilities used primarily to expedite intellectual advancement or are they used primarily for E-mail, surfing the worldwide web, and playing multimedia games? Anyone who thinks student life has not changed should tour a dorm and see how today's students spend their time.

On the financial front, many universities struggle to survive in a world of diminished budgets and squandered resources. The funds that support education can either be used to maintain a low student-to-faculty ratio and to provide academic support resources, or they can be used to support athletic programs, to subsidize construction projects, and to enhance the burgeoning bureaucracy.

Let's imagine a scenario in which a university can either add another faculty member to the chemistry department or can spend the same amount of money to increase the size of its public information office. An additional chemist may significantly impact the lives of a small number of future leaders. In contrast, the office of public information impacts everyone. Where will the money be committed? Questions about the validity of this concern can be quantitatively answered at any university. Simply, compare the growth in the faculty in the chemistry department with the growth in staff of the public relations office during the last twenty years.

What is the likelihood that American Nobel Laureates would have risen to the pinnacles of their professions if they were processed like sausages in large lecture classes while being bombarded with extracurricular distractions? If curricular changes within American higher education are to succeed, they will need to be accompanied by a radical realignment of priorities at many, if not most, colleges and universities.

Jim Leary is a Professor of Chemistry.

DAVID LEDDY
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HOUGHTON, MI

INTEGRATING ANALYTICAL SCIENCES BACK INTO THE CHEMICAL ENGINEERING CURRICULUM

Thirty years ago it was hard to differentiate chemistry majors from chemical engineering majors until their junior years. Both took general chemistry, organic chemistry and the first course in analytical chemistry, and physical chemistry. In the late 1970s, chemical engineering programs gradually dropped their analytical chemistry courses. It now appears likely that physical chemistry courses in the chemical engineering curriculum also will be reduced, and similar credit-hour cuts are anticipated for organic chemistry. It is obvious that if we wish to educate engineering students into the principles of the analytical sciences, we will have to integrate basic analytical techniques and modern instrumental methods into the chemistry courses that remain in the chemical engineering curriculum.

In the future, chemical engineers will probably earn a B.S. degree with a minimal knowledge in chemistry.

Here at MTU we know that if we want to educate engineering students about analytical science principles, we will have to integrate the material into the chemistry courses still available in the chemical engineering curriculum: general, organic, and physical chemistry. Fortunately these courses have laboratory components that can be modified to meet some chemical engineering needs. We also know special efforts must be made to help the chemical engineering faculty introduce process analytical chemistry into the senior-level, chemical-process laboratory.

The trend in engineering is to use on-line, real-time analytical procedures in the process industries. So, a basic knowledge of these concepts and procedures will have to be introduced into undergraduate course work.

"Process Analytical Chemistry," a senior-level, laboratory-based course is designed to appeal to chemists and chemical engineers who plan careers in chemical processing. The chemical industry has applauded the course. Classes, however, are small. Many chemical engineering students want to take the course, but their chemical engineering schedules prevent it. So, we have yet to enroll a chemical engineer.

I suggest students in chemical engineering, environmental engineering, chemistry, physics, and the biosciences be directed into a special, first-year, general chemistry course with significant analytical content. This course would include basic measurement statistics, sampling protocol, titrimetric and gravimetric analysis, and basic instrumental analysis such as u.v.-vis or i.r. spectroscopy, gas chromatography, liquid chromatography, mass spectroscopy, and simple electrochemistry. These topics could be effectively taught by covering only basic chemical equilibrium in general chemistry and by eliminating the more sophisticated calculations in most courses.

In organic chemistry, more experiments using chemical instrumentation should be introduced. On-line analysis can be illustrated using i.r. techniques for distillation and esterification processes. Examples of how commercial processes are monitored in industry can be illustrated in lecture.

Changing laboratory experiments to ones that demonstrate the use of simple instruments would be necessary and would require an investment in instrumentation.

In physical chemistry, instrumentation of the lab experiments to illustrate data collection and analysis would reinforce the need for proper experimental design. Our physical chemistry lab at MTU is moving rapidly in this direction.

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MILDRED SMALLEY
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HELPING HIGH SCHOOL CHEMISTRY STUDENTS AND THEIR TEACHERS: A SUMMER PROGRAM

CHEM 240 provides an integrated package of lectures, problem-solving sessions, examinations, computer interactions, laboratory experiments, field trips, and seminars.

The NSF-supported Environmental Microscale Pre-College Analytical Chemistry Program, (EMPAC-PAC), offers high school students an intensive, eight-week summer course in college analytical chemistry at Southern University--Baton Rouge. CHEM 240 carries four hours of college credit. Students who earn at least a B may petition a university to accept CHEM 240 in lieu of an equivalent undergraduate chemistry course.

Each summer, SUBR's program serves 20 academically advanced high school juniors, seniors, and recent high school graduates from local high schools. Students, preferably minorities, must have completed at least one year of general chemistry and must have at least a 3.0 GPA in high school chemistry, science, and mathematics courses.

The high school students work with two SUBR faculty, two local high school chemistry teachers, and an undergraduate SUBR chemistry major, who serves as a student mentor and computer assistant. During the summer session, students work in course-related activities five days a week from 9 a.m. to 4 p.m.

Student improvement and a low drop-out rate help dispel the thoughts of many minority students and others that SEM courses impose insurmountable difficulties.

On average, students earn a C grade, but the program focuses less on grades and more on skill development in students and the high school teachers. EMPAC-PAC first seeks to motivate high-achieving high school students to pursue careers in engineering, mathematics, and science, preferably chemistry. CHEM 240 challenges students with a college-level, analytical course and exposes them to the tools they will need to successfully matriculate as college majors in science, engineering, or mathematics (SEM).

Second, the program offers high school chemistry teachers the chance to work at a university as teacher apprentices. Their experiences with a college-level chemistry course make them more informed and more effective high school science teachers.

The high school students show improved science skills as measured by the Associated Western Universities' general chemistry exam and the American Chemical Society Analytical Chemistry Examination. The marked improvement in most students' test scores is interpreted as an affirmation of the program's overall effectiveness.

During the eight weeks, students learn problem-solving and test-taking skills. Field trips expose them to career opportunities, and mentoring gives them personal attention.

EMPAC-PAC is a key recruitment tool for identifying and attracting good students to chemistry and other SEM departments at SUBR. These students, including some who earned Cs and Ds in CHEM 240, have proved to be among the best undergraduate chemistry majors. The program also meets its second goal of improving high school chemistry education by better preparing high school science teachers. Three years ago, students of one EMPAC-PAC high school chemistry teacher were among the weakest in the program. Now students from this teacher's classes are among the program's strongest and best prepared. Overall, there is continual improvement in the academic preparedness of students now enrolling in the program compared to the abilities of those who enrolled between 1991 and 1993. EMPAC-PAC shows that helping high school chemistry teachers alter their teaching strategies and expectations improves the science skills of their students.

Mildred Smalley is a Professor of Chemistry.

THOMAS J. WENZEL
BATES COLLEGE
LEWISTON, ME

LOOKING BEYOND THE TRADITIONAL APPROACH FOR NEW WAYS TO TEACH CHEMISTRY

Two years ago I had the chance to talk to several Bates College trustees about the new format of my analytical chemistry courses. During the question-and-answer period, I commented that the teaching methods that had worked in the past were no longer the best to use today. The immediate response from the trustees--people who had done their undergraduate studies in the fifties through the seventies--was to question what made me think that past teaching methods actually worked. They were uniform in their view that the group-learning classroom and project-based labs I described would have been a better and more interesting way for them to learn as well.

We need to significantly alter the traditional way in which we teach undergraduate chemistry. Analytical chemists solve problems. This does not mean they work through repetitive calculations as one would find in the problems at the end of chapters in any text on Quantitative Analysis.

I believe we need to question whether the traditional approach to teaching was ever the most effective way for students to learn.

Instead, analytical chemists are asked to devise procedures to accurately, precisely, and quickly analyze new samples with new matrices. That is why we need courses and laboratory experiences that prepare undergraduates to solve such open-ended problems. Eliminating the lecture approach and three-hour lab experiments in which students analyze certified samples are the first steps in developing an undergraduate curriculum that better educates students in analytical chemistry. It is essential that we incorporate classroom practices that focus on discovery and problem-solving.

We must develop laboratory projects that are multi-week to semester-long, that involve real samples and real problems, and that require students to critically examine the literature and to make the types of decisions that practicing analytical chemists routinely make.

The vehicle in which to establish such a new pedagogy is one that can depend on the interests of the instructor. For clearly the enthusiasm of the instructor is crucial if any new teaching method is to be successful.

The environment, living systems, materials, and consumer products are examples of areas that provide interesting samples around which laboratory projects can be designed. The skills that are utilized in solving problems in any one of these areas can be applied universally to all types of analytical problems.

Scientists are comfortable conducting experiments in the lab. We should be similarly comfortable conducting experiments with how we teach. My guess is that experimentation will lead to new insights and to improvements in our teaching that will benefit our students and ourselves.

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GLENN BOUTILIER
THE PROCTER & GAMBLE Co.
CINCINNATI, OH

AN INDUSTRY-SPONSORED SHORT COURSE WITH AN EMPHASIS ON PROBLEM SOLVING ENCOURAGES UNDERGRADUATES TO PURSUE ADVANCED DEGREES AND TO CONSIDER CAREERS IN ANALYTICAL CHEMISTRY.

Industries that rely on employees with advanced degrees in the physical sciences are concerned about the declining numbers of students who seek advanced degrees or who indicate an interest in working for industry upon graduation. The shortage of analytical chemists in particular prompted Procter & Gamble to create "Professional Analytical Chemists in Industry," a short course to help students learn more about the work of analytical chemists within industry.

This course bridges the gap between industry needs and the academic experience.

Those at Procter & Gamble who developed the day-long course believe that a lack of information about what analytical chemists do, about the importance and excitement of their work, and about their salaries and career opportunities is partly behind students' lack of interest in industrial analytical chemistry. Most science students cannot relate their campus studies to career opportunities within industry.

Analytical chemists are problem solvers. Students, however, have had little exposure to the problem solving typical in industry where problems often are solved by teams working on tight deadlines. Team members focus not only on a solution to a particular problem, but also on the solution's cost-effectiveness. Most often the solution must be easy to manage, safe, and targeted toward customer needs.

The university, which stresses grades and individual achievement, most often requires that students work alone. Undergraduates see faculty and graduate students doing research that often takes several years to complete and months to write. These projects may have little practical use for non-academics and generally do not involve considerations of deadlines and cost. The academic experience, therefore, does not help students consider how their education and training could be used in industry.

The course encourages undergraduates who have already identified themselves as science majors and attempts to interest them in continuing their educations as a way to prepare for careers in industry.

Since 1983, over 2,500 students, at about 50 locations, have attended over 80 presentations of Procter & Gamble's traveling short course. The number of students involved in each presentation has ranged from 10 to 150. The instructors are analytical chemists from Procter & Gamble. The course has no registration fee, and the company pays the instructors' travel costs.

The course is targeted at junior and senior undergraduates who have had at least one semester of instrumental analysis. The students need some previous training so they have enough background to understand the problems and the instrumental analysis the instructors use.

The course objective is to provide accurate information with regard to just what it is that scientists do in the industrial environment. The course content is unique because the problems we solve are actual industrial problems. Students ferret out answers to such questions as Why are the drums of ethoxylated alcohol bulging? What's the source of an off-flavor in a yellow cake mix? What's the cause of the off-color in a fabric softening product? and What causes a shampoo to smell like rotten eggs?

The remaining course time focuses on the analytical approach and techniques; career opportunities, including resume and letter writing and salary data; summer internship programs; graduate education; the role of the analytical chemist, and two question-and-answer periods.

Student feedback indicates the course helps them understand the relationship between their classroom work and the real-world problem solving that is at the heart of an analytical chemist's job. Students are enthusiastic about the course; they most like solving the problems and finding out what we really do in industry.

There is great satisf-tion in hearing a student say, "I will now consider a career I had not previously considered."

In their article "Professional Analytical Chemists in Industry," Procter & Gamble's Richard DePalma and Alan Ullman note that students need to learn about a variety of career opportunities such as chemistry teacher, bench scientist, research leader, college or university professor, and less obvious careers such as those in forensics, technical sales, or patent law. They add, "The training required for each career and some idea of the activities associated with that career need to be given to the students and that is part of what we do in our short course."

The company benefits from the positive results of these courses. Industrial scientists enjoy the opportunity to talk with students about the value of problem-solving skills, not just to an industrial chemist, but to everyday life.

Procter & Gamble's recruiting program is convinced this course is, in part, responsible for the upward trend in Ph.D. analytical production. It has changed how the company thinks about recruiting. The course is considered an excellent value and an effective use of Procter & Gamble money in the many programs supporting graduate education.

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BARBARA DUCH
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A PROBLEM-BASED, GROUP-LEARNING APPROACH TO A GENERAL PHYSICS COURSE HELPS STUDENTS SEE THE RELATIONSHIP BETWEEN ABSTRACT PHYSICS PRINCIPLES AND THE HUMAN BODY AND PHYSIOLOGY.

Many pre-vet, pre-med and pre-physical therapy students dread taking the two-semester, algebra-based general physics course because they lack confidence in their math and problem-solving skills. The honors general physics course is designed to demonstrate to them that physics is vital to their understanding of physiology, medicine, the human body, rehabilitation, and other health fields. The course also teaches them the material of the traditional, two-semester general physics course.

This problem-based learning course has five objectives:

- Give complex, real-world problems as a focus for learning physics principles
- Relate physics principles to biology, medicine, and the human body
- Require writing about physics principles
- Develop personal interactions, peer teaching, and individual responsibility by universal use of group learning
- Encourage hands-on learning to reinforce conceptual understanding

Students meet twice weekly for 75 minutes and once a week for three hours. The three-hour session replaces the traditional two-hour lab and one-hour recitation. The students meet in a lab room at traditional lab tables.

I randomly assign the 24 students into six permanent groups, which set their own ground rules and accountability standards and conduct peer evaluations. Each week, each person has a specific role or responsibility to perform for the group. The roles--discussion leader, recorder, reporter, and accuracy coach--rotate regularly.

- Discussion Leader keeps the group on track and maintains full participation.
- Recorder records data in labs and problem-solving strategies in class.
- Reporter writes up the final draft of the labs and problems.
- Accuracy Coach checks group understanding and finds resources.

The group provides support, and this support is important for students who lack confidence in their math and science abilities.

Cooperative group learning has several advantages. In general, cooperative assignments can be more challenging because many people work on a solution. Because group learning requires consensus, students must listen to the others' ideas and must explain their own ideas and defend their positions. Group learning values individual contributions and requires accountability and responsibility.

The course's major resource is a traditional, algebra-based, general physics textbook. But students are encouraged to consult other texts and articles. Unlike traditional approaches, students do not have to complete a weekly set of end-of-chapter problems. Instead their individual homework consists of conceptual questions that they must answer at the end of each major topic.

Each week the group solves specially designed real-world problems, often related to biology and medicine. Using physics principles, students may apply physics concepts to determine how to minimize the forces on the injured hip of an Olympic ski jumper or to predict the path of a basketball shot by a star player in the championship game. Using the principles of momentum, a sketch from an accident scene, and a police report, they analyze an actual car accident. They reconstruct the accident and decide who's at fault.

Even exams have a group component.

The course also has two hour-long exams and a final exam with individual and group components. The group component, which is 30 to 40 percent of the grade, is completed before the individual portion of the tests. The individual portion consists of conceptual problems like those assigned in the weekly homework.

Students' course grades are based on both their individual and group grades. Individual grades are based on homework problems, individual exam problems, and participation; while the group grade is based on a complex problem write-up, group problems on exams, and lab write-ups. In the spring semester, the group grade also includes a research project. Some of the topics for this semester-long project include electrophysiology of the heart, hearing loss and hearing aids, and the MRI as a diagnostic tool.

Students need to be actively involved in their learning and need to learn physics in the context of real-world applications. Problem-based learning helps college graduates develop the skills and thought processes they will need in their careers.

In the work place, professionals in all occupations need strong written and oral communication skills. Those seeking careers in the analytical sciences especially must be able to define problems, to gather and evaluate information, and to develop solutions. They must also know how to work with others as a part of a team. Finally, they must apply all of these skills to real-world problems, which more often than not are complex, not easily solved, and open to more than one solution.

Students appreciate the real-world problems. As one student notes, "They're like mysteries that need to be figured out, so we want to finish them." The students also respond well to the course. Attendance has been almost 100 percent and students are active participants and questioners. They are less stressed by physics because a group working together can usually solve the problem at hand.

Would I return to a traditional lecture format? Not a chance. The excitement and energy of a room of students working in groups, teaching each other, challenging each other, and questioning each other is what I'll always want to see in my classroom.

I was motivated to adopt this method of teaching because I strongly believe that students need to learn science as it is practiced.

I recommend the following approaches to those who want to bring problem-based learning into their courses:

- cooperative learning
- project-centered classes
- investigation-oriented laboratories and classes
- the use of case studies
- educational technologies

A good undergraduate course should be problem-driven. It should emphasize critical thinking, provide hands-on experiences, and be taught in the context of topics students confront in their lives. The course should also offer both the process and concepts of a discipline and show the links between related disciplines. It should place the subject in broader personal, historical, cultural, social or political context; and provide the intellectual tools needed to explore new areas.

"The groups definitely help--not only if you don't know the answer, but also if you have to explain it to others--you really have to understand it." --physics student

Barbara Duch is the Associate Director of the Science and Education Resource Center at the University of Delaware and a lecturer in the Department of Physics and Astronomy.

ROYCE ENGSTROM AND BRIAN LAMP
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STUDENTS PLAY A MAJOR ROLE IN DIRECTING THE LABS AND LECTURES OF AN HONORS CHEMISTRY COURSE THAT MODELS ITSELF, AS MUCH AS POSSISLE, AFTER A WORKING RESEARCH GROUP.

The second semester of general chemistry at the University of South Dakota offers an honors section that is open to freshmen through seniors. The course attracts chemistry majors and other sciences majors, as well as some non-science majors. The instructor deliberately seeks a high level of diversity to better reflect real-world research teams, which often bring together people from widely differing backgrounds.

This five-credit course meets five times a week with four lecture periods and one lab, with all students usually in attendance together. The course is taught by a member of the chemistry faculty, who is usually assisted by an undergraduate teaching assistant--someone who has taken the class.

The course is structured so that a new research question begins almost weekly. Following opening discussions of the question, students design the laboratory experiment that will be used to address the question. Between Monday's discussion class and the laboratory session on Tuesday evening, students write in their laboratory notebooks the objectives and anticipated procedure for the lab work. They include whatever calculations and planning are necessary for the experiment.

This laboratory- and question-driven course for about 20 to 25 dents makes extensive use of problem-solving and real-world analysis.

The experiment is conducted Tuesday evening, with students often pursuing different approaches to the problem. The lab session itself is a highly interactive affair, with students actively moving back and forth to compare results or procedures. On Wednesday, students discuss their results, with much data going up on the board. They discuss which results were the most reliable and why. Comparing the reliability of results obtained by different approaches is especially instructive.

They also discuss how to improve the measurement and whether the experiment(s) answered Monday's question. We may well decide that it didn't, and we may want to refine the question for next week. Thursday's and Friday's classes are usually devoted to lectures, discussions, and problem-solving related to the textual content of the class.

The questions vary from year to year, but here are two typical questions and the activities they prompted:

One year, the first week of class began with a discussion of global warming. Students were asked to read a short article in the popular press on the potential rise in sea levels that may result from global warming.

One reason given for this rise was the "thermal expansion" of water. The instructor and class posed the question: Can we experimentally measure the thermal expansion of water, and is this expansion a significant aspect of global warming? This involved discussion of the definition of thermal expansion, what units it would be expressed in, how it could be experimentally measured, and how precise its value needs to be. During this design time, the class alternated between full class discussion and small group brainstorming among two to four students.

We generally list on the blackboard all proposed ideas, and then try to reach a consensus about which we want to pursue. In this case, we ended up with three or four different approaches being used to generate data in the Tuesday lab session.

The students don't bring a great deal of experience to these discussions. But with some guidance and with consideration of some fundamental solubility rules, they can make impressive suggestions and ideas.

A trip to the sludge lagoon provides a second example. Into these settling ponds, the town pumps precipitates from the drinking water treatment plant. These large ponds contain an off-white material that students later find to be mostly calcium carbonate, with a significant amount of iron, and smaller amounts of manganese.

The material serves as an excellent sample. The question, What is this stuff?, prompts identification of the material's major and minor components. Before taking samples, the group asks, What constitutes a representative sample? During our experimental design session, students suggest chemistry that might be used to react uniquely with suspected components of the sludge, such as calcium, iron, or manganese.

This experiment often moves into a quantitative mode as students try to determine the concentration of one or more of the identified components. The quantitative aspects naturally lead into spectroscopy approaches, including atomic absorption spectroscopy for some of the students. Concepts and practice involving sample dissolution, preparation of standards, method validation, and standard methods all come out in this experiment. Usually, the experiment is followed by a field trip to the water treatment plant itself, where students see first-hand how the sludge was generated.

Other experiments during the semester include kinetics, chemical microscopy, electrochemistry, spectroscopy, and synthesis. It is always difficult for the instructor and students to choose whether to move onto the next question or to refine an approach to last week's question.

A WEB page posts student results and example data, and often includes photographic images. The WEB address is http://www.usd.edu/~blamp/chem116.htm.

The semester's last three weeks are devoted to special projects the students choose and design. These projects involve the writing of a project proposal, with feedback from the instructor. They also include three weeks of experimental or theoretical work and a class presentation. After investing so much time in their projects, students take great pride in their presentations. It is especially gratifying to see computer graphics, photography, statistical analysis, and a pretty thorough chemical understanding of their work.

Here's a representative list of the special projects students have tackled:

- Investigation of serotonin activity in rat brain by LC-EC
- Extraction of caffeine from tea
- Detennination of vitamin C in orange juice
- Determination of iron in breakfast cereal
- Titration of amino acids
- Spectroscopic determination of nicotine in cigarettes
- Manipulating physical properties of polymers
- Fabrication of a hydrogen/oxygen fuel cell
- Affects of acid rain on building materials
- Determination of dissolved oxygen in water
- Determination of aspirin in pain reliever
- pH dependence of fluorescein fluorescence
- Determination of nicotine in tobacco with nonaqueous titration
- Thin layer chromatography of amino acids
- Affects of solvent on fluorescence
- Spectroscopic determination of caffeine in soft drinks
- Gel electrophoresis of proteins
- Temperature and pH dependence of the oxidation of sugar with yeast

This course format results in two sacrifices. First, we cover a similar amount of material as the more traditional class, but we have less time for working examples and must depend more on outside-of-class study by the students. Second, since students are taking a major responsibility for designing the experiments, our approaches may be less sophisticated than in courses with more "canned" experiments. However, the experience that students gain in experimental design and problem-solving more than compensates for this loss of sophistication.

The Honors General Chemistry course has been one of the most gratifying courses to teach for the instructors, because the course promotes the type of self-learning used by a practicing scientist. Students respond well to the mixture of student viewpoints and to the emphasis placed on students to express and support their viewpoints. The challenge is to adapt this approach to larger classes of general chemistry, to the extent that this approach would be effective.

Royce Engstrom is a Professor of Chemistry at the University of South Dakota (USD), and Brian Lamp is a Camille and Henry Dreyfus Post-Doctoral Fellow at USD.

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A 350-GALLON MARINE AQUARIUM HELPS COLLEGE FRESHMEN AND HIGH SCHOOL STUDENTS LEARN AND UNDERSTAND TRADITIONAL WET CHEMISTRY TECHNIQUES AND PROVIDES VISIBLE EVIDENCE OF CHEMISTRY'S ROLE IN THE ENVIRONMENT AND BIOLDGICAL PROCESSES.

In 1992, a saltwater aquarium with coral reef fish was set up in a highly visible location at Georgia Tech to serve as a laboratory ecosystem. It was an effort to promote interest in wet chemistry and good lab techniques. A course based on the marine aquarium (ecosystem) was incorporated into the first of a two-quarter analytical chemistry curriculum initially for juniors and seniors. The entire course has been moved to the third quarter of the freshman year. The students are chemistry and biology majors or undeciededs.

The course has three objectives:

- to provide motivation and excitement for learning traditional wet chemistry techniques by using natural or real-world samples for laboratory analysis
- to provide evidence that solving scientific problems and difficulties drives the development of new instrumentation with improved analytical capabilities
- to provide visible evidence of chemistry's role in the environment and biological processes

In brief, students monitor the aquarium several days a week. They determine ammonia, nitrite, nitrate, and phosphates by spectrophotometry; sulfate by gravimetry; dissolved oxygen, salinity, and alkalinity by redox and potentiometric methods; and calcium/magnesium by EDTA titrations. It should be noted that with this system there were no deletions in the traditional lecture content.

Relevance of the marine aquarium to the topics of acid/base equilibria, buffer capacity, and solubility is obvious since students observe on a daily basis living organisms that require a buffered environment for survival. The need for ion-selective electrodes, ion-chromatography, atomic absorption/emission techniques, and other modern instrumentation was clearly evident after a six-hour lab period in which only two sulfate determinations by gravimetry were completed.

The chemical cycles monitored throughout the l2-week quarter are mediated by numerous species of bacteria and microorganisms. This aspect of the ecosystem is constantly brought to the forefront of all discussions in the lecture and laboratory. In fact, the microorganisms in the enclosed ecosystem (aquarium) are probably the most important organisms present.

Students have also used the aquarium as the basis for independent research projects. A senior used the algae growing in the ecosystem to look at bio-accumulation of metals. Another student performed a multivariate statistical analysis on the data obtained during the quarter for her statistics class. Others have investigated the compounds adsorbed to the activated carbon filter.

The aquarium design is flexible to allow different types of experiments and to allow students individual access.

Why a marine ecosystem? This unique environment encompasses many well-documented, dynamic chemical and biological systems. These elements are important factors in the biology of this environment. Concern about the world's environment has elicited a strong response from university and high school students. Coral reefs, rain forests, bioremediation of toxic waste sites, and oil spills are frequently covered by the national media, not always portraying chemistry in the best possible light.

The 8-foot by 2-foot aquarium is 2.5 feet high and contains 350 gallons of saltwater. Water is filtered by a gravity feed system. Four metal-halide lights can each be controlled by individual timers allowing simulation of sun movement. Flow in the system is provided by two, 2,000 gal/hour pumps directed at opposite sides of the tank. The pumps alternate on/off every 60 seconds providing some "tidal" action for the aquarium inhabitants.

The aquarium includes fish from the Damsel and grouper families. These fish are long-lived in enclosed environments, are tolerant to chemical changes, and are omnivorous. They are available in large numbers, are inexpensive, make an eye-catching display, and are extremely plentiful in the ocean, thus minimizing the impact of collection on the environment.

At one end of the tank is a "tap" for students to cleanly and easily remove samples. At the other end of the tank are nine, one-inch bulkheads with ball valves. These "access holes" allow incorporation of additional flow patterns, the ability to pipe water to nearby locations for on-line experiments, and the incorporation of up to nine ion-selective electrodes, temperature probes, and other measuring devices.

Responsibility is the KEY ingredient for making this kind of lab experience successful. It is also the KEY aspect that is missing from almost all traditional laboratory courses. The students' measurements have value in that they are the sole feedback source concerning the health of the ecosystem. Giving the students this responsibility changes their attitudes about the lab and their work and provides motivation for learning.

Students like that the experiments have meaning.

Student response to the ecosystem has been extremely positive. Over 50 percent of graduating seniors mention this course in their exit interviews, and others have praised the course in their student evaluations. Some students are now going to graduate school in earth and atmospheric sciences. Others who have gone on to work in industry write supporting letters.

The course has been a springboard for similar ones. Derivatives of the aquarium curriculum are now in use at Harvey Mudd College in California, Southern Community College in Ohio, Harrison High School in Georgia, Florida Institute of Technology, and University of Idaho, which uses a trout tank. The Fernbank Science Center and Museum in Atlanta has incorporated aspects into its curriculum, which targets several hundred middle-school students.

Students acknowledged the advantages gained from the course's rigor.

A workshop funded by the Eisenhower Program taught middle and high school teachers how to make laboratory measurements of water quality and how to use field test kits. Many are constructing ecosystems in their classrooms. The aquarium is featured in *Exploring Chemical Analysis,* published by W. H. Freeman & Co. The syllabus, as well as a real-time viewing of the tank, is available on the web:
http://www.chemistry.gatech.edu/class/4211.hughes/

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ADVANCED ANALYTICAL CHEMISTRY, A CAPSTONE COURSE FOLLOWING A COURSE IN QUANTITATIVE ANALYSIS AND ONE IN INSTRUMENTAL ANALYSIS, PREPARES UNDERGRADUATE SENIORS FOR THE EXPECTATIONS OF INDUSTRY AND GRADUATE SCHOOL.

For the past three years, I have taught a section of Advanced Analytical Chemistry (AAC) (one of four) on industrial analytical chemistry, relying heavily on my 30 years in industry. The first parts of the AAC course tend to be in-depth looks at special topics of the other professors' research interests.

Since the students already have a semester of instrumental and three units of special topics, I begin by announcing that I am assuming that their analytical tool box is full and ready to go out into the real world, whether it be industry, professional school, or graduate studies in analytical chemistry. My section then tries to show them how to use those tools and what industry will expect from them. Fifty percent of the 15 to 20 students in the class will eventually be employed in the private sector.

I use a four-stage model to illustrate the analytical process. The first stage, Research to Develop New Measurement Systems, often arises from university research programs. Some industries also have in-house programs for this purpose, and all industries expect their analytical chemists to be up-to-date on new techniques from physics, chemistry, and biology, and to get qualitative and quantitative data from analytes. Advancement at this stage is measured by publications and patents. In this idealized world--where the analyte is in de-ionized water--the aim is to get a signal from the analyte in some new way, leaving matrix effects as the second stage in the model.

The second stage in this process model is Develop a New Analytical Method for Analyte X in Matrix Y. The analytical chemist uses a new measurement method or adapts an existing method to this matrix. This model requires that the analytical chemist deals with the real-world matrix effects and meets accepted standards for such things as ruggedness, precision, accuracy, LOD, and LOQ. At this stage, the criteria for success is that the method developed be superior in one way or another to previous ones.

I assume their analytical tool box is full and ready to go out into the real world.

The third stage in the process is to refine the method from the second stage to be more user friendly, more automated, more accurate, and better able to meet the "customer's" expectations and needs. This refinement is accomplished by applying the method to actual samples on-line or wherever the actual work needs to get done.

The fourth step is to adapt the method so it will be suitable for a manufacturing environment, including procedures for statistical process control and 24-hour use. Success here is measured in terms of manufacturing operators being able to make the method work round the clock, perhaps even in a foreign labor market. Success here is also measured in terms of the lack of downtime encountered due to problems.

During the course, we cover analytical problem solving and use several publications that offer information on a unified process for problem solving. A twist I add is to pair students as a customer/analytical chemist duo. Each gets experience in the interrogation that must occur for setting outcome expectations to solve the analytical problem: cost, time, accuracy, and precision. When the students reverse roles, seeing the problem from the other perspective seems to solidify their understanding of the challenges.

The word team comes across loud and clear.

We also cover how to validate an analytical method and how to calibrate an analytical system, including the data handling device and the Laboratory Information System, if appropriate. Several good publications provide information on each of these important analytical processes. I also refer to a few textbooks that cover these subjects well. The learning tends to improve when we struggle with how to validate vendors' software and suppliers' processors and have these fulfill the requirements of Good Laboratory Practices and Good Manufacturing Practices. I use this introduction to GLPs and GMPs as a springboard to good record-keeping, good written communication skills, and the virtues of a laboratory notebook that complies with these practices.

Other lectures delve into statistical methods of process control, quality control, quality assurance, and quality assessment. As time allows, we use resources from statistics texts, short courses, and John K. Taylor's book *Quality Assurance of Chemical Measurement.* By the end of the course, students are aware that within industry analytical chemists must work with statisticians, manufacturing personnel, management, and labor.

Robert Libby spent 30 years as an analytical chemist in industry. In 1994 he joined the faculty at Truman State University as a Professor of Chemistry.

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A PROJECT-BASED LABORATORY CURRICULUM FOR UNDERGRADUATE QUANTITATIVE ANALYSIS TEACHES STUDENTS HOW TO THINK AND FUNCTION AS ANALYTICAL SCIENTISTS.

Quantitative Analysis at Northeastern University is taken between students' sophomore and senior years. It centers on the development and implementation of a project-based laboratory curriculum for Quant, the first of the two analytical courses in a typical chemistry major.

The idea for a quantitative analysis class grew out of my students' needs and concerns. The majority are not chemistry majors, but rather life-science majors. They did not see the relevance of the largely non-instrumental methods emphasized in the course to their own future careers and current interests.

Students were frustrated by the emphasis on quantitative problem solving in lecture and the emphasis on accuracy and precision in the laboratory. Labs should value the development of good technique, but they should also teach students how to choose between two alternative methods, how to use an instrument, how to design an experiment, and how to troubleshoot a problem.

I could empathize with the students' frustrations. They spent three hours a week in the laboratory in a nine-week quarter. They had little opportunity to really practice weighing, delivering reagents from a biuret, or to learn how to use a new instrument. The lack of time almost required cookbook experiments, because students had no time to think, much less reprep solutions and redo an experiment.

Grades based heavily on a student's ability to solve quantitative problems in a rote fashion and solely on the emphasis of good lab technique are not as satisfying or helpful to the student.

The course has not received industry support, but three NSF grants have underwritten the efforts. An NSF-ILI supported the purchase of a PerSeptive Biosystems BIOCAD and two Waters 4000E Capillary Electrophoresis systems. An NSF CCD grant is facilitating the development and implementation of a variety of project-based laboratory experiments using these instruments. Finally, an NSF CAREER Award has allowed me to experiment with ideas in chemical education at the general chemistry level, in Quantitative Analysis, and at the graduate level.

I think my approach is unique, compared to the approach of many others now using problem-based learning. I emphasize skills rather than specific analytical methods or instrumentation that must be covered or the mode with which the material is delivered to students. The emphasis is not on teaching my students a set of facts or methods, but rather on a way of thinking about existing problems in our world today and about developing real solutions.

A series of problem-based laboratory experiments, including the three mentioned below, have been developed:

- "Cyt C Project" teaches students how to design and execute an experiment using new and unfamiliar analytical methods based on a literature protocol from Methods in Enzymology.
- "Learning to Learn" teaches students how to teach themselves to use a new and unfamiliar piece of analytical instrumentation, specifically, a capillary electrophoresis instrument.
- "Planning a Day at PITTCON" teaches students the two principal methods of continuing education that scientists use to stay current: reading technical journal articles and attending technical research conferences such as The Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy. See Appendix C under *Mabrouk* and *Marzilli* for the publications that discuss these projects.

A number of my students have remained in touch and have expressed their gratitude for what and how they were taught analytical chemistry.

My analytical colleagues had little interest in changing Quant prior to my work. My efforts, however, have been strongly influenced by those of Dr. Walters at St. Olaf, who published a series of articles on problem-based learning in Quant over a period of several years in the A-pages of *Analytical Chemistry*.

During the short, nine-week quarter, students least like the demand the course places on them to teach themselves. But the ones who work in industry for six months each year, through Northeastern University's nationally recognized CO-OP program, most appreciate the practical training they received from the course's problem-based learning.

As a result of developing this course, I now read technical journals with an eye toward developing problems for use in lecture and in experiments for use in the lab. I look for problems that represent the current interests in the field of analytical chemistry.

First, and most important, I'm pleased with my students' success after they complete this course and enter the work force. Second, analytical chemistry at Northeastern has seen dramatic growth since 1990. A number of other colleges within the university and departments within the College of Arts and Sciences now recommend that their students take analytical chemistry. These include Medical Laboratory Science, Geology, Chemical Engineering, and Biochemistry. About 50 undergraduates were enrolled in spring 1997.

Developing this course also has made me realize how important teaching is to me. It has encouraged me to pursue a career as a teacher-scholar and to blend my interests in education and research.

I am interested in teaching other educators how to use problem-based learning in their classroom. I specifically would like to show them how they can use their own natural research interests and abilities to empower their own students. I want them to know that their students will truly value their efforts. I am now putting the final touches on an A-page article for *Analytical Chemistry* that focuses on the PITTCON exercise.

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JOY MCMILLAN
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A PARTNERSHIP BETWEEN BIOSCIENCE INDUSTRIES AND A TWO-YEAR TECHNICAL COLLEGE HAS CREATED A DEGREE PROGRAM THAT INTEGRATES THE CONCEPTS OF BIOLOGY, CHEMISTRY, AND MATHEMATICS WITHIN TECHNICAL COURSES TARGETED TO MEET INDUSTRY NEEDS.

Since 1987, the Biotechnology Laboratory Technician Program at Madison Area Technical College has offered an associate degree in biotechnology. Developed in cooperation with industry, the program prepares graduates for entry-level technician positions in industrial or academic laboratories engaged in the biosciences. Many of the program's graduates find jobs with employers in the Madison area.

The program's curriculum was developed around the skills and competencies local bioscience employers needed. The curriculum, therefore, was designed both to meet specific industry needs and to be pedagogically sound.

I supervise and manage 12 of the college's technical programs, including the Biotechnology Lab Tech program. Students in this two-year, technical program receive a focused inter- and multi-disciplinary education that provides a great deal of hands-on experience and skill development.

Our students have an opportunity to work with various instruments that allow them to measure, identify and quantify all kinds of molecules. For example, in a first-semester course in instrumentation and basic lab techniques, students spend considerable time and energy on measurements, the scientific method and basic statistics. Why? Because they are pursuing a degree that will enable them to find employment as a technician in biotechnology laboratories.

The line between chemistry and biology is hard to distinguish, so the program offers students courses that include a broad sampling of instruments and techniques. They experience hands-on work with spectrophotometers, centrifuges, gas chromatographs, other chromatographic techniques, various pipetting devices, electrophoresis apparatus, scintillation counters, balances, and plate readers. Because these students are preparing for careers as technicians, their education also includes the use, basic maintenance, and troubleshooting of these instruments.

The program is demanding and includes an emphasis on written communication skills. One aspect we stress is the written documentation of the students' work. Although students are not enthused about the importance we place on this documentation, our uates are. They tell us that once they were on the job, they came to appreciate the writing skills they'd learned in the program.

The high level of interaction between the students and the program's industry partners gives students another boost when it's time to find a job. For a primary benefit of this program is how well our biotech grads are accepted on the job. Employers frequently welcome our graduates into the company's research or production groups.

Students like the level of hands-on laboratory work. They appreciate being taught the "how to" and "why" in their laboratory exercises.

Lisa Seidman, an instructor in the program is now writing a textbook for the introductory and basic laboratory techniques. This text will include the theory and application of basic instrumentation, as well as the mathematics of basic laboratory work such as calculations involved in solution making. The text also will address the role of the technician in the work force.

Anyone interested in learning more about this program should contact me or the program's director, Joseph Lowndes; or instructors Lisa Seidman and Jeanette Mowery; and instructor assistants Dana Brandner and Tiffany Nelson.

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IN THE ART PROJECT, A JUNIOR-LEVEL ANALYTICAL CHEMISTRY COURSE, STUDENTS USE SELECTED ART OBJECTS FROM THE PERMANENT COLLECTION OF THE DAVIS MUSEUM TO STUDY PIGMENT CHEMISTRY IN DEPTH. THESE STUDIES LEAD TO AN UNDERSTANDING OF THE MULTIPLE STEPS NEEDED TO SOLVE REAL PROBLEMS.

The principles and practice of wet chemical analysis and spectrophotometry, analytical measurement, and data analysis are well-represented in the introductory chemistry laboratories at Wellesley College. Consequently the junior-level analytical chemistry course, known as The Art Project, had an instrumental analysis and problem-solving focus.

This semester-long project comprises a quarter of the assigned non-lab work. It culminated in term paper proposals for the identification of pigments in selected art objects from the permanent collection of Wellesley's Davis Museum. I developed the course in the fall semester of 1996 in a collaboration with Melissa Katz, curatorial coordinator of the Davis Museum.

Katz introduced the project with a gallery lecture on the history of pigments and the role pigment identification plays in the authentication of an art work. She also showed students the objects selected for their studies: paintings, ceramic figures, stained glass, Chinese lacquer, and an African mask. Each student chose an individual object with an assigned pigment of the primary colors. The class then was organized in teams around these colors to optimize collaboration.

The objects of each team represented a variety of media and historical periods, so that all students studied pigment chemistry in depth. Students developed their proposals in clearly defined stages with frequent meetings with their team members, reference librarians, Katz, and myself.

The first written segment contained a description of the student's object, its historical context, and a discussion of the possible chemical identities of the assigned pigment. This short paper, which would eventually be the introduction of the final term-paper, was written in drafts with peer reviews by other team members; a similar process was used for each portion of the term paper. Oral and written instructions were given for the format of the paper and for peer-reviewing. The final drafts of the introductory section were checked to ensure that the student had correctly identified possible pigments.

The variety in the art objects themselves, the team approach, peer-reviewing, and consultation with experts made this collaborative project an excellent vehicle for teaching analytical chemistry.

The major portion of the term paper contained proposals for chemical analyses that would unambiguously identify the assigned pigment using two methodologies: one based on classical wet chemical methods and one based on instrumental methods currently used in museum laboratories. This portion of the project exposed students to the literature of analytical chemistry and provided a forum for discussing sampling and comparing destructive and non-destructive methods.

A guest lecturer, Dr. Janice Carlson, senior scientist at the Winterthur Museum, gave the class additional insight into the analytical chemistry of art. A field trip to the conservation laboratory of the Fogg Museum allowed students to observe the application of many of the techniques proposed in their papers. The students' final papers, revised after this visit, were a rich blend of art history and analytical chemistry.

The Art Project will be expanded in future offerings of the analytical course. It will include experimental work such as the characterization of the fatty acid composition of oils used to suspend the pigments in artists' supplies. Student enthusiasm led the 1996 class to present a highly professional seminar and series of gallery tours to showcase this project in an on-campus student research conference in May

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PERFORMING A COMPLETE CHEMICAL ANALYSIS OF COMMERCIALLY AVAILABLE PRODUCTS ENHANCES THE PROBLEM-SOLVING SKILLS OF FIRST-YEAR GRADUATE STUDENTS.

In an attempt to enhance the analytical problem-solving ability of our entering graduate students, we have implemented a laboratory activity in our first-year graduate analytical laboratory. Two laboratory coordinators for analytical and physical chemistry, who spent time working in industry and who were intimately familiar with analytical problem-solving in an industrial setting, helped in the project's development. With their assistance, we began what has become known as the Materials Characterization Project.

The student is given the product, along with a series of five to ten specific questions, which are intended to guide the student's activities. The student is responsible for articulating the entire analysis problem and for conceptualizing solutions through information gathering. The student identifies the analytical method or methods needed for answering the questions posed, designs the experimental protocols, acquires the data, and analyzes the results. Then the student writes a report and makes an oral presentation of the analysis. In short, the student is responsible for the entire analytical process on his product. Students are given their product at the beginning of the semester, but most students spend about four to five weeks of laboratory time in earnest on their analysis.

Real-world products or formulations used for this purpose are purchased at a local store and are selected almost at random from among the thousands of items available. Examples of products or formulations analyzed by our students include a solar calculator, scented crayons, lipstick, weed killer, a glue stick, an automobile halogen light bulb, Lava soap, an electronic kitchen timer, an audio CD, a home lead test kit, spray paint, shampoo, a fluorescent light stick, a wall clock, plant food, and an "instant ice" pack.

From a chemical analysis perspective, we attempt to ensure that each product analysis will require two things: analysis of a polymer and quantitative analysis of major and trace metals content. In most instances, the student analyzes the product's packaging to ensure that the first goal is met. Finally, where appropriate, we try to steer students toward the use of classical wet chemical analyses at least once during their project to reinforce their importance and utility in real-world chemical analysis.

This project involves a student's complete chemical analysis of a commercially obtained product or formulation.

These analyses require student access to a wide variety of analytical instrumentation; we are fortunate to have excellent instrumentation facilities at the University of Arizona. We make almost all instrumentation facilities within the Department of Chemistry and the university available to the students in the completion of their project.

In addition to a well-equipped instrumental analysis laboratory, the Department of Chemistry instrumentation facilities commonly used by these students include the NMR facility, the mass spectrometry facility, and the surface analysis facility. The most commonly used facility outside of the Department of Chemistry is the electron microscopy facility in the Department of Materials Science and Engineering, in which SEM/EDX analyses are performed. Although students do not actually run the instruments in the surface analysis laboratory or electron microscopy facility, they prepare all of the samples for these analyses and are involved with trained staff during data acquisition on their samples.

In addition to the use of departmental and university instrumentation facilities, students are strongly encouraged to seek out and use individual faculty research capabilities when necessary and available. Additional resources used include--but are not limited to--the library, instrument facility staff, and knowledgeable faculty. Finally, the students are encouraged to communicate directly with the technical department of the manufacturer of the product to ascertain what information or technical guidance might be available for their analysis. These interactions are often the first professional interactions students have outside the academic environment.

The importance of using all available resources, including human resources, is stressed.

Over time, the pedagogical value of this exercise has become evident, and a version of this project for the undergraduate instrumental analysis laboratory has emerged. At the undergraduate level, we have implemented the Materials Characterization Project as a three- to four-member team project spanning four-weeks with six lab hours per week. All other aspects of the project remain essentially the same.

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PROFESSIONAL OR RETIRED CHEMISTS WORK WITH HIGH SCHOOL STUDENTS AND UNDERGRADUATES IN AN INDUSTRY-PARTNERSHIP PROGRAM THAT COMBINES A CLASSROOM SEMINAR, INDUSTRIAL SITE VISIT AND PBL EXPERIENCE. THESE INTERACTIONS OFFER STUDENTS AN OPPORTUNITY TO EXPERIENCE INDUSTRIAL CHEMISTRY AS AN EXCITING CAREER.

The idea for the Ambassador Program grew out of a 10-year tradition of industrial collaboration that was fostered through the NSF-funded Partners for Terrific Science program at Ohio's Miami University Middletown. The Center for Chemical Education established the Partnership for the Advancement of Chemical Technology (PACT) Consortium in 1993 with the goal of creating a well-educated, chemistry-based technical work force. Today, the consortium consists of 425 members representing chemical industries, high schools, two- and four-year colleges, and professional societies.

In 1994, PACT received a NSF grant to fund program activities, including the Ambassador Program. This program brings practicing or retired chemists, engineers or technicians (Ambassadors) from industry, small business and government into direct contact with high school students and undergraduates. Its goal is to improve chemical technology education. The program is a central component of PACT's student enrichment and outreach efforts. It receives in-kind support from industry in the form of the industry Ambassadors' time, laboratory supplies, use of equipment, and food.

PACT has found that the most successful program uses a team approach: an industrial scientist (the Ambassador), a university-based science faculty member, and a high school teacher. These three people work together to plan and implement the program at a particular school. In addition to modeling the school-to-work link, the team approach lessens the burden of extra work for any one team member and also provides the necessary range of viewpoints, resource persons, and role models.

Ambassadors can provide resources for teachers, give classroom seminars, do demonstrations for students, help teachers in the laboratory, give tours of their industrial facilities, or provide students with problem-based learning experiences.

The program follows a multi-phase approach with three components: the classroom seminar, in which an Ambassador interacts with students in the classroom; the industrial site visit or tour, in which students see technology at work; and the capstone problem-based laboratory experience, which is based on the participating industry's use of chemical technology.

Each Ambassador Program reaches 10-30 students. Since 1995, more than 300 students have participated in conjunction with Miami University Middletown. Undergraduate and high school students have been paired with such local industries as Henkel Corp., Formica, Miller Brewing Co., Procter & Gamble, Quantum Chemical Corp., Magnode Corp., and Children's Hospital.

The program helps educators bring real-world problems and problem-solving skills into the classroom. These problems make science learning more meaningful for students and their teachers. Because industry draws on many science disciplines in its day-to-day operations, the program fosters an interdisciplinary approach to science learning.

In one Ambassador program, high school students analyzed additives using High Performance Liquid Chromatography (HPLC). The students played the roles of chemical technicians and extracted additives from a polymer sample. They brought their extracts to Miami University and ran their standards and samples on the HPLC. The next week each student team submitted two written reports of its findings. These reports merged what students learned in their seminar and from their Ambassador, from their literature research on polymer additives, and from their analysis of their own sample.

Students are engaged in solving real problems and in applying the scientific method to situations industry encounters on a daily basis.

The program clearly helps students see how the science they learn in class is applied in industry. Most programs include rigorous out-of-class assignments, which demand a great deal of time and extra effort. While these assignments are not students' favorite part, the students seem to rise to the challenge. Typically, less enthusiastic students show a willingness to go the extra mile, usually with great success.

The Ambassador Program is distinguished from many student outreach programs because it targets students who might have shown an interest in science and technology, but who may need an extra push to realize their own learning potential. These students may not realize they like science until they experience chemistry within the context of work-world applications.

Everyone benefits. Students have personal interaction with industrial scientists and develop an increased interest in chemistry and chemistry-related careers. Their teachers are given ways to spark student interest in chemistry and chemical technology.

Industry strengthens its community image and gives local citizens a better understanding of the technological problems it faces. Companies build a larger base of informed and better-prepared students for recruitment and gain a better appreciation for teachers' needs and concerns. For colleges, the programs improve public relations, enhance the preparedness of future college students, and serve as an excellent recruiting tool.

Industrial/academic partnerships such as the Ambassador Program foster a scientifically literate citizenry and a better prepared work force. The community at large benefits because today's students are tomorrow's leaders, voters, and employees.

Involvement in the PACT Ambassador Program has reinforced the importance of getting industry involved in chemical technology education. It has provided me, as an educator, with a successful way to put the content of chemistry in the context of real-world applications. I now incorporate outside resources into many of my classes.

Students enjoy meeting and interacting with industrial personnel and see people not unlike themselves working as scientists in industry.

The best thing a student said to me was, "I realize just how important chemistry is in our daily lives. I used to think it was just a bunch of old, white-haired scientists standing around looking at the periodic chart all day long. It wasn't that way at all. Now I'm considering pursuing a career in chemistry."

The Ambassador Program is included in the NOVA Corp.'s Top 100 IdeaBook. The success of this Ambassador Program also has led us to develop a guide, "Bringing Industry-based Science into the Classroom: A PACT Ambassador Guide," which contains more than 80 pages of comprehensive, step-by-step instructions on how to set up a PACT Ambassador program, based on our model. The guide is written for industrial scientists, high school teachers, or college professors who would like detailed information on how to establish their own Ambassador program.

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TWO REVISED ANALYTICAL CHEMISTRY CLASSES AND LABS NOW STRESS GROUP PROBLEM SOLVING AND ALLOW STUDENTS TO APPLY THE ANALYTICAL PROCEDURE TO REAL-WORLD SAMPLES AND DISCOVER HOW SCIENTISTS WORK.

Like many science educators, I questioned the methods used to teach science. I wanted to move from a traditional lecture approach and cookbook labs to one that taught the process of science. I wanted my students to see how scientists pose questions and seek answers. Based on 14 years of having students involved in independent research projects, I think students equipped with problem-solving skills will be able to learn the content needed to solve the problems they encounter in the future. This problem-solving experience may be the most important in students' undergraduate careers.

In 1991, I introduced a series of changes to the traditional undergraduate analytical courses. Introduction to Analytical Chemistry covered statistics, gravimetric and volumetric analyses, equilibrium, spectrophotometry, acid-base chemistry, electrochemistry, and theory of chromatography. In the traditional wet-methods lab, students were primarily given unknown white powders and graded on the accuracy and precision of their analyses. The second semester course, Instrumental Methods, covered gas and liquid chromatography and methods based on electromagnetic radiation: NMR, IR, Raman, UV/VIS, fluorescence, atomic absorption and emission. The lab involved use of these instruments.

Several things prompted the changes to problem-based learning with group interactions. The overlapping material and the artificial separation of the two courses was troubling. I wondered about the false separation between the quantitative course and the mental one. Was the lab experience realistic in light of what scientists really do? I wanted to stress the importance of separations in chemical analysis, to help students understand chemical equilibrium, and to give students a valuable research experience.

No one has ever completed the projects, but completion is not the goal.

I evaluated the traditional lab experience against the five steps of the analytical procedure set forth by H.A. Laitinen and W.E. Harris in *Chemical Analysis:*
- define the goal
- sample
- separate the sought-for-constituent from other species present in the sample
- measure the desired substance
- evaluate and interpret the data.

The first three of these steps were virtually ignored, particularly in the first semester's lab. The revamped courses, Separation Science in the first semester and Analytical Electrochemistry and Spectroscopy in the second, present basically the same course material as before, but they use the group-learning approach. In the lab now, small groups of two or three students spend a semester trying to practice the analytical procedure. They work on a project that involves real samples and that asks them to figure out how to get results. For example, groups have tackled the following projects:
- analyze benzene and toluene in air (used GC-MS)
- analyze trihalomethanes in drinking water (used GC-MS)
- analyze nitrate and sulfate in rain (used ion exchange chromatography and indirect spectrophotometric detection)
- analyze the amino acid content of vegetables (used reversed-phase LC and fluorescence detection)
- analyze the caffeine, theobromine and theophylline in chocolate
- analyze the PAHs in smoke and charbroiled meats (used LC with fluorescence detection)
- analyze coffee for its volatiles and acid-base neutrals (used GC-MS); for its amino acids (used LC-fluorescence); and for caffeine, theophylline and theobromide (used LC-UV)

The students become engrossed in their semester-long projects and most work far more than their required 30 hours.

Through their attempts, students develop a deeper understanding and appreciation for standards, reproducibility, sampling and accuracy and reliability. They come to appreciate how difficult it is to obtain a good analytical number, especially when performing trace analysis.

The problems of assigning a grade to each student for a group effort led to the requirement that each person devote a minimum of 30 project-related hours to work in the lab, library and field. The time is logged in the lab notebook.

Each person submits his or her own written report in the format of a journal article for *Analytical Chemistry*. Group members share their data, but the presentation and discussion of the data are done individually in each person's report. On the last day of the lab, each group is required to present its project to the class. In this group effort, the presentation time is divided almost equally among the group members.

In the classroom portion of the course, the class is divided into groups of three or four members; these groups are different from those for the lab. The groups usually contain a mix of chemistry and bio-chemistry majors, and the more experienced students are disbursed throughout the groups.

Each day the students are given problems to work within their group. I serve as the facilitator and move among the groups offering suggestions, but not answers. The group's members are encouraged to teach to each other. If one student in a group sees a point, they are to explain it to the others. When all the students in the class appreciate the point, I call 'time out' to highlight the point. Homework problems are assigned on a daily basis, and the groups must meet outside of class to discuss and solve the problems before they are due.

A problem with the new format is the lack of a suitable text for an undergraduate course in separation science. Most quantitative analysis texts provide too little coverage of chromatography and most instrumental analysis texts do not cover chemical equilibrium in enough detail. So, I've created a reserve reading list on topics being covered instead of using a traditional text.

Students can have a good feeling about analytical chemistry, without sacrificing the discipline that is needed to perform reliable, analytical measurements.

The advantages of the new format, however, far outweigh the limitations. The students are clearer about what they understand and where they still have confusion. The lab, with its out-of-class work, contradicts the notion that science occurs in three-hour time blocks. The project-based labs also are more fun.

Several students have gone on to graduate school, to jobs in industry, or to summer research projects. And there have been no complaints about having inadequate background in analytical chemistry. There have been many comments about how much the lab helped them to know what to expect.

I am convinced that the group learning approach is an effective method for teaching quantitative topics such as chemical equilibrium. I urge any skeptics to try it once. I think that with the help of teaching assistants skilled in the use of the equipment, the course could be scaled up for larger sections.

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