ENHANCING RESEARCH IN THE CHEMICAL SCIENCES AT PREDOMINANTLY UNDERGRADUATE INSTITUTIONS

A Report from the Undergraduate Research Summit
Bates College, Lewiston, Maine
August 2-4, 2003

Supported by the National Science Foundation

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The final report, original proposal to NSF, white papers used to guide discussion at the Summit meeting, and upcoming activities aimed as disseminating the recommendations contained in this report can be found at the Summit web site:

http://abacus.bates.edu/acad/depts/chemistry/twenzel/summit.html

EXECUTIVE SUMMARY: KEY RECOMMENDATIONS AND CONCLUSIONS

Goals of Undergraduate Research

Undergraduates participating in research must be involved in an original investigation aimed at creating new knowledge.

The findings of an undergraduate research project should be intended for dissemination among the relevant community through established means such as conference presentations and peer-reviewed publications.

Research activities at predominantly undergraduate institutions benefit the discipline, the student and faculty participants, and the institution. The specific goals emphasized in an undergraduate project (e.g., student learning, student recruitment and retention, faculty development, recognition within the discipline), and how they are balanced, often differ from project to project and individual to individual.

Assessment of Undergraduate Research

Assessment is needed to ascertain whether there are unique learning outcomes associated with conducting research at the undergraduate level and to identify effective practices.

Assessment exercises are likely to be more successful if they involve collaborations between faculty members who actively involve undergraduates in research and individuals who are expert in conducting assessment.

Diversifying the Chemical Sciences

Diversity within the chemical sciences is important because of future workforce needs and the additional perspectives that result from a more diverse work force.

Diversification of the chemical sciences needs to be an important concern for all institutions and chemistry departments.

Diversification of the chemical sciences will require an unprecedented level of outreach and partnerships. Undergraduate institutions must work together to achieve this goal.

Institutions and departments need to make a genuine commitment to hire and admit a more diverse set of applicants.

A Research-Supportive Curriculum

A research-supportive curriculum develops in students the skills needed for successful participation in a research project and provides ample time and opportunities for students to undertake research.

A research-supportive curriculum integrates research and research-like experiences throughout, and culminates with a capstone research experience.

Departments should strive to develop a research-supportive curriculum.

A research-supportive curriculum has the potential to impact favorably the diversification of the chemical sciences by actively engaging students in scientific investigations early in their undergraduate careers.

Partnerships and Collaborations

Research at predominantly undergraduate institutions will increasingly be done in partnership with investigators in other disciplines and at other institutions. An increasing reliance on collaborative research does not minimize the scope and value of single-investigator projects, but is reflective of current realities about the complex nature of many scientific investigations.

Partnerships must be equitable. Both sides must contribute and benefit intellectually and scientifically from a collaborative project. Care must be taken when crafting partnerships and defining the specific roles of the participants.

Collaborations should serve to increase the capacity to involve students from predominantly undergraduate institutions in original research.

Departments and institutions must recognize the value of collaborative projects. Individuals must be able to explain the scope and importance of their contributions to the collaboration.

Funding agencies must recognize that flexibility is a key feature in fostering successful collaborative projects and partnerships.

Responsibilities of Faculty Members

Individual faculty members bear primary responsibility for initiating and sustaining active and productive research programs.

Many funding opportunities exist to support research at predominantly undergraduate institutions. Faculty members should therefore pursue external grants to support their research.

Faculty members need to pursue activities designed to generate and refine ideas for research projects.

Faculty members must prioritize research so that they devote time to it.

Responsibilities of Faculty Departments and Institutions

Faculty members need instructional teaching loads that provide sufficient time to mentor undergraduate research.

Departments need to create teaching schedules that provide blocks of time for research.

Departments and institutions need to establish a culture of undergraduate research such that participation in research permeates the life of the department and institution and becomes an established and valued tradition.

Departments and institutions need to develop practices and provide infrastructure to support and encourage proposal writing.

Departments and institutions need to promote and support activities that will help faculty members generate and refine ideas for research.

Institutions need to recognize the importance of and provide adequate levels of support staff.

Institutions need to provide support for faculty members' research activities at all stages of their career.

Departments and institutions should develop strategic plans aimed at promoting undergraduate research.

Institutions need to speak to their mission as a dynamic integration of teaching and research, with each aspect reinforcing the other, and dispel a view that teaching and research are competing activities.

Promoting Undergraduate Research

Professional organizations with an interest in promoting undergraduate research are urged to work together in areas where their interests overlap.

There is a need for a clearinghouse on undergraduate research that would include items like information on funding opportunities, research-supportive curricular practices, assessment outcomes, and research opportunities for undergraduates.

FOREWORD

The purpose of the Undergraduate Research Summit initiative was to examine issues involved in undertaking and sustaining chemistry research at predominantly undergraduate institutions (PUIs) and to provide recommendations on how to enhance the amount, quality, productivity, and visibility of chemistry research at PUIs (*1*). Recommendations in this report are aimed at individuals, departments, administrative offices, academic and other institutions, and funding agencies.

Involvement of undergraduate students in research has gained national significance. Reports such as *Shaping the Future* by the National Science Foundation (NSF) (1996)(*2*), *Reinventing Undergraduate Education* by the Boyer Commission of the Carnegie Foundation for the Advancement of Teaching (1998) (*3*), and *Science Teaching Reconsidered* by the National Research Council (1997) (*4*) helped bring the value of undergraduate participation in research to national prominence by underscoring themes such as the following:

> "every student should be presented an opportunity … to be involved in some way in scientific inquiry" (*Shaping the Future*)
>
> "undergraduates need to become an active part of the audience for research" (*Reinventing Undergraduate Education*)
>
> "cooperative activities, active learning, and connections with practicing researchers and research activities improve the learning environment for all students" (*Science Teaching Reconsidered*)

Throughout these documents, the importance of discovery and inquiry in promoting student learning is emphasized.

Many faculty members at undergraduate institutions are enormously successful at undertaking significant research in collaboration with undergraduates and, through their activities, embody a teacher-scholar model. For example, *Academic Excellence*, a recent comprehensive study of faculty scholarship in the sciences at a spectrum of undergraduate institutions, reports that over the decade of the 1990s, science faculty members at PUIs in the study averaged one peer-reviewed publication every two years (*5*). Recent data on the baccalaureate origin of Ph.D.s show that PUIs are responsible for a disproportionate number (*6*).

While research has become an important component of undergraduate education, there are a number of issues that confront faculty members at PUIs who wish to remain productive research mentors. Some of these issues have been around for years, but others are a result of the dramatic changes in the landscape of undergraduate research (and in fact all research) in recent years. These changes present challenges, but also opportunities if we are able to take advantage of them in creative ways.

> Many problems in chemistry do not fall neatly within sub-disciplinary areas, and sometimes the single-investigator model may not be the most meaningful way to

conduct research in chemistry. Even though a number of individual investigators have successfully worked on complex multidisciplinary projects, research today frequently involves multidisciplinary teams in which different scientists contribute different areas of expertise. The complexity of many scientific problems under examination necessitates the formation of such collaborations. Furthermore, the knowledge base in chemistry is expanding so rapidly that faculty members at PUIs may have difficulty keeping abreast of the changes.

The demographics of PUIs are changing. Just at other types of institutions, students have different backgrounds and expectations than they did 25 years ago. Increasing numbers of students from traditionally underrepresented populations will make up the student population, and the student population can be expected to exhibit a wider array of learning styles than formerly observed at many PUIs.

The makeup of the faculty, especially at undergraduate institutions, is changing as well. *Academic Excellence* reports that in the 1990s, 40 percent of new tenure-track faculty members in the sciences were women, compared to only 21 percent in the 1980s (*5*). Growth in the representation of minority faculty members is not nearly as dramatic, but considering demographic trends, can be expected to increase in the future. Hiring decisions and career development issues are increasingly impacted by “dual-career” families. Personal responsibilities must be balanced against the considerable amount of “after-hours” time that is needed to be an active and productive teacher-scholar.

Scientists are increasingly interested in integrating research throughout the curriculum and developing a research-supportive curriculum. These efforts have the potential to bring the beneficial learning that occurs through participation in research to more students and provide faculty members more opportunity to undertake research.

There are increasing pressures to assess whether educational activities, including research, actually improve student learning. Educators must demonstrate that curricular changes and research activities have the intended effect of improving learning.

The changes that have occurred have raised the question of whether and how faculty members at PUIs are keeping pace and positioning themselves not only to continue their productive role in contributing knowledge to the discipline and educating students through research, but to enhance the quality of their own research programs.

These issues created the momentum for the Summit initiative. With funding from the Chemistry Division of the NSF, two symposia were held at the Spring 2003 meeting of the American Chemical Society to begin discussion of the issues. An Undergraduate Research Summit meeting followed in the summer of 2003 at Bates College in Lewiston, Maine. The Summit meeting brought together a broad array of members of the chemistry community, ranging from those with a long history of success in undergraduate research to beginning faculty members who have started on a trajectory of success. Participants represented a variety of constituencies including public and private undergraduate institutions (faculty members and administrators), doctoral-granting institutions, industry, national laboratories, and funding agencies. Participants explored a variety of topics at the meeting, the discussion of which was facilitated by a series of white papers, the full text of which can be found at the Summit web site. Throughout the discussion, the emphasis was on the positive steps that could be taken to facilitate research at PUIs. While some of the recommendations do require additional financial resources, many of them can be implemented with minimal or no additional resources. Barriers to undergraduate research were discussed with an eye toward how the community could lower or remove them.

The optimistic and positive attitude that pervaded the meeting were reflected by comments of representatives of funding agencies who were in attendance. It was their contention that research with undergraduates can be done in any environment. This is not to imply that improvement of the undergraduate research environment should not be a goal, but that PUIs are often their own worst critics and thus limit what they accomplish. A flourishing research enterprise at PUIs requires a commitment from individuals, departments, institutions, funding agencies, and other organizations. This report contains a series of observations, commentary, and recommendations on how PUIs can enhance the quality and quantity of undergraduate research.

A variety of dissemination activities are planned to communicate the outcomes of the Summit meeting and to foster implementation of the recommendations contained in this report. An updated list of future activities can be obtained at the Summit web site.

GOALS OF UNDERGRADUATE RESEARCH

Definition of Undergraduate Research

Humans are remarkable in their ability to create knowledge and understanding. Our urge to create knowledge is fueled in part by our innate curiosity about understanding how the universe works and in part by our desire to improve the quality of human existence. Summit participants were in agreement that a person "conducting research," whether or not she or he is an undergraduate, must be involved in an original investigation aimed at creating new knowledge. Equally essential to summit participants was the belief that the findings be disseminated among the relevant community through established means. This usually entails publication of the work in a peer-reviewed scholarly journal.

The following definition of undergraduate research, which was developed at a session entitled "What Constitutes Undergraduate Research" at the 1997 April Dialogue conference organized by the Council on Undergraduate Research (CUR), was endorsed by the Summit participants (*7,8*).

Undergraduate research is an inquiry or investigation conducted by an undergraduate that makes an original intellectual or creative contribution to the discipline.

Why do Research with Undergraduates and at PUIs?

Ample evidence exists that chemistry research undertaken at PUIs has contributed in significant ways to the discipline and hence society. For example, the series of *Directories of Undergraduate Research* published by CUR show the extent and significance of published work from chemistry departments at PUIs (*9*). Also, the recent study *Academic Excellence* shows that faculty members at PUIs actively publish the results of their scholarly work (*5*).

Summit participants recognized that undergraduate research has benefits other than the creation of new knowledge. Basing a research program around undergraduates is almost certain to be less productive at creating knowledge than a program that relies upon similar numbers of graduate students, postdoctoral associates, or career research professionals. An active and productive research program at a PUI is valuable because it also offers benefits to student and faculty participants. Institutions benefit as well from having an active undergraduate research environment. The benefits to students are often emphasized when articulating the reasons for doing undergraduate research. However, the other important benefits do not obviate the basic tenet that undergraduates participating in research should conduct original work that will be published if successful.

As noted by Summit participants, the primary motivation for involving undergraduates in research is the potential for enhanced learning and intellectual development. Undergraduates involved in a well-constructed chemistry research project will have the opportunity to search and read the literature, master equipment and laboratory skills needed to undertake their project, and participate in oral and written communication. Students will gain a depth of understanding about aspects of their project that extend well beyond their peers. They will design experiments, solve problems, interpret data, and by conducting an investigation of an original project without a known answer, think and act like a scientist. Participation in a research project also enables undergraduates to become socialized into the discipline. Admittedly, many of these skills can be developed through a well-designed investigative project, regardless of whether it is original or not, although such projects may require concealing information from the students or discourage reading of the scientific literature. The value of an original project rests on the supposition that it is more difficult to create knowledge than it is to learn something that is already accepted by people in the field. If so, then creating knowledge has the potential to take learning to a heightened level.

The creation of new knowledge requires an exceptionally high level of proof, and is an incredibly exacting enterprise. The persons conducting the research must be able to convince an audience of peers that the new knowledge is valid. Creating knowledge requires a special persistence and attention to detail because the real answer is not known. Many experiments will not work as originally planned, and success will ultimately depend on the skills and creativity of the investigator(s). With original work, there is no place to go for the definitive answer. Being the first person to know something has the potential to create a tremendous sense of empowerment, confidence and intellectual growth, especially for undergraduates (who have usually never had such an experience). Since people will continually encounter problems without established answers throughout their lives, learning the skills needed for participation in original research aimed at creating knowledge has the potential for long-lasting, beneficial consequences.

Summit participants recognized that participation in research has rewards for faculty members as well. A productive research program with peer-reviewed publications, grants, and conference presentations will enhance the likelihood of gaining tenure, promotion and merit raises, open doors to other opportunities, and provide visibility in the field. Faculty members gain intellectually from participating in research and can improve skills in the same areas as students. Faculty can also gain tremendous personal satisfaction from the enjoyment of bringing a research project to completion, seeing students grow intellectually, and working successfully as a mentor with students.

Institutions benefit from the enhanced student learning and faculty engagement that occur through participation in research. Institutions also gain prestige and recognition by having their faculty actively involved in scholarship. Finally, involvement of undergraduates in independent or collaborative projects under the tutelage of a faculty mentor can be a powerful tool in recruitment and retention of students.

Summit participants appreciated that students, faculty members, departments and institutions often have different priorities when undertaking research or involving undergraduates in research. Some may choose to focus on student learning and skill development, others on gaining recognition within their discipline, whereas others may value the potential of undergraduate research as a tool for recruitment and retention of students, especially as it relates to the participation of groups historically underrepresented in science. Goals may change from project to project depending on the level of the student or needs of an individual, department, or institution.

Adherence to the view that undergraduate research must be original and that successful projects are shared with others through established means was deemed as essential to the Summit participants. However, reaching broad consensus on the specific goals of original research at a PUI was not viewed as essential. It is important that individual faculty members, departments, and institutions articulate their goals for research. Institutions and departments need to be clear about whether uniformity among faculty members is desired or differences are encouraged. Departments especially need to communicate this to untenured faculty members and need to ensure that the department goals, values, and expectations align with institutional goals, values, and expectations.

ASSESSMENT OF UNDERGRADUATE RESEARCH

Claims about the value of undergraduate research are lofty, but few well-designed research studies that have measured the benefits of undergraduate research are available. A recent review of the literature on research, assessment, and evaluation of undergraduate research concluded that there were only nine papers, reports, or conference proceedings in which the findings about of undergraduate research are well-supported (*10*). These include four formal research studies on the benefits to students of the undergraduate research experience, and five well-designed program evaluations, three of which were done by the Learning through Evaluation, Adaptation, and Dissemination (LEAD) Center at the University of Wisconsin-Madison. More often, papers and reports include descriptions of the benefits of undergraduate research without providing sufficient supporting evidence. These studies do not address deficiencies in the design or methodological descriptions of the assessment.

Participants at the Summit discussed several reasons why so few well-supported studies designed to assess the value of undergraduate research have been undertaken? One is that many faculty members involved in undergraduate research do not value the importance of or need for assessment. They see the learning that occurs on a one-on-one basis in their mentoring of students and do not appreciate the need to document the learning through an assessment instrument. Another is that most science faculty members who do research with undergraduates are not versed in designing valid assessment instruments. Furthermore, assessment tools for undergraduate research are not available for implementation on a broad scale. Faculty members may resent the time it takes to do assessment, which detracts from the time available to conduct research. Also, some faculty members may fear that assessment outcomes will create a source of outside control that diminishes the individual faculty member’s autonomy over her or his relationship with undergraduate research collaborators. Summit participants agreed that research and assessment are mutually interactive activities with each one helping to guide the other.

Despite the resistance of many individual faculty members toward assessment, the voices calling for assessment of undergraduate research are growing and Summit participants were in agreement that they should not be ignored. Participants generated several reasons why undergraduate research needs to be assessed. (1) Incorporating assessment into the overall scope of an undergraduate research program will lead to a better articulation of goals from the outset. By articulating the goals, participants will be more likely to alter practices to enhance the experience, and more likely to examine whether the goals may be broadened. (2) Assessment exercises will help identify more effective practices that can enhance the experience for everyone involved. (3) Some individuals either doubt the value of undergraduate research or are not aware of its value. Many of these individuals are in position to control policies and/or funding for institutions of higher learning. Anecdotal evidence may not persuade such individuals. (4) Outcomes from well-constructed assessment studies will help make a stronger case for undergraduate research with college administrators, state and federal legislators, policy makers, and funding agencies that have the ability to support undergraduate research.

Because most science faculty members are not qualified and/or interested in designing and conducting assessment of undergraduate research, the risk is high that assessment activities will be undertaken by people versed in assessment but often not in science. People conducting the assessment may not have much experience with undergraduate research. Participants felt that it is imperative that science faculty who actively involve undergraduates in research become involved in assessment activities. Active researchers should help frame the questions, help develop a set of uniform criteria, and critically examine the outcomes of assessment studies. Assessment of undergraduate research in chemistry is going to be most effective if it is conducted as a partnership between chemical researchers, chemical educators, professional organizations, and assessment experts. Assessment exercises must be done in a way that evaluates the specific goals as they will differ from project-to-project and place-to-place. Thus, multifaceted assessment tools are needed to evaluate the variety of goals associated with undergraduate research.

Summary of Assessment Activities to Date

Several papers and reports on undergraduate research begin to provide insights into its benefits to students, faculty, and institutions, and the program characteristics that lead to successful outcomes.

Students involved in research reported greater gains in research skills, greater productivity (as measured by papers and presentations) and stronger interest in research as a career choice than students in a control group. The research students were also accepted into and attended graduate programs rated higher in research productivity than the control group of undergraduates (*11*).

Students asked to self-assess their level on a list of fourteen research skills before and after their research experience reported gains in all of the skills. The gains were stronger in skills such as oral communication or observing and collecting data, while only modest gains were reported in skills such as developing a research question and hypothesis, and designing a way to test the hypothesis (*12*).

Another study examined the general intellectual gains students made during their research experience. This study categorized most college students as being in a transitional knowing stage, where knowledge is believed to be both certain and uncertain, and emphasis is placed on being able to understand and apply knowledge. About one-third of the undergraduate researchers moved from transitional to independent knowing, whereas none in a comparison group exhibited this shift. In the independent knowing stage, knowledge is believed to be uncertain and everyone has his or her own beliefs, and emphasis is placed on independent thinking (*13*).

The Undergraduate Research Opportunities Program (UROP) at the University of Michigan increased student retention in college, but it is interesting to examine the details of the results. For first-year participants, white and Hispanic students showed no difference in retention rates compared to the control group, whereas African-American students showed improved retention, albeit not of statistical significance. For students participating in UROP as sophomores, all three groups showed improved retention, with African-American students showing the strongest and statistically significant improvement. In particular, low-GPA African-American students appeared to benefit most strongly from the UROP program (*14*).

In an evaluation of UW-Madison's Summer Undergraduate Research Program, the LEAD Center found that the program was an effective tool for recruiting students to graduate school at UW (*15*). Importantly, because the summer research program was aimed at minority students and students from institutions without research programs, it proved to be an effective way to recruit minority students to UW.

In an evaluation of the Spend a Summer with a Scientist program at Rice University, the LEAD evaluators clearly documented the effectiveness of the program with respect to the recruitment of minority undergraduates into graduate school and the retention of minority graduate students at Rice University (*16*). More importantly, the evaluators were able to delineate the specific characteristics of the program that led to its success. These characteristics are described in a well-documented list of essential elements, which might be used to replicate the program at other institutions. For example, students were asked about which parts of the program influenced their decision to attend or remain in graduate school. The top three responses were: interactions with the program director, being in the company of other minority students, and interactions with other students in the program.

An extensive alumni survey to study the impact of undergraduate research was conducted at the University of Delaware and found that undergraduate research participants reported greater enhancement of several important cognitive and personal skills (*17*). They also reported higher satisfaction with their undergraduate education and higher rates of going to graduate school. It should be noted that the study does not account for the possibility that students who went on to graduate school may have been predisposed to participate in research as undergraduates.

While these studies consistently report positive aspects of undergraduate participation in research, they are limited in scope and require further replication under different circumstances before firm conclusions and truly effective practices can be identified and supported.

There are at least two significant studies underway to examine the nature and impact of the undergraduate research experience. The National Science Foundation (NSF) is sponsoring a study by SRI International to survey thousands of undergraduate student researchers as well as faculty members, postdoctoral associates, and graduate student mentors about their experiences with undergraduate research (*18*). There are additional study components planned, such as site visits and follow-up surveys. The objective of the study is to better understand the types of research experiences students have, why faculty and students choose to participate in undergraduate research, and how the experience influences the students' academic and career decisions. The study includes students and faculty who participated in Research Experience for Undergraduate Site programs (REU), NSF-sponsored research centers, Research at Undergraduate Institutions awards, and others including the Louis Stokes Alliance for Minority Participation (LS-AMP), Tribal Colleges and Universities Program (TCUP), and Historically Black Colleges and Universities Undergraduate Program (HBCU-UP). The student survey included questions about factors in the decision to do research, activities during research, kinds of things learned (how to plan a research project, problem-solving skills, etc.), best and worst aspects of the research experience, and perceived effects of the research experience, including effect on academic major and career choices.

In a more limited study, Elaine Seymour, of the University of Colorado, and David Lopatto, of Grinnell College, are carrying out a study at four liberal arts colleges to "clarify and estimate the relative importance to students of the benefits of 'good' undergraduate research experience and the processes whereby these are achieved, in a sample of science disciplines and from the viewpoints of participating and non–participating undergraduates and faculty" (*10,19*). Student comments were "overwhelmingly positive" with 91% of student statements referring to gains they had made. The top two reported gains were described in the report as "personal/professional gains" and "thinking and working like a scientist" gains. Within the personal/professional gains category, three-quarters of the student statements referred to their increased confidence to "work as a scientist." The "thinking and working like a scientist" category included statements about gains in the ability to apply knowledge and skills, gains in understanding the scientific process and the process of research, and general gains in science knowledge and understanding.

Future Assessment Needs

Summit participants advocated for assessment data that substantiates or refutes claims that undergraduate research provides a unique or unparalleled learning opportunity for students. Similarly, studies on undergraduate research or research by faculty members at PUIs should examine the potential benefits to faculty members and to the institution. Such studies may substantiate the value of having faculty members who are active and productive researchers, and show whether or not this contributes to their effectiveness as mentors and classroom teachers. Participants believed that an additional outcome of such assessment studies would be the identification and dissemination of effective practices.

It is recommended that other data regarding the outcomes of undergraduate research and research at PUIs be gathered as well. The numbers of peer-reviewed publications from PUIs, the number of publications with undergraduate student coauthors, and the impact of these papers on the discipline as evidenced by citation studies are important metrics on the vitality of research at PUIs, especially if tracked over time. Information on the extent of participation by minority groups in undergraduate research, the effect of undergraduate research on retention, and the impact on career choices is needed.

A survey of graduate schools, professional schools, and industrial employers of chemists with bachelors degrees should be undertaken to determine what effect participation in undergraduate research has on their admittance or hiring processes. Every representative of a doctoral-granting institution or industry affiliated with the different phases of this project stated that participation in undergraduate research was either essential for admittance or hiring or was used as a filter to identify more desirable candidates. Irrespective of whether participation in undergraduate research actually leads to intellectual growth, if the employers of graduates with bachelor's degrees believe it does, then participation in research as an undergraduate is an important experience.

Participants expressed a desire that appropriate entities develop, identify, and disseminate multifaceted tools that can be broadly used for assessment of undergraduate research. Concern was expressed that some of the assessment methods currently being used or developed are too labor-, time-, and expertise-intensive to be broadly applicable in the hands of novices. Professional organizations such as the CUR are encouraged to identify assessment instruments that are shown to work and incorporate them into a "How To" manual on assessing undergraduate research. Federal funding agencies such as the NSF and the National Institutes of Health (NIH) need to help identify and disseminate assessment instruments and provide the opportunity for principal investigators of research grants to include funds to support assessment activities on undergraduate research.

DIVERSIFYING THE CHEMICAL SCIENCES

The chemical community is still not fully diversified demographically despite a longstanding awareness of this issue. Strides have been made in the number of women receiving the bachelor's degree in chemistry (47% in 2000) (*20*), but the numbers drop off at the Ph.D. level (31% in 2000) (*20*) and especially so in the number continuing on to faculty positions at Ph.D.-granting institutions (12% of the total chemistry faculty at the 50 institutions that spent the most on chemical research in 2000) (*21*). There are groups in American society, notably African Americans (Bachelor, 6.1%; Ph.D., 1.7%), American Indians (Bachelor, 0.6%, Ph.D., 0.3%) and Hispanics (Bachelor, 5.4%; Ph.D., 2.3%), whose participation in the physical sciences is disproportionately low relative to their populations in the larger society (*22*).

The Value of Diversity

Participants at the Summit identified two significant reasons to value diversity within the chemical sciences. One involves future workforce needs. The demographics in the United States are changing such that minority groups underrepresented in chemistry are growing in the overall proportion of the population. In some areas of the country minority groups either have reached or will soon reach majority status. The 2000 Census confirmed that California joined New Mexico and Hawaii officially as "minority majority" states, and have a combined minority population in excess of 50%. Texas will soon follow.

Shirley Ann Jackson, President of Rensselaer Polytechnic Institute, reiterated the concern of labor economists and educators that we have a looming personnel crisis in American science and technology (*23*). The United States educational system is not producing sufficient scientists and engineers to meet current or projected demand. A quarter of the current science and engineering work force is over 50 and will retire within the decade. The nation has been able to attract talented foreign workers from around the globe, but many factors mitigate against this being a sound future strategy. Improving economies in several parts of the world, globalization's opening greater opportunities abroad for careers in science, and increased security consciousness of the United States after September 11, 2001, means that the ready availability of foreign talent can no longer be taken for granted. Dr. Jackson notes that the under-representation in science and technology is no longer merely a social problem or even a moral question. "It is now an economic and security requirement – and has become a national imperative."

A second reason is the additional perspective that will be brought to the chemical sciences through a more diverse work force. Chemistry progresses in proportion to the quality and novelty of the research questions posed by its practitioners, and the creative effort expended in answering these. Participants noted that our worldview: our life history and circumstances, including gender, ethnicity, and social class influences the research questions we ask. Individual human uniqueness allows each one of us to frame research questions – and the answers to them – from different perspectives. A better understanding of molecular phenomena is gained by having many chemists form and answer chemical questions from various perspectives, and subject these questions to experimental verification and reproduction.

Experimental data exist on the value of diversity to the research enterprise. Kevin Dunbar, while at McGill University (now at Dartmouth) reported that the social composition of the research group may influence conceptual change (*24*). Two laboratories, one with a group of people from different backgrounds; the second with all members from the same background, faced the same type of research problems. The lab with members from the same background attempted to solve the problems using brute force experimentation whereas the lab with people from more diverse backgrounds solved the problems using analogies. The lab with the diverse background that made use of analogies solved problems faster than the more homogeneous lab.

Training and education are required for, but do not necessarily translate into, participation (*25*). For almost two decades about one-third of chemistry graduate students have been women, yet these gains have not been reflected in commensurate participation of women in chemistry faculty positions at major research universities and in top positions in chemical industry. Yet, chemistry will be somewhat different and richer when a greater number of women chemists are in leadership positions in academia and industry because of the different experiences and perspectives they will bring with them.

Initiatives to Improve the Diversity of the Chemical Sciences

Federal agencies, primarily NIH and NSF, whose missions include development of a scientific workforce, have established programs to create a diverse workforce in industrial and academic science, and these have seen real, although limited, success. Though significant, participants noted that these efforts have been small parts of agency activities (for example NIH programs targeting minority participation have generally been less than 1-2% of overall NIH budgets over the past 30 years). The American Chemical Society (ACS) is paying more attention to the low participation by minority group members in the sciences and has become a major player in encouraging the participation of minority group members in chemical sciences careers through its educational programs, through Project SEED (*26*), and through its ACS Scholars Program (*27*), a commitment of several million dollars in undergraduate scholarships.

Participants believed that diversification of the chemical sciences needs to be an important concern for all institutions and chemistry departments, not just minority-serving institutions. Everyone in chemistry must appreciate the value diversity brings to the discipline and work to improve the situation. Diversification of science must be embedded as a core value in a department and institution's mission and not viewed as an add-on. Participants voiced their concern that diversification of chemistry will not happen on its own, and without a concerted effort, will occur at too slow a pace relative to the change in demographics that are projected.

Diversification of the chemistry community will require an unprecedented level of outreach and partnerships. PUIs must be active participants in these alliances. Members of minority groups are choosing not to study chemistry through to the point of obtaining bachelors and higher degrees. This leakage from the pipeline occurs at all stages, from elementary school on through college. Institutions, departments, and individuals will need to partner with K-12 schools, two-year, and community colleges. Data from the NSF show that 44% of college students are enrolled in two-year colleges, although the proportion of students who actually receive two-year degrees is disappointingly low. Only 24% of those who began at a two-year college in the 1989/90 school year had received an associate's or higher degree by 1994. Only 13% of the associate's degrees were in science and engineering fields (*28*). Higher percentages of black (46.2%), Hispanic (54.3%), and Native American (51.5%) students are enrolled in two-year institutions. Participants in the Summit felt that institutions, departments, and individual faculty members must foster connections between four-year and two-year institutions and that funding agencies must enhance their programs to support these partnerships. Programs such as the NIH Bridges to the Baccalaureate (*29*), NSF Alliances for Minority Participation (*30*), and the NSF Chemistry Division's new Undergraduate Research Centers program (*31*) are invaluable but need to be expanded. Existing college/K-12 and college/community college partnerships have improved minority participation in science and chemistry. More of these efforts are needed among PUIs. Funding agencies also need to augment and better advertise the availability of supplemental funds for ongoing projects that identify opportunities to increase diversity.

The NSF Research Experiences for Undergraduates Site Program (REU) has additional potential to foster minority participation in science (*32*). Participants noted that many deserving applications to the REU site program are not funded. More funds should be allocated to the REU site program. Participants at the Summit also felt that documented plans for recruiting minority students to REU sites should be emphasized when evaluating proposals. REU sites should primarily provide research opportunities to students who would not otherwise have the chance to participate in undergraduate research. It is also recommended that the definition of what it means to be a "site" in the REU program be broadened to promote partnerships designed to enhance minority participation in science. Current REU sites mostly bring students to a central facility and little goes back to the student's home institution. At the time of this report, only one dispersed site is currently funded in chemistry. There are two programs with international connections and a limited number of other sites that involve more than one institution. Broadening the definition of a site to promote more equitable partnerships has the potential to create undergraduate research infrastructure and capacity at a wider variety of institutions, especially many of the smaller PUIs, and to increase the diversity of those participating in chemistry. Longer-range collaborations are possible in today's world of electronic communication. Sites no longer need to be limited by geographic proximity. Participants at the Summit encourage other funding agencies to develop programs similar to the REU site program.

The desirability of incorporating aspects of diversifying chemistry into a broader range of proposals was noted. The concern was voiced that many funding programs have no consequences for the principal investigator who does not address issues of diversity. Investigators who demonstrate inclusiveness through who they involve in research should be rewarded in the review process. Participants felt that the increasing emphasis of the "broader impact" criterion by NSF has the potential to facilitate diversification of science, provided it is rigorously applied in the review and award process.

There was recognition of how the development of a research-supportive curriculum, the components of which are described later in the report, can favorably impact a department's ability to recruit and retain underrepresented groups in chemistry. Involvement of high school students, rising first-year college students, and undergraduates in research has considerable potential for diversifying the chemical sciences. Involvement in research earlier in a student's undergraduate studies has been shown to improve retention of minority groups in science (*14*). Other studies have shown that retention of all students, but especially minority and women students, improves significantly when they form academic and social connections (*33*,*34*,*35*,*36*). The cooperative group activities that characterize many investigative laboratory experiments will connect minority and women students to other students in an academic setting. The closer interaction of a faculty member that often occurs in investigative and problem-based activities as well as research will aid retention. Studies have shown that the "chilly climate" that many women and minority students experience is improved through cooperative forms of learning (*37*,*38*,*39*,*40*). These studies show that little things matter when addressing issues of diversity. The language and styles used in courses and laboratories can influence a student's impression of whether chemistry is a welcoming discipline.

The National Survey of Student Engagement 2000 Report describes five national benchmarks of effective educational practice developed from extensive survey data and research literature on factors that impact student persistence or retention (*41*). Undergraduate research contributes positively to four of these benchmarks by providing "academic challenge" and "enriching educational experiences," and leading to opportunities for "active and collaborative learning" and "student interactions with faculty mentors." Summit participants noted how research opportunities allow students to do and appreciate real science and become acculturated to the vigor and vitality that can exist within a science research laboratory or community. Participation in research enables students to develop a cohort of peers with a shared experience, and brings students closer to faculty mentors who can serve as role models and provide guidance. Students, especially early in their studies, are drawn toward culturally relevant work so programs must strive to develop research projects that particularly interest high school, rising freshman, and first-year minority students.

Many students rely on jobs for living and college expenses. Participants felt that funding sources needed to adequately support stipends for student participants. This would decrease their reliance on other jobs and allow them to devote more time to their research and academic pursuits. Programs that involve minority students at the earliest stages of their development must be carefully structured to increase the likelihood of success. Programs involving students early in their undergraduate studies are less likely to be productive in traditional measures of research productivity (e.g., publications). Programs that have students from minority or other underrepresented groups conduct research early in their studies must enable them to continue research during their entire undergraduate career. Grant programs must recognize that a commitment to the entire career of the student is necessary. To be successful, undergraduate research must occur at more types of institutions, faculty should consider using a more team-oriented approach with younger students who are less prepared for an independent project, and faculty within a department should consider more shared mentoring and collaborative arrangements.

Finally, participants expressed the need for institutions and departments to make a genuine commitment to hiring and admitting a more diverse set of applicants. Doctoral-granting institutions will need to expand the pool of institutions from which they recruit and accept students. Departments will need to expand the prioritization of credentials that are used to rank applicants for faculty positions, recognizing that diversification offers the value of different perspectives. Chemistry departments should also consider the needs of diversification over the needs of coverage of sub-disciplinary areas. Advertising more broadly on disciplinary grounds is likely to result in a more diverse applicant pool.

A RESEARCH-SUPPORTIVE CURRICULUM

Participants agreed that chemistry departments have almost complete control over their curriculum, and can create a curriculum that is supportive of research. A research-supportive curriculum will have two overarching components. One is an emphasis on developing the skills that are needed for successful participation in an independent research project. The other is a structure that facilitates student participation in research by allowing time and offering credit for undertaking research. A research-supportive curriculum will necessitate giving up some other requirements in the major. Adding a required research project to a packed schedule of instructional courses and laboratories will diminish the gains that can occur through research.

The American Chemical Society Committee on Professional Training Guidelines

Chemistry is unusual within undergraduate disciplines in having a rigorous approval process administered by the American Chemical Society (ACS) (*42*). In the past, it was reasonable for a department to feel constrained by the expectations put forward by the Committee on Professional Training (CPT) of the ACS, and reasonable to believe that these expectations hindered the development of a research-supportive curriculum. Participants at the Summit felt that such a criticism of the CPT guidelines is no longer justified. The CPT guidelines now embrace research as a valued part of an undergraduate curriculum in chemistry. For example, the ACS-CPT guidelines state, “undergraduate research can integrate the components of the core curriculum into a unified picture and help undergraduates acquire a spirit of inquiry, independence, sound judgment, and persistence.” Furthermore, “the Committee strongly endorses undergraduate research as one of the potentially most rewarding aspects of the undergraduate experience” (*43*).

The CPT guidelines are now written in a manner that gives a department considerable flexibility in designing an undergraduate curriculum, although departments will need to explain their curriculum and justify how it satisfies the general expectations of a rigorous undergraduate chemistry education.

Unfortunately, examples of non-standard, research-supportive chemistry curricula are rarely described in the published literature (*44*). It is more common to have publications that describe the changes to an individual course or laboratory experiment. Participants felt that the ACS-CPT, which learns of non-traditional, research-supportive curricula through its certification efforts, could help members of the chemistry community by cataloging and disseminating these models through its web site.

Components of a Research-Supportive Curriculum

Summit participants believed that the quality of undergraduate science education will be enhanced if students are exposed earlier in the curriculum to experiences directed at developing critical research skills that include and go beyond the technical laboratory experience. These curricular components should enable students to achieve the following objectives:

- Search, read and evaluate the chemical literature;
- Articulate a concise, approachable research question and its context;
- Design and execute experimental approaches to a research question employing appropriate instrumentation and techniques;
- Critically interpret the data obtained through their experiments and utilize it in an iterative manner to devise new experiments;
- Solve problems as they arise during the execution of an investigation;
- Appreciate ethical, environmental and safety issues associated with laboratory experimentation;
- Collect, assess and communicate experimental data and scientific information; and
- Communicate clearly the nature of the research and its significance.

Participants expressed the view that it is not enough to try to develop these skills by involving students in research activities toward the end of their undergraduate education. Instead, it is the purposeful integration of the specific components and activities associated with successful independent research throughout their undergraduate experience that can help cultivate the skills and attitudes necessary to prepare students for successful research experiences. Lecture and laboratory courses should be designed to introduce, refine, and reinforce a range of skills required for research. Students need to undertake laboratory investigations where answers are not known and in which they have to make decisions and solve problems. Students educated in a research-supportive curriculum will have more productive capstone experiences that, if done in collaboration with a faculty member, will result in greater faculty productivity as well.

Important curricular discussions related to pedagogical strategies and the on-going struggle to balance process and content in the curriculum continue to be invigorating and innovative. A rich and exciting literature exists that details creative pedagogical strategies and objectives for problem-based learning and inquiry-based labs. Such teaching and learning methods can be included at both the individual course level as well as throughout a curricular program. Such initiatives enable motivated educators to move beyond a teaching model which has students a) passively listen and watch lectures and b) execute laboratory exercises – a model better characterized as self-demonstration than actual experimentation. Participants believed that scientific investigations should start in the first year of a student's study in chemistry and continue throughout the curriculum. A common benefit associated with the newer teaching strategies is that they afford students and faculty the opportunity to engage in the lively discourse that illustrates the vitality and dynamic nature of our discipline and the type of discourse they will likely encounter in the research lab. A research-supportive curriculum can also facilitate an examination of how a person's social and cultural context can influence their interests and the type of work they choose to investigate.

Creating the Time for and Encouraging Research

Summit participants provided examples of ways in which departments have adopted a variety of strategies for creating research space within the seemingly rigid chemistry curriculum. The traditional approach has been a system in which almost every course has an associated laboratory. Departments should examine whether this is really necessary if research opportunities are substituted instead. For example, some departments have eliminated the laboratory components of all senior level courses, thereby enabling seniors to focus on their capstone research project. Others have combined the upper-level lab experiences into a joint laboratory, typically offered in the junior year, in which students focus on advanced techniques, instrumentation, and experimental design. In some instances, departments have formally separated the laboratory components from all individual courses to emphasize the critical and distinct role that experimentation and laboratory work plays in science. Some have reduced the vertical and restrictive aspects of the chemistry curriculum and expanded the number of options available to students. In general, a research-supportive curriculum will encourage more electives and have fewer requirements. Reducing the number of laboratories with courses and replacing them with integrated, investigative offerings may free up faculty time for research or facilitate faculty-student research collaborations.

It is possible to have students in instructional laboratories associated with courses undertake actual components of a faculty member's original research project. Another possibility is to have students do a rotation through faculty members' research projects during the sophomore or junior year as an alternative to instructional laboratories associated with courses.

Participants recommended that departments encourage students to do research for credit in earlier years, and require research in the senior year if the numbers permit. As evidenced by the most recent ACS data, most chemistry departments at PUIs graduate a fairly small number of majors (*45*), which suggests that most chemistry departments at PUIs could require research for the major. One resistance to requiring research is the belief that only the best students ought to get to do research. This thinking not only sells students short, but denies those students who have not done as well in classes the opportunity to benefit from the type of learning that can occur through participation in research.

PARTNERSHIPS AND COLLABORATIONS

Why Become Involved in Partnerships and Collaborations?

Participants at the Summit recognized that conducting and maintaining a productive research program at a PUI is challenging given the numerous constraints on faculty time, money, equipment, specialized methodologies, personnel, and research space (*46*,*47*,*48*). These challenges are often cited by faculty at PUIs as reasons for preventing them from keeping current through the literature (*47*) and from generating new research ideas, particularly ones that are interdisciplinary in nature (*46*,*47*,*48*). Many PUIs may have such poor infrastructure or support mechanisms in place that collaborations often represent the most viable mechanism for initiating a research program. A closely related problem is the need for a chemistry department at a PUI to cover the breadth of a discipline with a small faculty. It can be difficult at a PUI to find a colleague who is able to participate in detailed discussions concerning recent advances in a particular research area. Finally, the nature of scientific investigation today is such that many problems cannot be solved through the single-investigator model. The complexity of many projects necessitates a multi-disciplinary and multi-investigator approach.

Collaborations within and between institutions provide faculty members with an opportunity to interact with a wide range of scientists with complementary interests, and colleagues with which to discuss their fields of research. Collaborations usually arise out of a desire to do improved science, but can also lead to joint proposals and funding. Participants voiced the opinion that, in many ways, colleagues at PUIs are positioned to develop unique interdisciplinary interactions. With smaller faculties and departments it is often easier for scientists to interact with colleagues from other science, social science, and humanities departments. These interactions have the potential to foster collaborative projects of unusual scope. Collaborations can also have a significant impact on diversity at institutions, allowing students and faculty to interact with a broader cultural, ethnic, and gender base of scientists. Such interactions will likely lead to the development of new and stimulating research ideas.

The Benefits of Successful Collaborations

Successful collaborations arise only from projects that are of deep interest to all parties and address the needs of everyone concerned. Collaborations must not be viewed as service from doctoral institutions or other laboratories to PUIs, but as mechanisms for reaching goals of mutual interest. Further, each party must make a unique and significant contribution to the collaboration. The benefits of a fruitful collaboration include the following:

- Collaborations promote the generation of new ideas, especially for multidisciplinary projects, such as biochemistry and chemical biology, nanoscience, material science, environmental science, and others. A lack of good or current ideas is often the biggest impediment to faculty members at PUIs staying active in externally funded research.

- Collaborations can enable faculty members to stay abreast of and respond to the rapid changes occurring in certain fields. Collaborative projects offer a way to bring research-dormant individuals back into productive research projects.

- Collaborations can provide experienced researchers to mentor beginning investigators.

- Collaborations raise the level of research productivity, as measured by the number of scholarly publications and professional presentations. This serves as a highly successful technique for combating faculty disenfranchisement from mainstream research (*49*).

- Collaborations permit access to state-of-the art instrumentation, as well as specialized methodology, glassware, and other equipment.

- Collaborations encourage interactions with a broader range of highly trained personnel with more diverse backgrounds and interests. They provide the opportunity for faculty and students at PUIs to work with graduate students, postdoctoral fellows, resident scientists, technicians, and others. The shared goals and experiences are likely to generate enthusiasm for the research and the externally imposed accountability fosters high quality work.

- Collaborations can facilitate a sustained and continuous involvement in research. Maintaining continuity within an undergraduate research program is often difficult with such a frequent turnover of student collaborators.

Opportunities to Collaborate

Opportunities for faculty at PUIs to develop collaborations are vast and diverse, and participants at the Summit provided a range of examples of successful collaborations from their own personal experiences. In addition to collaboration with doctoral institutions, some faculty members at PUIs have forged collaborations with government or industrial research laboratories. Many government facilities have active programs for supporting faculty and their students during the summer as well as sabbatical leave opportunities for faculty. Similar programs also exist in the laboratories of some of the major chemical, pharmaceutical and biotechnology companies. Regional companies may also be interested in supporting summer projects for faculty and faculty/student teams, either in company facilities or at the faculty member's institution. Public institutions may want to pay particular attention to developing collaborations with industries in the region. State legislators are concerned about economic development and the creation of new jobs. Academic-industrial partnerships and the ability of academic institutions to serve as the catalysts for the development of new companies or new products within a company, especially in "high-tech" fields, may generate economic development funds for buildings and equipment that would not otherwise be available.

Numerous reasons were generated for why outside laboratories are interested in collaborating with faculty members from PUIs. While the most obvious is for the recruitment of talented students into graduate programs or company workforces, this may not be the only, or even the most important reason. Faculty members from PUIs possess valuable technical skills that may not be available at collaborating institutions. Companies sometimes seek investigators for significant research topics that are of interest, but are not crucial to a core mission. Thus the company may be unwilling to devote its own personnel to the problem. Furthermore, chemistry departments at PUIs may have certain instrumentation that the collaborating laboratory may be unwilling to purchase or support, but does occasionally require. Finally, some of these laboratories are interested in collaborating with faculty members at PUIs to enhance their visibility in the community and to provide outreach activities for targeted students and institutions.

It was noted that faculty members at PUIs are also finding ways to interact and collaborate with colleagues at their own or other PUIs. Particularly valuable are collaborations involving faculty members from four-year institutions and community colleges (CCs). As already noted, CCs educate a large proportion of college students. Partnerships with CCs provide the potential for recruitment of talented students to complete four-year degrees at PUIs. Partnerships and collaborative activities with CCs will be essential in efforts to increase diversity within the chemical community, and increase the nation's capacity for providing undergraduate research experiences.

Potential Pitfalls of Collaborations

Even though there are enormous benefits in developing research programs at PUIs through collaboration, Summit participants acknowledged that there are potential pitfalls as well.

While an effective way to begin a collaboration may involve having the faculty member from a PUI or two-year institution conduct research in their collaborator's laboratory, such an arrangement will not enhance an individual's independent scholarship in the long run. In addition, this arrangement lessens the impact on students and the research infrastructure at the PUI. Faculty members at PUIs should strive to establish their own productive and independent research programs. While there will certainly be situations where faculty members from PUIs will wish to spend time in their collaborators' laboratories to learn new techniques or to access specialized equipment, it is healthier to the long-term interaction if everyone involved brings a unique and valued contribution to the collaboration, such that the collaboration represents an equitable partnership. Both sides must benefit intellectually and scientifically from the collaboration. Collaborations must serve to increase the capacity to involve students from PUIs in original research experiences.

It is imperative that the collaboration eventually result in refereed publications. This is of particular concern in industrial collaborations, where publication in the open literature is rarely a priority. A publication record is an important factor for securing future research funding, and a lack of publications will compromise the long-term success of the faculty member, the institution and even participating student coworkers.

Participants were especially concerned that faculty reward systems within departments and institutions recognize the value collaborative projects, and appreciate that collaborative projects are increasingly the norm in science. The complexity of many problems makes it essential that a team of investigators with different areas of expertise and resources work together to undertake research. At the same time, participants noted that it is incumbent upon individual faculty members, especially if untenured, to demonstrate or explain the scope and importance of their contributions to the collaboration, since involvement in collaborative work does not eliminate the expectation that a faculty member from a PUI make significant intellectual contributions to the project.

Some collaborations and partnerships will require a considerable amount of administrative oversight. One-on-one collaborations between individual laboratories may be easy to implement. Collaborations or partnerships that bring in groups of individuals or support a wide variety of flexible opportunities will require administrative support. The need for the institution or grant that funds the program to provide appropriate levels of support for administrative responsibilities was noted.

Starting a Collaboration

As exemplified by Summit participants, starting a collaborative project is not that difficult for a faculty member at a PUI since many investigators are receptive to the benefits of collaborations. Faculty members must identify what they have to offer to a potential collaborator. A phone call, email message, or letter of introduction may well be sufficient to generate interest and lead to further discussion. Some Summit participants noted how creating a web site that described their scientific expertise resulted in contacts that led to collaborative projects. Attending specialized, smaller research conferences such as Gordon Research Conferences is an opportunity for networking that can help identify mutually beneficial collaborations. Sabbatical opportunities provide a chance to visit another laboratory can lay the groundwork for an extended collaborative project. National laboratories, in the interest of building national infrastructure, often promote collaborative projects. Searching of appropriate web sites may turn up information on how to initiate contact and indicate the types of projects underway at the facility.

Faculty members at PUIs have several mechanisms for supporting collaborations. The Merck/AAAS undergraduate science program specifically targets collaboration between chemists and biologists within an institution. A new program by the ACS Petroleum Research Fund (Undergraduate Faculty Sabbatical program) (*50*) provides sabbatical leave support for undergraduate faculty interested in establishing new research collaborations. Participants viewed the Undergraduate Research Centers (URC) and Discovery Corps programs (*51*) that were recently instituted by the Chemistry Division of the NSF as exciting new opportunities that should be promoted and expanded. The URC Program is specifically designed to promote partnerships that will increase undergraduate research capacity. These must involve students in their first or second year of study and the partnerships will presumably include some member institutions that do not have a rich track record of involvement in undergraduate research. Funding agencies such as NSF and NIH will fund a range of international collaborations. There are also ways to foster collaborations through traditional research grants available from federal agencies such as NSF and NIH, and private foundations such as Research Corporation (*52*) and the PRF. These can include requests by a principal investigator for support of external collaborations. It is possible to submit joint proposals from two or more institutions. Collaborative components of an overall project that will enhance the scientific outcomes and serve to expand research infrastructure and capacity usually strengthen proposals to funding organizations.

Funding agencies must recognize that flexibility is a key feature in fostering successful collaborative projects and partnerships. One model will not work for all circumstances and situations. The Research Opportunity Awards (ROA) Program is an underutilized resource within the Chemistry Division of NSF. This is partly due to a historically weak record of support within the Chemistry Division of NSF for individual ROA awards and partly because the awards will only support a limited collaboration. Participants also felt that the Chemistry Division of NSF has not effectively utilized the Collaborative Research at Undergraduate Institutions (CRUI) (*53*) program as a way of promoting collaborations among faculty members at PUIs. Support for opportunities in chemistry under the CRUI Program is encouraged.

Overall, participants felt that funding agencies must actively explore initiatives designed to promote a flexible range of collaborations and partnerships with the aim of increasing the nation's capacity to provide research experiences for undergraduates.

THE ROLE OF INDIVIDUAL FACULTY MEMBERS IN INITIATING AND SUSTAINING RESEARCH

Summit participants were consistent in acknowledging that individual faculty members bear primary responsibility for initiating and sustaining an active and productive research program. Staying productive in research takes time, and many faculty members rightfully express concerns about the many competing demands on their time. But individuals prioritize how they spend their time, and faculty members must make research a high priority.

External Grant Opportunities

Participants pointed out that faculty members have a responsibility to pursue external grant support for their research. The NSF, NIH, PRF, Research Corporation, and Camille and Henry Dreyfus Foundation (*54*) all have programs specifically targeted toward faculty members in chemistry at PUIs. However, it is recommended that funding agencies such as NSF and NIH consider providing four-year grants in the Research at Undergraduate Institutions (RUI) (*55*) and Academic Research Enhancement Awards (AREA) (*56*) programs. Longer grants would recognize the slower pace that typically characterizes work at PUIs and allow investigators to undertake riskier projects. Faculty members can also obtain grants for equipment through the NSF-Major Research Instrumentation (MRI) (*57*) and Course, Curriculum, and Laboratory Improvement (CCLI) (*58*) programs. The MRI program no longer requires matching funds for requests from PUIs. The CCLI program requires a 50% match on the equipment portion of a request.

Research in the Summer

Participants uniformly felt that a summer research program is essential for a faculty member at a PUI to sustain productive undergraduate research. Free from classroom and instructional obligations, a summer program allows faculty members to exclusively focus on their work with student researchers and to encourage each other in individual research endeavors. Students who start in the summer are usually more productive on projects continued during the ensuing academic year. New hires should be aware that they are expected to participate in the summer research program as a requirement for tenure. Senior faculty members need to set an example by maintaining summer research programs as well. Most external research grant programs provide a summer stipend to the faculty member.

The Individual Champion

There are many examples of the individual champion who conducted research under what seemed like impossible circumstances, with the effect of gradually changing the research culture of her or his department and institution (*5*). In all likelihood, most PUIs that are known today for the quality and quantity of their research at one time had an environment considerably less supportive of research. Individuals at these institutions showed that research could be done and that it added value to the department and institution. Participation in research gradually became appreciated and valued and the infrastructure, expectations, and reward system were altered in ways that better supported efforts by the faculty to engage in research. It is probably rare that an institution becomes active in research in a top-down approach. Successful development of an active research environment will require faculty members who are enthusiastic about being productive in research.

Generating and Refining Ideas for Research

Participants noted that any quality research project must begin with a good idea, and that the lack of good ideas is often the largest impediment to securing funding and maintaining a productive research program. The quality of an idea is a judgment made by professional colleagues. Research in science usually requires financial support from funding agencies, so judgments of importance also tie into issues of societal and national significance. Staying abreast of the changes in national priorities can be a challenge at a PUI. Reading current literature and requests for proposals from funding agencies is essential in identifying areas of national interest. In many ways, the PUI environment is less rigid and allows for rapid movement into new areas and new collaborations. Ideas must therefore be put before one's colleagues for peer review. Participants discussed how peer review can be obtained in relatively "low-risk" activities such as informal discussions with colleagues or presentations at conferences, or in more "high-risk" ventures such as grant proposals or submissions of manuscripts for publication.

Data in the recent *Academic Excellence* study showed that between 1986 and 2001, proposal submission and funding rates from the science faculty from the schools in the study remained essentially flat, while the size of the science faculty grew more than 21% (*5*). The data on proposal submission rates suggest that faculty members at PUIs have an increasing aversion to putting their work out for high-risk forms of peer review. If so, this is a serious problem, as a lack of proposal volume may ultimately threaten the existence of these programs. Faculty members at PUIs have to overcome their reluctance to peer review. For those who need assistance in grantsmanship and proposal writing, the availability of workshops or institutes on proposal writing by the CUR (*59*) and the ACS PRF was mentioned. At these gatherings, experienced writers pass on their knowledge to other faculty members and institutional officers who wish to develop skills in the preparation of successful proposals.

A problem identified by many Summit participants was the relative dearth of low-risk opportunities available to faculty members at PUIs to float their ideas. Many faculty members in chemistry departments at PUIs work in isolation and are often the only persons in their sub-disciplinary area. There are no colleagues in the department able to provide meaningful feedback. Faculty members at PUIs also have fewer resources and opportunities to travel to conferences to present their work. Faculty members at PUIs need to create more low-risk opportunities in which to try out and refine their ideas, and ways of creating such opportunities were discussed.

The important role that partnerships and collaborations can have in the generation and crafting of ideas has already been mentioned. The value of attending smaller, more specialized conferences that provide more opportunities for informal discussions and personal contracts with professional colleagues has been mentioned as well. Research presentations at smaller conferences also provide a means of gaining visibility within one's field. Meeting periodically with faculty members in your sub-disciplinary area from nearby PUIs with the expressed intent of sharing and discussing research projects and ideas is an excellent way to solicit informal feedback. Ensuring that your sub-disciplinary area is represented in external speakers who visit your department and freely sharing your ideas with visitors from doctoral-granting institutions is an excellent way to get advice and feedback. Most graduate programs are willing to send visiting seminar speakers for recruitment purposes and most visitors enjoy engaging in discussions about ongoing research projects and ideas. There is a tendency at PUIs to optimize the seminar experience for the undergraduates, and it is important to remind oneself that seminar programs are important aspects of professional development for the faculty as well.

The Chemistry Division of CUR coordinates a mentor network in which experienced researchers from PUIs will be matched with colleagues to provide advice and feedback on anything relevant to being successful at a PUI. Many successful grant recipients are willing to share their insights with those new to the process. There are several other initiatives that can be implemented by grass-roots organizations such as CUR that would better service the PUI community. For example, online conferences could be convened that emphasize current research at PUIs in emerging areas, such as nanoscience and bioinformatics. In this way, and without leaving the comfort of the home institution, faculty at PUIs seeking to gather strength in new research areas can develop a better sense of which strategies work at similar institutions. The conferences could serve as a catalyst for collaborations.

The Importance of Sabbatical Leaves

Sabbaticals are perhaps the most efficient of all mechanisms for the generation of new research ideas. The opportunity to become a member—even if only temporarily—of a new research community and to become immersed in a new field can lead to significant changes in research direction. Faculty members from PUIs do extensive teaching and sabbaticals should provide an opportunity to focus exclusively on research. There are many programs that promote sabbatical leaves in the United States (*50,60*) and abroad (e.g., the Fulbright Fellowship Program)(*61*). The new PRF program that supports sabbatical leaves is an excellent addition to the PUI community. The number of submissions in the first year of the program suggests that there is a significant need for sabbatical support for faculty members at PUIs. Going abroad is made all the more attractive by tax exemptions on salaries through the Foreign Earned Income Exclusion clause of the tax code. Also, some foreign institutions, such as the Max Planck Institutes, run their own sabbatical programs, with significant financial support for salary. Faculty members need to be willing to participate in sabbatical and leave opportunities at other laboratories.

In spite of these attractive features, participants noted how going abroad—and sometimes even moving temporarily to a different state within the US—can be very problematic for two-career families. A desire that sabbatical and other leave programs be flexible and support opportunities of variable time and length so that the needs of the faculty member can best be met was expressed. Support for split sabbaticals so a person can spend time away but also time at the home institution to start a new research area is needed. Some faculty members may want to bring students along who can help in getting the project started back at the home institution. Attention should be given to the support of well-designed and justified in-house sabbaticals, which are currently discouraged by most funding agencies. There may be times when an individual already has an excellent idea but just needs the time afforded by a sabbatical leave to implement it. Considering the success of the new sabbatical program from PRF, participants at the Summit recommend that other funding agencies are urged to develop programs that support a range of flexible sabbatical opportunities.

Postdoctoral Fellows at PUIs

A recent trend is the increase in the number of postdoctoral fellows and laboratory technicians being hired by faculty members at PUIs. Participants discussed the somewhat controversial aspect of populating research laboratories at PUIs with postdoctoral fellows. On the one hand, opponents of the idea are wary of shifting the focus away from the education of undergraduates in research methods. On the other hand, endorsers of the idea point to positive impact on research productivity, continuity of the research program, recruiting and training of potential new faculty, and enhanced opportunities for generating new ideas via interactions with young professionals who are knowledgeable in cutting-edge concepts and techniques. The Camille and Henry Dreyfus Scholar/Fellow Program has had a major role in fostering the recognition that research-teaching postdoctoral experiences at PUIs are valuable. There are many examples of individuals with Dreyfus postdoctoral associates succeeding as faculty members at PUIs. The recent Discovery Corps initiative through the Chemistry Division of NSF further underscores the potential value of postdoctoral appointments that are at PUIs or affiliated in some way with PUIs. Postdoctoral associates have considerable flexibility with their time and can especially help in facilitating collaborations between and among colleges. This type of support can be especially beneficial in attempts to build links and establish research capacity at two-year colleges. Faculty members at PUIs should be encouraged to seek support for postdoctoral associates to work in their laboratories.

There needs to be recognition by the chemistry community that there are a variety of suitable formats for postdoctoral experiences. Postdoctoral experiences that are different than the traditional research postdoctoral position at a research university should not be career-limiting. NSF, NIH, and other funding agencies need to recognize the important role a postdoctoral associate can fill at facilitating research at PUIs and should encourage support of postdoctoral associates through special programs like the Discovery Corps and through regular funding channels like RUI and AREA grants.

INITIATING AND SUSTAINING A DEPARTMENTAL CULTURE OF UNDERGRADUATE RESEARCH

It is important for departments at PUIs to create a culture of undergraduate research, such that participation in research permeates the life of the department and becomes an established and valued tradition. Summit participants described a variety of ways in which departments can create and promote a culture of undergraduate research, many of which cost no money or require only minimal expenditure of time. For example, the importance of developing a research-supportive curriculum has already been described.

Creating Time for Research

In the recent study *Academic Excellence*, respondents were asked: "What are the major barriers to the performance of research at your institution?" Over 80% of the responses focused on the lack of time, specifically in terms of the multiple demands on faculty members at PUIs (*5*). Respondents cited their heavy teaching loads and the expectation that they provide significant amounts of individual attention to students as activities that limited their time to conduct research. Many departments are powerless to alter their overall teaching responsibilities, which are usually established by the institution. However, as participants discussed, departments do have considerable ability to adjust parameters of each individual faculty member's schedule.

For instance, departments can create for faculty members a day with no classes or laboratories, and encourage devoting such a day solely to research. Departments often have the ability to create for faculty members a situation in which the teaching load is higher in one semester than the other. Since different faculty members may desire different strategies for creating time (e.g., uneven semester loads, free days, morning versus afternoon teaching responsibilities), it is essential that departments openly discuss course scheduling. Departments need to meet and the topic of yearly scheduling must be put on the agenda. Scheduling ought to be based on aspects of research productivity rather than seniority.

Department discussions aimed at creating time for research can also facilitate discussions about aspects of balancing family and personal responsibilities with professional obligations. Some departments have long-standing activities and traditions that may have been started in an earlier era. The times that these activities are scheduled may not be accommodating to two-career families. Maintaining open lines of communication is important and will help foster a supportive environment within the department.

Strategic Planning

Summit participants advocated the value of a department strategic plan aimed at establishing future goals, objectives, and directions. Strategic planning is especially important for departments without a rich track record of research that want to conduct more research. Strategic planning can be especially effective when it is done in conjunction with a review by external consultants. If the institution does not have a regularized program of external department review, and if the department is unsure how to organize such a review, organizations such as CUR and Project Kaleidoscope (*62*) run consulting services. These organizations will help identify reviewers and provide guidelines for materials to prepare for the review. One advantage of a CUR-organized review is that the external committee will specifically examine and make recommendations aimed at improving the extent and quality of research in the department among the other items in their report.

Strategic planning will allow a department to define its mission and examine its own goals in light of the institution's goals. A strategic plan will enable a department to articulate how its interest in undertaking undergraduate research is aimed at addressing the broad educational goals of the institution. Strategic plans may involve goals for equipment acquisition, with specific plans for submission of proposals to appropriate funding agencies. A strategic plan may involve plans for future revisions of the curriculum. It may include plans for developing departmental funds to support research, and include plans for approaching local industries. The plan can anticipate new hires made possible by impending retirements. Specific plans, activities, and goals for increasing the level of undergraduate research should be included, and may incorporate outreach initiatives to underrepresented groups and the possibility of team projects and shared mentoring arrangements.

A well-constructed strategic plan is likely to impress administrators. If the plan demonstrates the department's commitment to undertake activities aimed at improvement (e.g., writing equipment proposals, developing a research-supportive curriculum), administrators are more likely to support requests for additional resources or matching funds for grant proposals.

Promoting Success

Participants pointed out that a department should take an active role in promoting its successes. If an institution does not have a yearly forum for research presentations by students, the department should organize a poster session for presentation of student research and class projects. The event should be announced in the school paper or bulletin and administrators should be invited to attend. Departments should work with the institution's public relations office to get articles in the local paper on faculty grant awards or student presentations at professional conferences. Development of a web site that highlights the research activities within the department is especially important. Faculty members at public institutions may need to spend time promoting their curricular and research activities with state legislators. This can involve poster presentations by students at the state capitol or invitations and visits by local legislators to the campus for a research event (*63*). The goal is to present in a positive way the good things that are happening in the department.

Student Recruitment

Student recruitment is another area where participants felt that departments could get involved and make a difference. Departments should not depend solely on the admissions staff for student recruitment. This dependence may result in low numbers of chemistry students and even fewer who want to participate in undergraduate research (*64*). Faculty members should work with the admissions staff to recruit students who are excited about science and also want the hands-on experience that a research program will allow. Meeting with prospective students who express an interest in chemistry and having prospective students talk with current majors who are involved in research projects are two ways to aid in student recruitment. The personal contact with a potential student can be a powerful influence on their decision-making and justify the small expenditure of time involved.

A Department Seminar Series

The importance of a regular departmental seminar series was discussed. An active seminar program brings a range of scientists to campus so that faculty and students can learn about new areas of research and build informal connections with researchers. Many graduate schools will send visitors at no cost to the PUIs for recruitment purposes. Active researchers from local PUIs can be integrated into the program. Faculty members from the department and students doing research projects in the department can give seminars as well. These seminars will provide a mechanism to foster discussion of each other's research. If the department has an active summer research program, it is worth considering the establishment of a summer seminar series.

Hiring Decisions

The importance of hiring decisions and the hiring process arose repeatedly over the course of the Summit discussions. Departments should invest considerable time in their hiring decisions and work hard to recruit the best possible candidates. Departments should consider applicants from a wide range of schools and value the added benefits of having a diverse faculty. With the goal of developing an active culture of research and an environment that supports research, departments may want to consider hiring with an eye toward research compatibility. The isolation that characterizes faculty research areas at PUIs can be a considerable deterrent to staying active. Two or more people in a department with compatible research interests can make an enormous difference. Removing some of the disciplinary restrictions on who will be considered for new or replacement positions also has the potential to increase the diversity of the applicant pool.

Allocation of Resources

Departments also need to discuss the allocation of support staff and ensure that resources are distributed equitably. Adequate levels of support staff are crucial in maintaining a research program, especially as it relates to the routine maintenance and operation of equipment. Departments lacking adequate support staff and faced with institutional constraints may want to consider whether it would be better to convert an open faculty position into support staff positions. It may be possible to convert one faculty position into two staff positions so that the remaining faculty can focus more time on developing and sustaining productive research programs.

CREATING AN INSTITUTIONAL CULTURE OF RESEARCH

Institutions need to develop a culture that embraces undergraduate research. Individuals and departments can accomplish a lot on their own, but participants recognized that support from the administration is necessary to sustain and enhance the extent of undergraduate research on campus. The institution's reward system must value undergraduate research. Faculty should be rewarded for published work and grants, especially when the publications describe research done in collaboration with students or the grants support student work. Writing external grant proposals requires a substantial commitment from faculty members and institutions need to create incentives to promote this activity. Senior members of the faculty must see rewards as well for remaining active and productive in research. Ideally an institution's commitment to the importance and value of undergraduate research would be reflected in its mission statement.

Strategic Planning

Like departments, institutions should develop a strategic plan for institutionalizing undergraduate research. One possibility is to create a committee of faculty members, administrators, and students charged with initiating and overseeing activities aimed at promoting undergraduate research on campus. Another is to participate in a program such as the CUR institute "How to Institutionalize Undergraduate Research". Institutions need to incorporate support for undergraduate research into their capital campaigns and generate permanent endowments that support research activities. Institutions need to actively pursue grants from private foundations and federal agencies that will support a broad range of undergraduate research activities, and especially those that will support summer research activities. Institutions need to implement efforts to monitor and assess the impact of research on their students and faculty, and to celebrate the positive outcomes of a research-active environment. Administrators at public institutions who want to support research need to work with faculty members to promote its value with state legislators and policy makers.

Support of Faculty Members at All Career Stages

Participants were especially concerned about the need for institutions to provide support to faculty members throughout their career. Junior faculty members need adequate startup funds and dedicated laboratory space for research. Junior faculty members benefit considerably from a pre-tenure leave program. In the sciences, it may be especially desirable to allow a new faculty member to start her or his position earlier in the summer to set up a laboratory. Science faculty usually need equipment to undertake their research and institutions must be willing to provide matching support for equipment proposals to external funding agencies. Departments will also need some shared research space that can be allocated on an as-needs basis. Many institutions focus considerable resources at getting faculty off to a successful start but spend less on keeping senior faculty members research active. Institutional grant programs are important for faculty members at all career stages. Senior faculty members are often asked to undertake unusual service responsibilities for the institution, and consideration should be given to providing a compensatory teaching reduction with the expectation that the time will enable them to continue scholarly activities. Alternatively, a senior member of the faculty with a productive research program who takes on significant service responsibilities may benefit from having a postdoctoral associate. The support for the postdoctoral position may be provided as matching funds toward an active external grant or by returning indirect costs from the grant to the faculty member. Another option for senior faculty members who have taken on significant service responsibilities is to provide an enhanced sabbatical opportunity after completion of the project.

Many faculty members speak of the need at undergraduate institutions to “balance” teaching, research, and college service. For those that hold research and teaching as conflicting enterprises competing for a fixed amount of time and resources, the “immediate pressures” of teaching win out. The multiple demands facing faculty make it increasingly challenging to find the time and resources for professional development. Participants noted how institutions have the ability to speak of their mission as a dynamic integration of teaching and research, with each aspect reinforcing the other. Institutions also have the ability to develop proactive policies that better support two-career families and the balancing of personal and professional responsibilities.

Travel to professional meetings is a critical activity for faculty members to stay up to date and connected to their field and institutions must provide adequate support for travel. Certain grant programs for the purchase of equipment require matching support. Institutions must be willing to provide this support. An office of sponsored research is important in assisting faculty members in all phases of proposal writing. Some institutions represented at the Summit found that such an office paid for itself through growth in indirect cost return because of increased proposal submission and grant awards.

To allow faculty members at PUIs to focus on their most important responsibilities – teaching and research with undergraduates – it is critical that they not be overly distracted by other duties. Participants noted how it is most often time for research that gets eroded away when another duty is added. It is not in the best interest of a PUI to have faculty members devoting time to peripheral functions such as routine instrument maintenance, laboratory prep work, stockroom management, or grant accounting. Shielding faculty from these time-intensive duties requires support staff to fill roles that do not require faculty expertise. Institutions may also want to free up additional faculty time for research with students by having non-tenured instructional staff teach introductory-level laboratory sections. Institutions need to earmark operating funds for instrument maintenance and repairs as well as to support instrument technicians in science departments. Institutions must provide departments with budgets that will support the infrastructure needed to maintain a productive research program. Administrators may want to discuss with a department whether it is better to replace a new or vacant faculty line with support staff as a way of improving the efficiency of the other faculty.

The effect of a faculty member’s teaching load on her or his ability to do research was a lively topic of discussion at the Summit. It was acknowledged that faculty members need a teaching load that provides sufficient time to mentor undergraduate research. The ACS will no longer approve a department if any instructor has more than 15 instructional contact hours per week. Obviously, faculty members who are also expected to maintain a productive research program need fewer contact hours. Based on a survey of faculty members at PUIs, it has been recommended that instructional contact hours not exceed twelve per week if faculty members are expected to maintain an active research program (*65*). Furthermore, it was recommended that nine or fewer contact hours per week is a more appropriate load if the faculty member is expected to write grant proposals, conduct research, and publish research results in addition to the normal expectations of teaching and service to the institution. Alternatively, institutions that just cannot lower the instructional load to twelve or fewer contact hours because of financial constraints or outside mandates imposed through a state system could allow faculty members to buy their way out of some teaching responsibilities if they are successful at getting external grants. There must be a limit to such "buy-outs," since below a certain level of classroom and laboratory teaching the very essence of what distinguishes the faculty-student relationship at a PUI becomes threatened (*66*). This tension between teaching and research was evidenced in the responses to the survey mentioned above. Faculty members at PUIs wanted sufficient time to work with students on collaborative research projects, but also wanted a vibrant relationship with students in classes and instructional laboratories.

Participants pointed out that the administration has an important role with those departments that are in transition from a teacher-only to a teaching-scholar model. Departments in this situation often experience tension among members who were hired under different sets of expectations. Administrators can help mediate these disputes, encourage and support an external review process, provide support for retreats aimed at self examination, and express support for those faculty members functioning as teaching-scholars. Administrators may also be uniquely positioned to encourage and facilitate research collaborations between junior and senior faculty as a way of enhancing cohesiveness within a department.

Support for information technology is a critical aspect of research, and students and faculty need access to research journals (preferably in both paper and electronic forms), book collections, and searchable electronic databases. Institutional holdings need to be augmented by an interlibrary loan program so that journal articles and books not available on campus can be obtained in a timely manner and at low cost. Participants acknowledged the high cost of some of these services, and encourage federal funding agencies such as NSF to explore the possibility of subsidizing the cost of computerized search methods for the scientific literature.

Institutions should promote multi- and interdisciplinary work, have a system that rewards these activities, but recognize that collaborative activities often require administrative support to flourish. The institution can help identify what types of collaborations will work in its community and assist in bringing together individuals who share a common interest and vision. Collaborations done across different constituencies of the institution have the potential to engage faculty members at all career stages and maintain vibrancy among more senior faculty. These collaborations also have the potential to garner sizeable levels of external grant support from federal agencies and private foundations.

Finally, the institution must make clear through its actions that it values a diverse faculty and student body. Individual departments may need training, awareness, and help in recruiting a diverse applicant pool at the time of searches.

PROMOTING UNDERGRADUATE RESEARCH

We are in the favorable situation of having professional organizations such as the Council on Undergraduate Research (CUR), the National Conferences on Undergraduate Research (NCUR), and Project Kaleidoscope that devote either all or much of their mission to promoting undergraduate research as defined in this document. The emphasis of CUR on faculty and administrator development is an excellent complement to the emphasis of NCUR on student development. Professional organizations such as the ACS have also shown increasing interest in undergraduate research as evidenced by their conference and other programming. In the aggregate, these organizations offer a range of excellent programs aimed at faculty, administrators, undergraduates, and other stakeholders with an interest in undergraduate research. Unfortunately, these organizations often work alone rather than collectively to promote undergraduate research. Since their collective voices will almost certainly have more impact than their individual voices, these organizations are urged to work together in areas where their missions overlap.

The large variety of interests, activities, and opportunities in the area of undergraduate research has created the need for a clearinghouse of information on undergraduate research. An organization like CUR should take the lead in creating a digital library on undergraduate research through the existing NSF digital library program. Such a site would contain information on things like funding opportunities; research-supportive curricular practices; how to generate new ideas; effective mentoring practices; effective practices for initiating and sustaining undergraduate research at the individual, departmental, and institutional level; materials to support undergraduate research; interdisciplinary experiences and opportunities; effective methods of assessment; outcomes of assessment studies; and research opportunities for undergraduates at locations such as REU sites, national laboratories, industries, and academic institutions. Such a digital library would be invaluable to those interested in undergraduate research, and would be a continuing resource that would represent the vibrancy of undergraduate research.

CONCLUDING REMARKS

Enhancing research in the chemical sciences at PUIs is only possible if faculty members, administrators, departments, academic and other institutions, funding agencies, and professional organizations value the various outcomes of undergraduate research. Well-designed assessment exercises that confirm valuable aspects of undergraduate research are needed. It is important to maintain high standards and expectations for undergraduates who participate in research. High standards necessitate that undergraduates participate in original work that is ultimately intended for publication in peer-reviewed journals. Utilizing assessment exercises to identify effective practices that are then broadly implemented is another way to maintain high standards.

The Summit participants were generally appreciative of the current funding situation for undergraduate research. In the aggregate, funding agencies support an array of programs that fulfill many needs. Some programs may benefit from additional funds, increased emphasis or enhanced flexibility in the activities that are supported, but overall, faculty members and institutions have access to a wealth of funding opportunities.

Enhancing the participation of underrepresented groups in the chemical sciences requires a commitment from individuals, departments, and institutions to develop new programs. Diversification of the chemical sciences will not happen on its own but will require direct action and efforts. It is important that departmental and institutional reward systems value efforts aimed at diversifying the chemical sciences.

An increasing reliance on partnerships, alliances, and collaborations reflects a reality of how many scientific investigations are practiced today. Partnerships often provide a means of improving the quality of science and enhancing the number of faculty members and undergraduates who have the opportunity to participate in research. Partnerships and alliances will also be an important component of efforts to diversify the chemical sciences.

Summit participants noted how faculty members are usually drawn toward the issues of time and infrastructure when they are asked to discuss critical aspects that impact their ability to conduct research. Discussions at the Summit on these important topics focused mostly on opportunities available to individual faculty, departments, and institutions that require changes in priorities and practices rather than additional resources. Departments have the ability to design a research-supportive curriculum that enhances opportunities for students and faculty to conduct research as part of the major requirements. Departments have the ability to devise teaching schedules that create blocks of time for research. Institutions have the ability to institutionalize programs and activities that send a clear message that undergraduate research is a valued activity. Certainly resources are needed to be productive at undergraduate research. But Summit participants noted through their own examples that a commitment of faculty, departments, and administrators to the cause of undergraduate research had a way of facilitating the attainment of resources. In order for undergraduate research to flourish at an institution, Summit participants recognized that it required the full support and participation of faculty members, departments, and administrators.

With professional organizations in place to help promote undergraduate research and broadly disseminate effective practices, with widespread receptivity among the various stakeholders in the chemistry community toward collaborative activities and partnerships with PUIs, and with the array of opportunities available to support undergraduate research, Summit participants looked to the future of research at PUIs with considerable enthusiasm and optimism. It is our hope that the recommendations in this report will facilitate discussions and actions aimed at enhancing undergraduate research.

APPENDIX 1: WHITE PAPERS WRITTEN IN SUPPORT OF THE UNDERGRADUATE RESEARCH SUMMIT

Definition of Undergraduate Research
Thomas Wenzel, Department of Chemistry, Bates College

Assessment and Evaluation of the Undergraduate Research Experience
Joanne L. Stewart, Department of Chemistry, Hope College

The Value of Diversity to the Chemical Sciences
Carlos G. Gutierrez, Department of Chemistry and Biochemistry, California State University, Los Angeles

Generating New Research Ideas
Julio de Paula, Department of Chemistry, Haverford College
John Stevens, Department of Chemistry, University of North Carolina, Asheville

Sustaining Research Productivity throughout an Academic Career: Recommendations for an Integrated and Comprehensive Approach
Kerry K. Karukstis, Department of Chemistry, Harvey Mudd College

Collaboration: An Opportunity to Become Productive Research at Predominantly Undergraduate Institutions
Moses Lee and Timothy Hanks, Department of Chemistry, Furman University
Shenda Baker, Department of Chemistry, Harvey Mudd College

Initiating and Sustaining Viable Undergraduate Research Programs at Predominantly Undergraduate Institutions
Kim Pacheco, Department of Chemistry, University of Northern Colorado

Research Infrastructure at Predominantly Undergraduate Institutions
Mark E. Bussell, Department of Chemistry, Western Washington University

Curricula Structures to Support Undergraduate Research
Diane W. Husic, Department of Chemistry, East Stroudsburg University
Tim Elgren, Department of Chemistry, Hamilton College

Politics and Higher Education: Barriers to Undergraduate Research Opportunities at Public Comprehensive Institutions
Diane W. Husic, Department of Chemistry, East Stroudsburg University

APPENDIX 2: VIGNETTES/COMMENTARIES PROVIDED BY SUMMIT PARTICIPANTS

A Consortium of Undergraduate Researchers with Similar Research Interests.
Marc Zimmer, Connecticut College

Our consortium, known as the Molecular Education and Research Consortium in Undergraduate computational chemistRY (MERCURY), was formed by George Shields in 2000 and consists of Jeffery Greathouse (St. Lawrence University, environmental), Maria Gomez (Mount Holyoke College, materials), Carol Parish (Hobart & William Smith College, biochemistry), George Shields (Hamilton College, biochemistry), Ramona Taylor (College of the Holy Cross, environmental) and Marc Zimmer (Connecticut College, bioinorganic). Our objective upon forming the MERCURY consortium was to help our undergraduate research programs to flourish. The intellectual focus of the consortium is computational chemistry. Our research projects utilize the tools of computational chemistry to solve significant problems in environmental, materials, physical and biological chemistry.

All of the faculty members in the MERCURY consortium are research active computational chemists at liberal arts and science institutions where undergraduates are our only focus. The very nature of our institutions dictates that faculty and students work side by side on research projects and necessarily develop strong personal ties. At the undergraduate level students begin their research careers with little or no experience and depend heavily on the mentorship of their research advisor. One of the joys of undergraduate education is watching the transformation of a young student into a mature, independent, creative scientist capable of critical thinking and accurate interpretation.

MERCURY faculty and students meet once per year for a formal presentation and discussion of research methods, results, technical and computing issues, as well as pedagogical issues and best practices. In addition, MERCURY faculty and students exchange information regularly via electronic mail. The consortium has resulted in very synergistic relationships between researchers and this has contributed to our increased productivity. Faculty members regularly visit one another's institution and provide a constant source of mentoring and support, particularly with respect to previewing research papers and proposals. Often, when faculty visit, they bring along their research students, thereby providing opportunities for students at two different institutions to engage in a "super-group meeting." This increases the social interactions among students from different consortial schools and allows them to see that other undergraduates are involved in computational chemistry and meeting the same successes and frustrations normally associated with research. MERCURY faculty and students have regular and frequent interactions as we all perform calculations on two shared supercomputers: a 32-processor and an 8-processor SGI Origin 300 that were purchased with NSF-MRI and Hamilton college funds. This grant has also allowed us to hire a system administrator located at Hamilton College who provides considerable and valuable support to MERCURY faculty and students and allows us to make maximum use of our computing resources. Hamilton College has agreed to provide support for this position beyond the NSF-MRI grant period.

To facilitate the exchange of information so important in the development of an undergraduate scientist and to provide ample opportunity for student-student, student-faculty and faculty-faculty interactions, the MERCURY consortium organizes an annual, national conference in undergraduate computational chemistry. Our last MERCURY meeting was held over three days at Hamilton College in July 2003. Over seventy people attended the conference.
The importance of the conference is evidenced by the growing number of students who elect to present their work: the first meeting attracted 25 student presentations while at the last meeting 40 students presented their work. Many non-MERCURY faculty members accompany their undergraduate students and the meeting takes on an intellectually rich and collegial atmosphere much like Gordon Research Conferences. The cross-fertilization that occurs during these meetings is invaluable. During the meeting students are housed together in dormitories and it is satisfying to see consortial and non-consortial students easily begin to function as a cohesive peer group during and after scheduled activities. Many students reported that their shared research experiences provided comfortable starting points for further conversations of technical and non-technical natures.

Using Undergraduate Research to fill the Pipeline - Experiences at Texas State University-San Marcos

Linette M. Watkins, Texas State University-San Marcos

Texas State University-San Marcos is a primarily undergraduate university located 30 miles south of Austin and 50 miles north of San Antonio. In Fall 2003, the campus had an undergraduate enrollment of 23,024 and a graduate enrollment of 3,282. The Department of Chemistry and Biochemistry at Texas State offers an ACS-certified B.S. in chemistry, a B.S. in biochemistry and M.S. degrees in both chemistry and biochemistry. The department and the College of Science have recently undertaken separate, but complementary, programs to increase the number and diversity of students graduating in science, technology, engineering and math (STEM) fields at our university.

The programs initiated in the department and college are aimed at increasing effectiveness in both recruitment and retention of students. In the College of Science, three programs are used to recruit qualified students into STEM departments. These programs include a Louis Stokes-Alliance for Minority Participation (LS-AMP) program, a Bridges to the Baccalaureate Program and the Science, Math, Technology Education Institute (SMTEI). At the core of all of these programs is participation in research and the presentation of research results.

Texas State is a participant in the NSF-funded Houston LS-AMP program. At Texas State, the LS-AMP program offers scholarships to underrepresented students in STEM fields. More importantly, however, it provides a collaborative learning community (CLC) for STEM majors. The CLC is a place for STEM majors to gather, study, receive tutoring, and attend seminars. All LS-AMP Scholars are encouraged to participate in research projects. Students can receive academic credit and/or wages for the work. A summer conference attended by students from the Houston LS-AMP program offers the opportunity to present research results and meet other scholars. Since 2000, over 150 students at Texas State have participated in this program and the number of graduates has been steadily increasing.

The goal of the NIH-funded Bridges to the Baccalaureate Program at Texas State is to increase the transfer of students from three San Antonio community colleges into NIH-funded areas at four-year colleges. The community college students are primarily members of underrepresented groups, although all students participate in seminars and meetings held at the community college campuses. During the summer, the underrepresented students participate in a ten-week research experience at Texas State. They are provided with housing and a stipend. At the end of the summer they present their research at a symposium and funding is available for travel to present results. Since 1999, 25 Bridges students have completed research experiences and, thus far, almost half of those students have enrolled in four-year colleges.

The NSF-funded SMTEI program brings high school teachers, primarily from low-income school districts, into research labs at Texas State. Over 80 high school teachers have participated in eight-week research experiences. Each of the teachers developed a lesson plan incorporating their research experience into the classroom. At the end of each summer, the teachers presented their research at a symposium. While assessment of this program has shown the research experience to increase research understanding and enthusiasm in the teachers, the longer-term effect on enrollment of underrepresented student in STEM is anecdotal, awaiting further assessment.

Our department has recruited students using the College of Science programs and a new biochemistry program. Recent initiatives are directed at developing a “chemistry community”. Entering students meet with both faculty and peer mentors. Students are advised by faculty in their area of interest, attend programs to enhance learning success and learn about career options. The Chemistry Club introduces students to the faculty and students at all levels of study. Finally, and most importantly, students are encouraged to participate in undergraduate research during the school year or during the summer early in their academic career. We have seen that once a student enters the lab, even during their first year, they will rarely ever leave the degree program. Similarly, when we invite students from other majors into the research lab, they often change their majors to chemistry or biochemistry. Since these initiatives began two years ago, our department has doubled the number of majors, tripled the number of degrees awarded, increased the number of students entering into Ph.D. programs, and increased the number of students from underrepresented groups participating in the chemical sciences. These trends are expected to continue in the coming years.

It is essential that individuals, departments and institutions recognize the urgency of increasing minority participation in the chemical sciences and initiate wide-ranging efforts to ensure a diverse chemical workforce. A single program in a department will be limited in its effectiveness and support. Faculty that are skeptical of “minority assistance” programs will support efforts effective at recruiting and retaining qualified students into their classrooms and research labs. Furthermore, all students at a PUI benefit from programs that develop a vibrant research community.

Community-Based Research Projects
Ray Turner, Roxbury Community College

We believe that culturally relevant, community-based research projects supported by organizational networking can have a profound effect on minority student participation in undergraduate research. The mobilization of urban youth to pursue careers in science and engineering is an honorable endeavor. However, we lacked a suitable model to predict outcomes that could affect future workforce demands. Over a decade ago, we believed that Roxbury Community College (RCC) was ideally situated and had among its ranks some of America's most talented professors. Collaboration and partnership with multiple institutions created a web of opportunity for our students. Today the benefits of that strategy resonate throughout the Roxbury Community. RCC students have performed research side by side with students and faculty at the nation's premier institutions for well over a decade. Over the past five years, the NIH supported ATOMS program provided funds and incentives for students to reach new heights. An analysis of what works and lessons learned from ATOMS forms the basis for project FUSION. We reasoned that a focus on community-based, culturally relevant research could improve recruitment. As the central science, chemistry in this context could mobilize students to pursue science in service to their community. FUSION (ATOMS II), our most recent proposal to NIH, incorporates this thinking. We tested the above hypothesis and the results show an increase in recruitment and retention. In addition, anecdotal evidence indicates major shifts in students' attitude towards science.

Undergraduate research centers should be built on strong collaboration and partnership with community based organizations, including community colleges. Replicating the Roxbury model requires one to focus on the uniqueness of opportunity. We focused on environmental health disparity because this is a problem in the community serviced by Roxbury Community College. Adoption of our model may require modification so that science exploration is framed in the culturally relevant context of a unique community.

The Value of Undergraduate Research: An Indispensable Part of Our Investment
Robert H. Rich, American Chemical Society Petroleum Research Fund*

My own undergraduate research experience was instrumental in leading me down the path to become a Ph.D. scientist. The experience of executing a research project (with some mentoring), from conception through discovery to publication, proved to me and to others that I was capable of making the transition to independent doctoral study. Like my peers who had open access to faculty-initiated research projects, I felt the benefits of participation were felt throughout my career.

While it is important for principal investigators at research-intensive universities to offer research experiences to their undergraduates, it would be a mistake to ignore the research programs at other schools. According to the latest NSF statistics (*6*), one-third of all recipients of doctoral degrees in science and engineering received their baccalaureate degree from a non-Ph.D.-granting institution. All of these students should have access to a research experience, if they so desire.

As was discussed at the Summit, there are many obstacles to a vibrant research program at an undergraduate college. Some of these arise from bureaucratic inertia, from ignorance, or from a hostile culture. Many, however, can be reduced to a need for resources. The availability of student stipends can allow students to spend their out-of-class time doing research instead of other employment. The availability of PI summer salary can allow researchers to avoid taking on yet one more summer school class simply to make ends meet. The availability of supplies and equipment money can allow these scientists to compete in the expensive world of cutting-edge research.

I am proud to say that ACS PRF has recognized these realities for a long time. Since its early days almost 50 years ago, the American Chemical Society Petroleum Research Fund (ACS PRF) has set aside funds exclusively for the support of advanced scientific education and fundamental research to be conducted in academic departments that do not award a doctoral degree (*67*). The basic grant is a three-year award, which currently is valued at up to $50,000. In 2003, 47 such Type B awards were initiated, in addition to 40 Type GB awards (for $35,000 over 2 years) for starting faculty in these non-doctoral departments. In 1981, the Summer Research Fellowship (SRF) program was created to allow faculty from undergraduate colleges to participate in PRF-assisted research projects. The fellowships for faculty continue, and this year 34 supplements were granted. In 2003, the first 10 Undergraduate Faculty Sabbatical grants were awarded, which provide a salary match for eligible faculty to conduct a year-long research sabbatical and revitalize their research programs. Clearly, ACS PRF has recognized that undergraduate participation in research is unmatched in its ability, as an educational activity, to empower young participants to thrive in an increasingly technical world (*68*).

It is indeed heartening to hear that other funding agencies have also begun to realize the importance of allowing faculty at these schools access to research funding. With sufficient resources, these educators can, in turn, work toward a goal of open access to research opportunities for all science and engineering undergraduates. The whole scientific enterprise stands to benefit.

*The opinions expressed in this article are those of the author and not necessarily the same as those of the ACS Petroleum Research Fund Advisory Board or the ACS Board of Directors.

Teaching-Postdoctoral Fellows at PUIs
Joseph Pesek, San Jose State University

The opportunity of having teaching postdoctoral fellows at San Jose State University has been a positive experience for both the individuals involved and the chemistry department. The first two teaching postdoctoral fellows came via Camille and Henry Dreyfus Foundation awards in the early 1990s. Both Fellows made substantial contributions to the teaching program and were active researchers that included working with undergraduates. They taught both lower-division and upper-division classes, seminars and were advisors to the Student Affiliates of the American Chemical Society organization in the department. One fellow remained on for two extra years in a temporary instructor's position to gain more teaching experience. After completion of their positions at San Jose State, each of the Fellows became permanent faculty at PUIs (Ursinus and Goucher). The Department and the College of Science then decided to support such teaching postdoctoral positions out of internal funds. Over the next several years, three people were hired into these positions using the model created for the Dreyfus Fellows. The benefits for the individuals and the Department mirrored those of the Dreyfus Fellows. Each individual acquired valuable teaching skills and helped increase the research productivity of the faculty with whom they worked. Each of these departmental postdoctoral fellows remained for two or three years and then sought other positions. Two obtained permanent faculty status at PUIs (University of Northern Iowa and Santa Clara University) and the third moved to a permanent research position at a Ph.D. granting university (University of Southern California). A third Dreyfus Fellow came to the Department in 2001 and again followed the previously established teaching, research and mentoring model. Upon leaving San Jose State in 2003, he obtained a permanent faculty position at the University of North Carolina, Greensboro. Despite an uncertain budget in the coming years, the Dean of the College of Science has strongly endorsed the concept of teaching postdoctoral fellows and will encourage all departments in the college to consider such appointments in their hiring plans. He also is encouraging such positions to be written into grant proposals where appropriate.

Expanding the Definition of Diversity by including Students with Disabilities in Undergraduate Research

Gina MacDonald, James Madison University

Many discussions and efforts aimed at diversifying the chemical workforce have centered on racial diversity. These efforts are crucial as we work toward a scientific workforce that more adequately reflects the increasing diversity in our society. Although there are many attempts to include minority students, and we need more, there are relatively few programs that strive to accommodate students with disabilities. In general, our community has made few efforts to recruit students with disabilities. The shortage of science educators and researchers intensifies the need to encourage all students to consider a career in the sciences. Furthermore, future science educators should be comfortable with accommodating students with disabilities such that all students may fully participate in chemistry laboratories in high school and college. This report will discuss the importance of expanding research opportunities to students with disabilities and briefly describe a summer research program at James Madison University (JMU) where deaf and hard-of-hearing students participate in chemistry research.

People with physical disabilities are underrepresented in the science and engineering workforce and remain the most underemployed group in our society (*28,69*). Unfortunately, the lack of disabled students who choose to major in the sciences may result from the educators' misperceptions that a physical disability may limit a students' ability to participate in laboratories (*69*). The American Chemical Society has worked to remove barriers for students with disabilities and has published a book for instructors (*69*) and a book with examples of disabled scientists who have successful careers (*70*). These books are valuable resources for professors and students. Although many disabled scientists have made amazing scientific contributions (*70,71*) many educators may not realize the extent of their contributions. For example, Sir John W. Cornforth, a deaf chemist, received the Nobel Prize (*71*). However, the road to success may not always be straightforward for those scientists with disabilities, as described by a blind chemistry student who encountered K-12 teachers that believed he could not be a chemist. This student is now in college, majoring in chemistry and participating in laboratories (*72*). Accommodating disabled students will have expanded impacts as other students and professors gain the understanding that a physical disability does not necessarily limit a student's participation. The inclusion of deaf students in our summer research program at JMU has certainly led to changing attitudes of our hearing student participants and has enriched the NSF REU summer program.

Our program was designed to: encourage deaf students to continue in the sciences, expand research opportunities for deaf students and teachers and finally, to train interpreting students with the unique considerations of interpreting in the laboratory (*73*). Initial efforts were supported with a grant to G.M. and were then expanded to our REU program (Dan Downey and G.M.). The program extended research opportunities for interpreting students through collaborative efforts with Dr. Brenda Seal, a professor in Communication Sciences and Disorders (*73*).

A professional interpreter must be used to ensure student understanding. However, many interpreters are not trained in the sciences. Thus, we have found that it is extremely helpful to have one interpreter who learns the chemical language and who can participate over an extended period of time. This is especially important for student seminars. Deaf students require more preparation time to ensure the interpreter will voice the presentation correctly. Additional considerations such as the professor taking frequent pauses, especially during demonstrations, allows the student to complete the multiple visual tasks required in viewing the demonstration and the language (*69*).

In addition to extended research experiences for deaf students, hearing students have also benefited from our more diversified summer research program. We have most recently found that offering a sign language class greatly enhanced communication between deaf and hearing students. Deaf students and interpreters taught the sign language classes. Hearing students welcomed the opportunity, practiced their signing, and had increased interactions with the deaf students. Most likely, these students and faculty will be more likely to include disabled students in their future laboratories and classrooms. This hypothesized domino effect could result in increasing the number of disabled students in the sciences and deaf participants may be more likely to continue in the sciences or education after gaining research experience.

In conclusion, as we move to increase diversity in the sciences we should work to identify our own misconceptions and strive to make those necessary modifications that will allow students who are blind, deaf, have limited mobility and other disabilities to fully participate in all classroom, laboratory and research laboratories (*74*). Removing barriers for students with disabilities will extend opportunities to a larger number of students and provide an enhanced academic atmosphere for professors and students.

Design of an Interdisciplinary Laboratory to Enhance a Research-Supportive Curriculum
Kerry K. Karukstis and F. Sheldon Wettack, Harvey Mudd College

In their white paper “Curricular Structures to Support Undergraduate Research”, Diane Husic and Tim Elgren make the case for incorporating research-enriching experiences throughout the undergraduate curriculum. They encourage faculty to introduce activities in instructional laboratories and classroom settings to develop the specific skills associated with successful independent research. In particular, the authors note, “Central to scientific inquiry is the iterative process of articulating questions and seeking answers.” Framing an experimentally-accessible research question and designing a viable approach to acquire meaningful data is a challenging task for even the most expert scientist. Undergraduates certainly could benefit from increased opportunities to articulate a concise research question and design as well as execute an experimental approach to address the question. Enabling students to consider these challenging objectives more often in their curriculum and particularly in introductory courses is a desirable pedagogical strategy. Husic and Elgren also maintain that students benefit from hearing about “the kinds of research questions that have piqued a faculty member’s interest.” Communicating one’s passion for research and learning is an effective way to convey the synergy between research and education and can further cultivate the research culture on campus.

At Harvey Mudd College we share the belief that undergraduate research contributes significantly to our learning environment. With the receipt of a NSF Award for the Integration of Research and Education in 1998, we sought new ways to extend the connection between research and education. In particular, we developed a new educational venture - the Interdisciplinary Laboratory - that infuses the results of faculty/student research into the curriculum and expands the role of research-like experiences in laboratory courses (*75*). The year-long Interdisciplinary Laboratory or "ID Lab" attempts to bridge together laboratory experiences from biology, chemistry, and physics for the first-year student. Taught by a team of faculty from each of these disciplines, the ID Lab further seeks to illustrate the commonality of investigative methods and laboratory techniques in these sciences in addition to introducing discipline-specific principles. The Interdisciplinary Laboratory consists of three-week long experiments that feature an investigative approach focusing on question and/or hypothesis formulation and testing.

Many of the experiments conducted in the ID Lab are directly derived from faculty research interests. For example, in the experiment *A Structure-Activity Investigation of Photosynthetic Electron Transport*, students test the effectiveness of substituted quinones as model herbicide inhibitors of photosynthetic electron transport in spinach chloroplasts. A spectroscopic assay is used to measure the rate of electron transport to an exogenous acceptor. Based on the correlations of quinone structure with inhibitory activity from their first week results, students form a hypothesis as to what substituents and structural features promote inhibition and test this hypothesis in the second week using a wider pool of available quinones. In the last week students share their results, examine the consistency of their predictions, and suggest the structural dimensions and hydrophobic/hydrophilic character of the herbicide binding site.

In another experiment developed from faculty research interests - *Synthesis and Characterization of Liquid Crystals* - students explore the origin of the brilliant colors of cholesteric liquid crystals by measuring the pitch of helical arrangements of molecules that form such a liquid crystalline phase. In the first week students synthesize and purify cholesteryl nonanoate and then prepare binary mixtures of cholesteryl nonanoate and cholesteryl chloride to form a cholesteric liquid crystalline phase over the range of 30-80^{o}C for certain solution compositions. To measure the pitch of the helix formed by the mixture, two measurements are necessary - the refractive index of the phase and the selective reflection of that phase. Reminiscent of a research collaboration to acquire sufficient data, student pairs select mixture compositions and temperatures to study, pooling their data in the third week to calculate the pitch of the helix as a function of temperature.

An important goal of the ID laboratory is to better instruct students on how to approach data, formulate hypotheses, and subsequently design experiments to test the posed hypotheses. Students valued the three-week timetable for experiments to allow for such experimental design. One student reflected, "Many experiments offered an opportunity to create and test one's own hypothesis. [This] allows for creativity and a personal stake in the laboratory activity." In comparison with students in the traditional laboratory course, various assessment measures demonstrate that ID Lab students exhibit both greater ability to design experiments that would adequately test their hypotheses and greater creativity in their experimental design and analysis of results. We feel that the investigative nature of the experiments develops student excitement, enhances student learning, and is a central reason for the immensely positive student and faculty reactions to this innovative laboratory course. Perhaps the penultimate measure of success for our new venture integrating research and education was expressed by a student who noted that the discovery nature of the experiments provided "the feeling that we were discovering and learning together."

Building a Research Friendly Environment at PUIs
Timothy Hanks, Furman University

The Undergraduate Research Summit held at Bates College during the summer of 2003 produced clear evidence that research is valuable for both students and faculty. This view was expressed not only by the majority of the participants from academia, but also by representatives from funding agencies and from industry. The latter voice may be the most significant of the three. Since the majority of chemistry graduates will end up in some sort of industrial position, institutions that do not encourage an undergraduate research experience are placing their students at a competitive disadvantage in the job marketplace. Indeed, one representative even suggested that his company would typically not consider the resume of a B.S. level chemist that did not include at least some research experience.

If research is so important, then why are active research programs found at only a minority of the primarily undergraduate institutions in the country? The usual reasons are familiar and significant; lack of time, equipment and other resources. Yet at the Summit, we learn of quality research activities taking place in some unlikely quarters and with the scarcest of support. We also heard repeated assurances by the funding agencies that they stood ready to help such endeavors. Those individuals who bring research experiences to their students in such trying circumstances are the heroes and heroines of the undergraduate teaching profession. They remind us all that scholarship is the product of the mind, not of the surroundings and that good mentoring is the highest level of artistry in education.

The problem with heroic individuals is that we are not all heroes. Worse yet, even heroes burn out in an unsympathetic institution. We need heroes to show us that great things can be done, but heroics do not create a long-lasting, sustainable research program. This best occurs when the academic environment, from the administration to the support staff, buys into the idea that research is an essential part of the undergraduate experience. Not merely "useful" or "desirable", but essential. When an institution becomes committed to this ideal, ways can be found to make it happen. Curricula can be modified, proposals can be written, matching funds can be found and reward structures can be implemented. None of this is simple or pain-free, but it is much more so in a supportive environment.

Let me propose some milestones that a department intent on building a robust research program might strive for:

1) *Research as a graduation requirement for all chemistry majors*. Recognition that research is beneficial to all students is the first step in building a quality research program.

2) *A critical mass of research conducted at the home institution*. While there are many valuable off-site experiences for students, a sustainable program at the home institution requires the equipment holdings and intellectual environment that can only be achieved when sufficient numbers of people are working in close proximity. One possibility is to require students to complete at least one term of research at the home institution, while allowing for additional terms elsewhere.

3) *All faculty members participating in research activities*. This one is more difficult, but valuable for several reasons. Of course, research inactive faculty members make it harder to achieve the critical mass of researchers discussed above. In addition, no matter how verbally supportive, a research inactive colleague has nothing invested in the research enterprise. In the struggle for resources that arise at every institution, these individuals will have priorities that will conflict with the development of a strong research program. Obviously, not all faculty members are at the same points in their academic careers. Not all are able or willing to develop novel research ideas and to manage a research program. But anyone skilled enough in the discipline to be teaching students also has knowledge and expertise that could contribute to the activities of a research team. Collaboration is an integral part of modern science and is the perfect way to tap into the skills of individuals that might otherwise be disenfranchised by a growing research initiative. Universal participation also illustrates to students the value of teamwork and the many different roles that may be involved in an investigative study.

4) *Summers dedicated to research, not classroom activities*. Research is difficult. It takes concentration, commitment and most of all, uninterrupted time. Without a dedicated block of time each year, real progress in the laboratory is nearly impossible. There are important compromises that are inherent in this idea, particularly financial ones. Every effort should be made by the institution, the department, and the individuals involved to alleviate these difficulties. The issue is one of priorities. If research is indeed essential, a way must be found to make it possible.

Chemistry is a vast discipline and there are many ways to actively participate in it. To be a practicing scholar and to introduce the concepts of this scholarship to a new generation of scientists can be both extraordinarily rewarding and valuable. Research is truly science education at its best.

North Carolina A&T State University Greensboro area Mathematics and Science Education Center (GAMSEC) Pre-college Program
Vallie Guthrie, North Carolina A&T State University

The UNC Mathematics and Science Education Network (MSEN) Pre-College Program was established at North Carolina A&T State University in 1986-87. It is a state-assisted program. The official name for the program at North Carolina A&T State University is the Greensboro Area Mathematics and Science Education Center (GAMSEC) Pre-College Program. The goal of the GAMSEC Pre-College Program is to broaden the pool of students who graduate from high school with the academic preparation and motivation to pursue mathematics- and science-based majors and careers. The GAMSEC Pre-College Program actively recruits and prepares students of average to above average ability in grades 7-12 who have not been sufficiently exposed to mathematics- and science-based courses and careers.

All activities of the GAMSEC Pre-College Program are academically intensive, challenging, and enriching. These activities are designed to supplement the regular school-year program and to help improve and refine student knowledge, problem solving, and analytical skills. Through this program students are provided both individual and group instruction. Admission to the Pre-College Program is a multi-year commitment for grades 7-12.

Students participate in the following university-based activities:

The Saturday Academy: The GAMSEC Saturday Academy Program brings participants to the campus of North Caroline A&T State University for 12-14 weeks. The students receive instruction in science, mathematics, English/language arts, college/career counseling and technology from 8:30 a.m.-12:30 p.m. Parent workshops and meetings are also convened on Saturdays when the Saturday Academy is in session.

The Summer Scholars Program: The GAMSEC Summer Scholars Program brings participants to the campus for a four-week (100 hours) session of math/science, computer science, problem solving, accelerated communications courses including science and technology field trips, college and career counseling, personal development, test-taking skills, techniques and interactions with professional and peer role models from scientific and technical fields. The students receive academic development to overcome their prior year weaknesses in mathematics, science and communication skills and are academically prepared for the courses for the upcoming academic year.

Parent Involvement and Development: Parent workshops and programs are planned and implemented to assist parents with the parenting responsibilities of their children. GAMSEC provides opportunities for parents to discuss workable support structures at home and in the community and to gain information on mathematics, science, communication skills, mathematics/science competitions, technology/computer science, career counseling, etc. GAMSEC implements 6-8 parent workshops per year.

Teacher In-Service Students: The teachers of the GAMSEC Pre-College Program students receive at least 50 hours of intensive professional development including strategies and techniques to attract students to science and math courses and careers to ensure students' success in science and mathematics courses. The teachers of the university-based programs include university faculty, middle and high school teachers, graduate students and STEM professionals.

School-based Academic Enrichment Programs: A Parents Involved for Excellence (PIE) Club is organized at each of the Pre-College Program schools. The parents of the students meet monthly to network to build academic support bases for students in the community, to raise funds to support the community programs for the students, and to provide an on-the-school campus peer support group for students interested in high academic achievement in the sciences and mathematics. These clubs build a sense of community within the GAMSEC Pre-College Program group; especially since not all of the programs' students will be in the same classes or study groups.

The GAMSEC Pre-College Program also includes a number of other activities and services. Academic, college, and career counseling is provided to participants. A yearly math/science competition is held. The chance to compete against their peers affords GAMSEC Pre-College students the opportunity to enhance their problem-solving skills and critical thinking skills, gain confidence, increase their self-esteem, learn sportsmanlike manners, and to give the valuable experience of competition. A recognition and awards program is also a component of GAMSEC. Students who are outstanding based on their academic performance and participation receive medals and certificates for their achievements. Field trips are organized. These enable the students to gain personal contact with the broad spectrum of career opportunities that are available in science, technology, engineering and mathematical fields. Representatives from the university/college (both faculty and student), public schools (peer), businesses, community professional organizations and public officials are brought in as role model speakers for the GAMSEC participants. GAMSEC also offers SAT/PSAT preparation classes and score interpretation sessions for students and parents.

Integrating the Sciences at Haverford College
Julio C. de Paula, Haverford College

Modern scientists often rely on collaborations to develop ideas that are likely to result in new contributions to knowledge. Yet, collaboration is not always easy at PUIs, where a faculty member tends to work in isolation on teaching assignments and research projects. As a result, the challenges of designing new curricula and being competitive in research can be rather overwhelming. But, compared to research institutions, the PUI environment is less rigid and can facilitate the continual development of faculty. For example, faculty members at PUIs are not under pressure to sustain large research programs. Also, PUIs tend not to punish their faculty—particularly after tenure—for taking certain risks, such as drastically changing research areas and making extensive use of collaborations. Haverford College is taking advantage of the inherent flexibility of the PUI setting to make significant changes in its science curriculum and its research environment. The focus of this article is Haverford's Marian E. Koshland Integrated Natural Sciences Center (KINSC), a group of faculty and students working on innovative curricula and harnessing the power of collaborations to conduct interdisciplinary research in such fields as neuroscience and nanoscience.

In a complex measuring 140,000 square feet, Haverford's KINSC brings together the Departments of Biology, Chemistry, Computer Science, Mathematics, Physics and Astronomy, and Psychology. From its inception to its completion, the facility was the product of collaboration between the administration and faculty from all departments. As a result, there are many shared spaces throughout the complex, such as a laboratory for instruction in biochemistry and biophysics, a microscopy suite, a laser laboratory, and computational laboratories. To date, the KINSC runs four programs: the Concentration in Biochemistry and Biophysics, the Science & Society Program, the Faculty Development Workshops, and the Nanoscience Program (*76*).

The Concentration in Biochemistry and Biophysics and the Science & Society Program are largely curricular initiatives that seek to introduce students to interdisciplinary fields of study. The Science & Society Program also bridges the gap between the natural and social sciences, giving opportunities for science majors to explore, in courses and research projects, issues in scientific ethics, health policy, and the impact of science and technology on society.

The Faculty Development Workshops, funded by a grant from the Howard Hughes Medical Institute Undergraduate Science Education Program, has retrained our faculty in bioinformatics and catalyzed the integration of advanced computing and statistics across the curriculum. Teams of faculty members from several departments spend a semester or an entire year exploring a topic, often with the help of experts who visit for seminars and tutorials. The process is facilitated by awarding participating faculty members a partial release from teaching duties or a stipend. That the retraining and discussions happen at the College and not at a remote location also makes it possible for the workshops to occur with minimal disruption of teaching and research activities. The Faculty Development Workshops have been very successful and we plan to expand the program as we meet challenges in curricular renovation and retooling of faculty in emerging research areas.

The Nanoscience Program, funded by a grant from the David and Lucile Packard Foundation, features a research collaboration among seven faculty members from chemistry, biology, physics, and mathematics. It is an example of our belief that PUIs can mount programs in rapidly developing areas by taking full advantage of teamwork among faculty and students who share common scholarly interests. Only in its third year, Haverford's Nanoscience Program has already enriched the local research culture. Faculty are teaching each other new concepts and techniques, are publishing together, and students are learning to merge concepts of chemistry, physics, and biology in their research. Other very significant dividends of the intra-institutional collaboration are the continual retraining of faculty—who do not have to rely entirely on sabbatical leaves for broadening scholarly perspectives—and increased research productivity. By working together, our faculty members generate more ideas, develop and maintain new technology and expertise at the home institution, and help each other to conduct experiments and publish their results. The net result is a mechanism for mitigating the effect on productivity of not having large research groups populated by graduate students and post-doctoral fellows.

Haverford's experience suggests that integrating the sciences requires equal attention to building facilities and to fostering collaboration between the teacher-scholars and students who bring the classrooms and laboratories to life. We have challenged ourselves to eliminate walls and habits that once hindered our progress in areas of scientific inquiry that require constant dialog between the traditional disciplines of biology, chemistry, physics, mathematics, and psychology. As a result, we are making sizable strides toward our ultimate goal of responding to advances in science by creating teams of faculty members who can design innovate curricula and collaborate on new research efforts.

How to Better Support Undergraduate Research
Sunhee Choi, Middlebury College

By now I hope it is obvious to everybody, including the non-scientific community, that undergraduate research is vital to our advancement of science because it cultivates future scientists as well as contributes to the discovery of new knowledge.

One thing I am not so certain of is if everybody understands the role of mentors at undergraduate institutions. We write grant proposals, teach students science knowledge, and teach students how to create new knowledge by teaching them research skills. Generally undergraduate students do research for about a year, so their accomplishments are not many. By the time they grasp the concepts and skills needed for productive research they graduate. We start all over again with new students. After several years, many students, and many experiments, we come up with a story for publication. We repeat all the experiments, prepare tables, figures, and write the manuscript by ourselves.

Over the past 16 years I had an average of three research students in my lab each summer, three research students in my lab during the academic year, wrote at least one grant proposal, and wrote the equivalent of half of a paper. All in all, I mentored about 37 students and published ten papers with undergraduate co-authors. Most of my students went on to graduate school or medical school. I bring my research for presentation at international conferences. At two different conferences I even got the award for the best poster. Yet many times reviewers criticize my research proposal because I do not produce enough, and I ask for too much summer salary.

Many funding agencies as well as institutions like ours are willing to support student research assistant stipends during the summer, but few agencies and no college will compensate the faculty mentors for their time and effort. When a professor teaches a course during the summer, they get paid, but it does not seem to be obvious those faculty mentors of undergraduate research assistants should also be paid. I have heard that many funding agencies are wondering why the number of quality grant proposals is going down. One problem I see is that there are too many small grants (in my state these are VT EPSCoR and NIH/BRIN), which require the same amount of time to prepare. Pre-tenure faculty members have their own equipment these days because of generous start-up funds. The success rate is too low, and after many years of trying, people get burned out, and quit. Many institutional grants (HHMI, AAAS/Merck, various Mellon varieties) support student, travel, supplies, and equipment, but they do not give any incentive for faculty to write the mini-proposals and take on the mentoring tasks.

I propose that NSF consolidate grant programs and set aside research funds for undergraduate researchers whose research proposals will be reviewed by only peer researchers at undergraduate institutions. Consideration of the teaching component implicit in mentoring undergraduate research and discontinuity of student expertise should be a required part of the review process. The duration should be five rather than three years.

Being Clear on Goals and Definitions for Undergraduate Research
David F. Brakke, James Madison University

Discussions of the importance of undergraduate research can often be confused by the use of language that includes research, research experiences, senior projects and other terms that are used quite differently on campuses across the country. Perhaps we need to take a step back and make an attempt to define what we mean by undergraduate research as opposed to other kinds of activities conducted by students, and while doing so recognize that we may conduct research or provide research experiences with different goals in mind.

Undergraduate research is original work conducted by undergraduate students working in collaboration with a faculty mentor. As research, the intent is to provide new knowledge and requires the communication of results in written and oral formats. Desired outcomes of undergraduate research include student development and publication of results in the peer-reviewed literature. Programs of undergraduate research may involve a group of students working with several mentors and may be designed to achieve additional goals, including improving placement into graduate or professional programs or retention. In any case, undergraduate research requires sufficient preparation and mentoring such that a student is ready to conduct work for which neither the faculty member or student know the answer and with the expectation they will share the results with their peers and the scientific community. It is also assumed that the student will have investment and intellectual ownership of the project being conducted. In the best of circumstances, undergraduate research leads to peer-reviewed publication. It can also be a key component of a learning process for an undergraduate, while also being a process of scholarly endeavor and advanced form of teaching for a faculty mentor.

Research contains certain elements regardless of the person doing research. Research, then, is research. In contrast, research (or research-based) experiences may include some or many but not all aspects of research. Research experiences may be designed primarily for reasons other than the advancement of a field and creation of new knowledge. They still may contain many of the attributes of research. For example, research experiences may be largely developmental in nature. They may begin with investigative inquiry in introductory labs and moved into integrated labs involving open-ended experiments at other levels. One desired outcome of research experiences is to give students the kind of experiences that would prepare them to conduct original research later on. Research experiences may be used to get students more involved in active learning and doing some of the work of science, while also be designed to improve recruitment and retention. Research-based experiences attempt to meet students where they are, provide challenging and supportive settings for their development, and hopefully ready students for collaborative research with faculty while they are still undergraduates. However, we should not assume that all students will reach a level of interest or development to accomplish original research.

Research experiences should also include important aspects of research in having expectations of sharing the information orally and in written form. These need not include presentations at meetings or peer-reviewed articles, but be work shared in posters or oral presentations as part of campus symposia or class presentations. Sharing results should be viewed as part of a process in intellectual development of a student in the context of what is expected in doing science. While the goal of research experiences may largely be developmental in nature, some students may be engaged in work that produces original results. In this case, students should be encouraged to work with faculty to develop them further into research projects, incorporate them into grant proposals and develop plans for undergraduate research.

There are practical limits to the number of research opportunities and research experiences that can be provided. However, a department that values research and sees it as an ultimate form of teaching can examine its curriculum and design it to prepare students for research and then provide those opportunities. At best, they would include semester-long periods for research, always striving for quality over quantity.

If we see undergraduate research as the pinnacle of a developmental process, we would assume that it is a lofty goal that not all students might achieve depending on developmental state, which will vary across campuses. Those who do original research derive great benefit, but those who eventually may not conduct and publish research will still gain from research-based experiences integrated throughout a curriculum.

While undergraduate research is inherently centered on student learning, it is dependent on a research-active faculty committed to providing the best experiences and mentoring possible. It also requires time and appropriate equipment to support meaningful research opportunities for undergraduates. And, in order to be most effective, a collective vision of the role of research, clear goals and measurable outcomes that can be assessed is essential.

APPENDIX 3: SUMMARY OF PRE–SUMMIT SYMPOSIA AT THE AMERICAN CHEMICAL SOCIETY MEETING, NEW ORLEANS, MARCH 26, 2003

The summaries of the talks were prepared by Thomas Wenzel.

BEST PRACTICES IN UNDERGRADUATE RESEARCH

Fifteen years of REU and its impact on undergraduate research
John Stevens, Robert Kucskowski, Nancy Levinger

Drs. Stevens, Kucskowski, and Levinger provided a general overview of the Research Experiences for Undergraduates Program. The REU program supports sites, which involve a summer research program involving a group of students, and supplements, which provide additional money to support the summer stipend for an undergraduate student to participate on an existing NSF research grant. Total funding was $32M for sites and $17M for supplements in FY01.

About 20-25 site awards are made each year in chemistry. The success rate is about 30%. There are currently a total of 68 sites funded in chemistry. The sites support a total of about 675 students per summer, although another 640 students are supported each summer through matching funds. About 5,400 students apply for the available positions, suggesting there is demand that is not being met.

Chemistry REU sites constitute a variety of different models, and include programs with an international component, students with disabilities, more than one institution, more than one discipline, community colleges, focused research topics, high schools, and student-faculty teams that travel to the site to work together during the summer. Information about the REU program is available on the NSF web site (*32*).

Looking backward and forward in the development of a flourishing undergraduate research program at Western Washington University
Mark Bussell

Dr. Bussell provided an overview of the activities within the chemistry department at Western Washington University (WWU), where there has been a substantial growth in the amount of research in recent years. Faculty members started the changes in the department, but the administration strongly endorsed the conversion to a more research-rich environment.

WWU is a comprehensive public institution with approximately 12,000 students. The chemistry department has 17 faculty members, 5.5 support staff, and about 35-45 majors per year. The department has been the recipient of a departmental research award from Research Corporation that includes a sizeable institutional matching component.

Prior to its recent history in undergraduate research, curriculum development took place in the department, but it was a faculty-only endeavor. No students were engaged in the process. In 1991, faculty members taught 80% of the 100-level laboratory sections. By 2002, the addition of support staff enabled the faculty members to teach only 20% of the 100-level laboratory sections. Introductory labs were also reduced from meeting twice a week to once a week. Selected lab sections with the organic chemistry course will also be taught by a laboratory instructor in the future.

The department has created high quality research space for active faculty members, obtained a substantial quantity of modern equipment, and has access to off-campus-facilities (principally at Pacific Northwest Laboratory) for some specialized areas of research.

The department has taken an active role in helping junior faculty members develop as scholars. Junior faculty members have a lower teaching load. The university has a competitive half-time release program for junior faculty members provided the person writes an NSF or NIH proposal. Senior members of the department actively mentor junior faculty, and help them foster connections with program officers at the granting organizations.

The department actively seeks feedback on its programs. This has involved members of the department visiting other institutions with admirable records of undergraduate research, visits to program officers at granting organizations, bringing in external consultants to review the department, inviting prominent researchers to speak on campus, and hosting conferences.

The curriculum has been altered in ways to better prepare students for research. There are more investigative laboratory experiences and an honors general chemistry sequence. Courses now require oral and poster presentations. There is a culture in the department that draws new students into research.

For the faculty, teaching is still the primary mission, and high quality teaching is expected. But faculty members are also expected to obtain substantial external funding for their research, preferably from organizations like NSF and NIH. Research productivity, as evidenced by peer-reviewed publications with undergraduate coauthors, is expected of faculty members.

The department has two important challenges ahead. One is to target research areas for future hiring decisions so that faculty members can collaborate more on projects. The other is to maintain the collegial environment that presently characterizes the department.

Overview of the comprehensive metropolitan university: challenges and opportunities for developing a productive research program
Joseph Pesek

Dr. Pesek provided an overview of some of the research activities occurring at San Jose State University (SJSU). SJSU is a comprehensive, public institution with a total enrollment of about 30,000 students. About 25% of these are graduate students in schools of engineering, business, and education.

At SJSU there is a university-wide commitment to increase research, and many active grants to support research and educational activities. These include individual, multi-investigator, and institutional awards.

There are also collaborative activities underway that involve partnerships between individuals at academic institutions and several programs between faculty members at the institution and industry. Some of these collaborations with industry have involved small business grants that have led to the marketing of commercial products from scientific discoveries by faculty members at the institution. The institution has been a participant in the NSF Grant Opportunities for Academic Liaison with Industry (GOALI) program, which funds collaborative work involving academic institutions and industry (*77*). The main industrial collaborator on the GOALI program has been IBM.

The institution has also been involved in a successful MBRS program funded through NIH that is to help build the research infrastructure at minority-serving institutions.

Interdisciplinary research as a tool for career development
Cynthia Friend

Dr. Friend discussed the importance of undergraduate research in the admissions process for graduate school, and described some of the activities taking place within the chemistry department at Harvard to better prepare their students and post-doctoral associates for careers in chemistry.

In line with other comments made throughout the Summit process, participation in research is largely a "de facto" requirement for admission to most, if not all, graduate programs in chemistry. For example, 97% of the graduate students in the chemistry department at Harvard have had an undergraduate research experience. They have observed that undergraduates who have had the chance to participate in interdisciplinary research are especially well prepared for their graduate program. They also see undergraduate research as a potential tool to aid in the diversification of science.

At Harvard, 38% of the undergraduate chemistry majors participate in research, although a smaller fraction of women do research. Harvard also has a REU site through the chemistry division and a special postdoctoral program for women. One of the goals of the postdoctoral program is to have the postdoctoral associates bridge with undergraduates during the course of their work. The postdoctoral program also includes broader aspects of career development and attempts to develop community by bringing the women participants together for various activities.

Members of the chemistry department have an interest in drawing a diverse group of students to chemistry, and have found that efforts to diversify the student population require long-term interactions with faculty members at minority-serving institutions.

Research beyond the bubble: reward and perils of collaborating with industrial, government, and academic laboratories
Tim Hanks

Dr. Hanks focused his talk on the use of research within the chemistry department at Furman University as a means of providing new opportunities for collaboration. Furman University is a private institution with a total enrollment of about 2,600 students. The Chemistry Department has 9 faculty members and approximately 20-30 majors per year. The department supports over 50 undergraduate students on research appointments each summer.

Successful collaborations take energy on the part of those involved. There also must be benefits to all parties, each institution needs an advocate to make a collaboration happen and succeed, each party must make a unique contribution to the collaboration, open lines of communication are important, and allowances must be made for changing motivation on the part of the collaborators.

The chemistry department at Furman has a number of collaborations with industry. These include “micro-collaborations” that may involve running a NMR spectrum for someone, “minor collaborations” that may involve instrument training or structured workshops for people to learn about a new technique, to more encompassing “major collaborations” in which faculty-student teams work on joint research projects for periods of months or years. Maintaining significant levels of collaboration with industry requires an infrastructure within the department to handle the various activities. The chemistry department at Furman now has an industrial liaison on their staff. This person handles the myriad of logistical aspects that are necessary to properly maintain these collaborations. Other activities to promote collaborations with industry include a yearly corporate luncheon, preparation of a prospectus that describes the department’s resources and activities, workshops and educational sessions, an academic fair, and preparation of a yearly progress report. Some of the pitfalls of collaborating with industry are the different cultures between academic institutions and industrial firms, different definitions of success, a different sense of time, and aspects of publication, patent issues, and ethical questions.

Members of the department also have ongoing collaborations with government laboratories and with other academic institutions. These collaborations allow people to address problems of national significance, gain access to unique instrumentation, travel to interesting locations, and work with world-class scientists. The national laboratories and the research done at them are very “academic” in focus and there are special programs in place at the labs to establish collaborations.

There are many advantages of collaborations. For academic partners, this involves financial support for research, expanded research opportunities, intellectual enhancement, and employment opportunities for students. For industrial partners, this involves access to faculty expertise and instrumentation, community good will and recruiting, and a means of trying high-risk projects without a large expenditure of resources.

Ways to establish collaborations include attending conferences and meetings, inviting potential collaborators to campus to present a seminar, attending seminars at nearby institutions, looking for summer opportunities, and working the grapevine.

Finally the department participates in two REU site programs. One is organized around a theme of nanoscience. The other is a site involved in environmental science.

The Science Initiative at the University of Richmond
John Gupton

Dr. Gupton discussed the Science Initiative, a new program at the University of Richmond. The University of Richmond is a private institution with a total enrollment of about 3,000 students. The chemistry department averages between 15-25 majors per year. The Science Initiative began with grassroots discussions in the mid 90s. Teams of external consultants were brought in to review the departments and science at the university. Coupled with a new President, the development of a campus-wide strategic plan, and a desire to enhance the research climate and productivity of the faculty, the Science Initiative was started.

The goal is to provide a highly personalized learning environment for students. One feature will be to incorporate inquiry-based learning throughout the curriculum. Another feature is a plan to require research for graduation. There is also a desire to promote interdisciplinary programs and investigations. The curriculum will be modified to meet the new goals, and small class sizes will be emphasized. There will be a purposeful intent to draw science-oriented students to the University through the admissions process.

The research done with undergraduates should lead to peer-reviewed journal articles, be funded through external grants, and result in presentations at professional conferences. It is anticipated that many of the research projects will have an applied flavor to them, so that students readily appreciate the relevancy of the work. To promote the applied flavor of research, new faculty hires will have research interests in the areas of materials, environmental topics, or biochemistry. Additions in these areas will promote the development of new interdisciplinary majors.

Curricular modifications will involve special attention to the content of laboratory offerings in courses intended for science and non-science majors and provide a diverse set of upper-level elective courses that are interdisciplinary in nature.

The administration recognizes that such a program takes resources if it is to be successful. A commitment has been made to increase the size of the chemistry department from 9 to 15 faculty members, and from 3.5 to 6 support staff. There is a commitment to provide the appropriate space, instrumentation, and teaching load needed to enable the increasing emphasis on conducting research with undergraduates.

Success will be measured by the number of majors, the careers of graduates, and the numbers of scholarly publications and external grants by members of the department. An external advisory board has been established and the department will participate in regular external evaluation by visiting committees.

NEW MODELS FOR CONDUCTING RESEARCH AT UNDERGRADUATE INSTITUTIONS

Undergraduate research: how to do it, where are we going, and why did it become a dominant paradigm?
Thomas Tritton

Thomas Tritton, President of Haverford College, began his talk by posing two questions: "what research is?" and "what research isn't?"

Research is an important activity because it is about problem solving. Research is meaningful, because without it, no progress can be made. And research is fun, because it involves thinking a thought that no one else ever had or discovering knowledge that is not known.

Research is not just science, because at academic institutions it ought to involve all disciplines. Research is not just for scholars/academicians. Everyone ought to and has the ability to participate in research. And research is not something that is done in opposition to teaching. Teaching and research are complementary activities.

President Tritton then went on to examine some of the important conclusions he noted from those institutions that participated in the *Academic Excellence* (AE) study.

- Everyone professes that undergraduate research is valuable, and everyone says that it is not research versus teaching.
- All institutions put money into research.
- The number of science degrees, science faculty, and science students doing research increased, but all grew more slowly than the overall institutional budgets.
- Institutions put a higher percentage of new resources into things other than science.
- Institutions fund buildings and start-up costs whereas funding agencies support equipment and the work.

Next, he noted some of the things about the AE study that he found surprising.

- The breakdown of how faculty members spend their time was similar among all types of institutions in the study.
- The amount of time that faculty spent on different activities changed little over the decade, although faculty may have spent a little more time doing research.
- Administrators and faculty members both had similar results for their assessment of how faculty members apportioned their time.
- Only 25% of the publications from PUIs had faculty coauthors.

And finally, he outlined some other important opinions and conclusions from the AE study.

- Investigator-driven project grants are the most important.
- Institutions in the study with graduate programs (masters level) were not more productive with regards to research.
- The percentage of women on the faculty improved significantly (from 21% to 40% over the time period of the report), women outperformed men in getting grant dollars, but women had fewer publications than men.

- The average cost per publication at the institutions was $36,000.

President Tritton then described five existing models for ways in which “research” is done at academic institutions.

1. Courses and laboratories in which investigations are performed.
2. The collection and application of data to solve practical problems, but the results of the work are not intended for the public domain.
3. Library and on-line investigations.
4. An investigation that adds new knowledge to the discipline, and the outcomes are then published or archived in some other way.
5. A discovery of new knowledge that is at the cutting edge of the field, and in which the student is a co-investigator and not just an apprentice.

He regards the first three as not being “real research,” but instead represent tools for learning and for becoming better at doing real research. He would only consider the last two activities “real research.”

In his closing comments, he spoke about how we can improve the environment for getting research done. A key factor is providing faculty members more time for research. This needs to be unfettered time for uncluttered research. Another important activity is to develop more interdisciplinary connections. Faculty members at PUIs need to cross boundaries. Institutions need to change their attitude and culture, and develop systems that reward students and faculty for doing research. Institutions also need to incorporate a means for doing more research into their long-range plans. Finally, we all need to recognize the effort and commitment that it takes to do research and put sufficient effort into the activity.

Industrial and community partnerships as an alternative route to enhancing the campus research environment
Diane Husic

Dr. Husic described the enormous progress East Stroudsburg University (ESU) has made in the past two to three years in developing industrial and community partnerships that have facilitated involvement in undergraduate research. ESU, a public institution with a total enrollment of about 6,300, had not had a tradition of research and scholarship. Until recently, there were only a handful of research-active faculty members, which led to a two-tier faculty in which people were either research-active or research-inactive. The replacements for a large percentage of retiring faculty members brought in new ideas for curricular changes and scholarship.

Prior to the 1980s, ESU was a teaching, or Normal, school. In the 1980s, the institution was controlled by the state legislature. Several steps needed to occur for the situation to change. These included changing the institutional culture, obtaining some critical pieces of equipment to enable certain types of research to occur, and getting some track record of research in place.

Several particular events took place at ESU that enabled a change in the culture with regards to participation in research. These included:

- The institution needed and did get more supportive administrators.
- The research-active faculty members participated in strategic planning.
- The State began mandating a five-year review of departments by an external committee.
- Members of the institution took place in a CUR Institute on institutionalizing undergraduate research.

Furthermore, there was a realization that things could be done to facilitate development of research. These included:

- Curricular changes to support a research environment.
- Efforts to publicize research activity taking place on campus.
- Partnering with regional industry (especially biotechnology) was seen as the most likely way to create a research culture and research infrastructure on the campus. A dialog was initiated with industries in the region.
- Become more politically active by identifying mutual needs with state legislators.

Out of these events came a concerted effort to start programs in a strategic alliance with the pharmaceutical industry in the area. This led to the formation of a biotechnology major and created the components of a biotechnology program. As this initiative developed, a number of other changes occurred at the institution. These included:

- The establishment of the Center for Research and Economic Development.
- The Development of the Sci/Tech Business Accelerator and other research partnerships.
- Summer internship positions became available for students.
- Collaborative research arrangements were developed.
- There were more team and multi-disciplinary approaches to research.
- Faculty engagement in research increased.
- The pool of students expanded because of the research and intern opportunities that were now available.
- There was a change in the visibility and reputation of the institution, as well as a change in the institutional identity.
- They were able to attract internationally renowned speakers through joint seminars
- There were more equipment acquisitions.
- There were more funding opportunities and more success at receiving support for educational and research activities.

The initiative was so successful that the institution has received millions of dollars in grants over the past few years to support these efforts. The rapid expansion of research has not been without its "negative" aspects or challenges. These include:

- Departments that are not involved in science and technology feel left out.
- There is some concern that industry and politicians may begin to dictate the curriculum and research focus.
- Some people have the perception that the emphasis on applied technology is too "vo-tech" and that the liberal arts is being de-emphasized.

- There has to be caution on not making over commitments on what can be delivered.
- It is necessary to make sure that the main institutional commitment of education is not lost in such a venture.

Several irons in the fire
Eileen Spain

Dr. Spain has been a faculty member in the chemistry department at Occidental for eight years. She talked about her perspectives and experiences on staying active in research at a PUI. She views her research as having two primary goals. One is to develop young scientists. The other is to contribute quality science to the literature.

What has worked for her in getting a research program underway and then in sustaining it was the submission of grant proposals very early in her faculty career (she had actually submitted three proposals before starting her position), developing a number of collaborations with faculty members at other institutions, and maintaining visibility within her field by attending conferences, presenting talks, and being pro-active in initiating opportunities.

Some of the value she sees in her grants is that they provide her the independence and flexibility to pursue her research. As she considered entering into collaborative projects, she found it important to assess her strengths so that she knew what she could offer to potential collaborators. These collaborations have provided her free visibility and allowed her to undertake a wider variety of research projects that have been adapted to a wider student audience. She has found the use of teaching-research post-doctoral associates as an important way to facilitate collaborations and sustain these efforts.

Attending conferences has been essential to maintaining visibility, especially smaller, more specialized meetings in her research area. By getting to know people in her field, she has then been invited to speak about her research at conferences. She noted that faculty members from PUIs rarely get invited to organize research symposia at conferences. She advocates that faculty members from PUIs make connections with others in their field to gain visibility and respect, and get involved in the organizing committees for meetings as a way of enhancing the likelihood of being asked to chair symposia.

Undergraduate research: the value to industry
Chris Hollinsed

Dr. Hollinsed of Dupont Central Research and Development discussed the value that participation in undergraduate research has to those going into industry. He began by stressing how participation in research starts to build a research identity in young people.

Participation in undergraduate research begins to teach students about our professional norms. These include:

- Universalism – that all science is objective.
- Organized skepticism – which occurs through the process of peer review.
- Commonality – empirical knowledge that is the property of the scientific community.

- Disinterestedness – we pursue for the sake of science and knowledge, and not personal gain.

But there are other norms that students going into industry must begin to appreciate as well. These include:

- Speed – new products are developed faster and faster.
- Information – it's impossible to keep up with the pace of growth.
- Complexity – need to combine concepts and technologies from a wide variety of disciplines.
- Workforce demographics – the pool of workers is more and more diverse, no longer just white males, and no longer has a nearly identical set of cultural and ethical norms.

Finally, there are professional norms in the industrial setting. These include:

- That industries are involved with making a living, making money, and making products.
- Intellectual property.
- That there are an increasing number of people who share the roles of college professor, researcher, and CTO of start-up companies.

One of the important reasons he advocates that undergraduates be encouraged to participate in research is that it will allow them to develop a research identity. He talked about studies that show that identity development is the primary activity of young people. Furthermore, career choices are highly influenced by whether or not a person can envision herself or himself in a particular role. Participation in research allows young people to determine whether a career involving research is one that they would enjoy. Those who have a research experience but opt out of a research career do so with their eyes open.

He also described other ways in which undergraduates can benefit by participation in research. Research helps students put their course work into perspective. The collaborative nature of research projects in chemistry provides a way for the student to more closely connect with a faculty member. Participation in research provides the student with a roadmap to joining the profession. Finally, communication skills are important to people in their careers and presentations of research outcomes in written and oral form helps students to develop communication skills.

Undergraduate research also has value to industry and to students pursuing a career in industry. Participation in a research project often provides a significant foundation for common ground in the interview process. The research area serves as a means to distinguish the student from all other applicants and provides a proven experience that can help in selling her or his candidacy for the position. Finally, students who participate in a research project not only gain a better background through their experiences, but also realize that they enjoy the field. As a result, they are more likely to succeed in an industrial position.

Undergraduate research participation increases minority retention and success in chemistry

Carlos Gutierrez

Dr. Gutierrez spoke about the impressive strides that California State University, Los Angeles (CSLA) has made in increasing minority participation in science. CSLA has an enrollment of approximately 21,000 students, 84% of which are from minority groups (8% African American, 54% Hispanic, 22% Asian/Pacific Islanders, 0.4% American Indian). Undergraduate research at CSLA has a long history, going back about 45 years.

In more recent times, the department has made great efforts to involve students earlier in their study in undergraduate research, and to form connections with nearby two-year community colleges. Students from the community colleges are brought in for research experiences, and as a result, many of them continue on for four-year degrees. An important goal is of these programs is to encourage students with low GPAs to participate in research as a way of enhancing their interest and commitment to science. The success of these efforts is impressive.

The department has garnered substantial grant support for these activities. Fortunately, the grants have enabled the department to put an infrastructure in place (e.g., paid staff) to handle many of the logistics of operating the programs, thereby freeing up faculty time to work directly with the students on research. As one example, funding through the Minority Opportunities Research Program (MORE) enables them to start students on research early in their undergraduate studies and continue it throughout. The success rate of students going on to graduation in this program is 95%, which is in distinct contrast to a success rate that is less than 30% for the entire university. Overall, the various programs within the chemistry department at CSLA have resulted in 557 journal articles coauthored with undergraduate students and more than 3000 meeting presentations. Many of the student participants have gone on to graduate school, and 11 are in faculty positions at colleges or universities.

ENDNOTES

1. Predominantly undergraduate institutions (PUIs) are defined by the National Science Foundation as U.S. two-year, four-year, masters-level, and small doctoral colleges and universities that (1) grant baccalaureate degrees in NSF-supported fields, or provide programs of instruction for students pursuing such degrees with institutional transfers (e.g., two-year schools), (2) have undergraduate enrollment exceeding graduate enrollment, and (3) award an average of no more than 10 Ph.D. or D.Sc. degrees per year in all NSF-supportable disciplines. Autonomous campuses in a system are considered independently, although they may be submitting their proposals through a central office.

2. *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology*, National Science Foundation, Arlington, VA, **1996**, NSF-96-139, http://www.nsf.gov/pubsys/ods/getpub.cfm?nsf96139

3. *Reinventing Undergraduate Education: A Blueprint for America's Research Universities*, Carnegie Foundation for the Advancement of Teaching, Princeton, NJ, **1998**, http://naples.cc.sunysb.edu/Pres/boyer.nsf/

4. *Science Teaching Reconsidered*, National Academy Press, Washington, DC, **1997**, http://www.nap.edu/readingroom/books/str/

5. *Academic Excellence: The Role of Research in the Physical Sciences at Undergraduate Institutions*; Doyle, M.P., Ed.; Research Corporation: Tucson, AZ, **2000**.

6. *Undergraduate Origins of Recent (1991-1995) Science and Engineering Doctorate Recipients*, NSF-96-334, http://www.nsf.gov/sbe/srs/nsf96334/start.htm

7. Wenzel, T. J., What is undergraduate research?, *Council on Undergraduate Research Quarterly*, **1997**, *17*, 163.

8. Wenzel, T. J., Undergraduate research as a capstone learning experience, *Analytical Chemistry*, **2000**, *72*, 547A-549A.

9. *Directory of Research in Chemistry at Primarily Undergraduate Institutions*, 7th Edition, Mills, N, Otto, C. Eds, **1999**, http://www.cur.org/Publications/Directories.html

10. Seymour, E., Hunter, A.-B., Laursen, S, DeAntoni, T., Establishing the benefits of research experiences for undergraduate: First findings from a three-year study, *Science Education*, **2003**, in press.

11. Kremer, J. F., Bringle, R.G., The effects of an intensive research experience on the career of talented undergraduates, *Journal of Research and Development in Education*, **1990**, *24*(1), 1-5.

12. Kardash, C. M., Evaluation of an undergraduate research experience: Perceptions of undergraduate interns and their faculty mentors, *Journal of Educational Psychology*, **2000**, *92*(1), 191-201.

13. Czaja, J. A. Rauckhorst, W. H., *Creating a Research-Rich Curriculum*, **2002**, http://www.pkal.org/documents/miamiohio.pdf

14. Nagda, B. A., Gregerman, S. R., Jonides, J., von Hippel, W., Lerner, J. S., Undergraduate student-faculty research partnerships affect student retention, *The Review of Higher Education*, **1998**, *22*(1), 55-72.

15. Foertsch, J. A., Alexander, B. B., Penberthy, D. L., *Evaluation of the UW-Madison's summer undergraduate research program: Final report*, **1997**, Madison, WI: University of Wisconsin-Madison, LEAD Center, http://www.cae.wisc.edu/~lead/pages/internal.html

16. Alexander, B. B., Foertsch, J. A., Daffinrud, S., *The Spend a Summer with a Scientist Program: An evaluation of program outcomes and the essential elements of success*, **1998**, Madison, WI: University of Wisconsin-Madison, LEAD Center.

17. Zydney, A., Bennett, J. S., Shahid, A., Bauer, K., Impact of undergraduate research experience in engineering, *Journal of Engineering Education*, **2002**, *19*(2), 151- 157.

18. SRI International, S. Russell, http://www.sri.com

19. Lopatto, D., The essential features of undergraduate research, *Council on Undergraduate Research Quarterly*, **2003**, *23*, 139-142.

20. *Science and Engineering Degrees: 1966-2000*, NSF-02-327, http://www.nsf.gov/sbe/srs/nsf02327/start.htm

21. *Chemical and Engineering News*, September 23, **2002**, *80*, 110-111; October 27, **2003**, *81*, 58-59.

22. *Science and Engineering Degrees, by Race/Ethnicity of Recipients: 1991-2000*, NSF-02-329, http://www.nsf.gov/sbe/srs/nsf02329/front.htm

23. Jackson, Shirley Ann, http://www.rpi.edu/web/President/speeches/nasa02.html

24. Dunbar, K. How scientists really reason: Scientific reasoning in real-world laboratories, In Sternberg, R. J., Davidson, J., Eds. *Mechanisms of Insight*, Cambridge Mass: MIT Press, **1995**.

25. Nelson, Donna J., http://www.awis.org/m_02windivphy.html

26. American Chemical Society, Project SEED, http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=education\student\projectseed.html

27. American Chemical Society, Scholars Program, http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=minorityaffairs\scholars.html

28. *Women, Minorities, and Persons with Disabilities in Science and Engineering: 2002*, Chapter 2 - Undergraduate Enrollment, Two-year Institutions, NSF—3-312, http://www.nsf.gov/sbe/srs/nsf03312/c2/c2s4.htm

29. National Institutes of Health, Bridges to the Baccalaureate Program, http://grants2.nih.gov/grants/guide/pa-files/PAR-02-084.html

30. National Science Foundation, The Louis Stokes Alliances for Minority Partnerships Program, http://www.ehr.nsf.gov/hrd/amp.asp

31. National Science Foundation, Undergraduate Research Centers Program, NSF 03-595, http://www.nsf.gov/pubsys/ods/getpub.cfm?nsf03595

32. National Science Foundation, Research Experiences for Undergraduates Program, NSF 03-577, http://www.nsf.gov/pubsys/ods/getpub.cfm?nsf03577, The June 2003 and September 2003 issues of the *CUR Quarterly* feature articles on writing successful REU proposals, http://www.cur.org/Quarterly/jun03/jun03toc.pdf, http://www.cur.org/Quarterly/sept03/sep03toc.pdf

33. Wenzel, T. J., Cooperative student activities as learning devices, *Anal. Chem.*, **2000**, *72*, 293A-296A.

34. Johnson, D. W., Johnson, R. T., Smith, K. A., *Cooperative Learning: Increasing College Faculty Instructional Productivity*, ASHE-ERIC Higher Education Report No. 4, The George Washington University, Graduate School of Education and Human Development, Washington, DC **1991**.

35. Johnson, D. W., Johnson, R. T., *Cooperation and Competition: Theory and Research*, Interaction book Company, Edina, MN, **1989**.

36. Treisman, P. U., A Study of Mathematics Performance of Black Students at the University of California, Berkeley, Ph.D. Dissertation, University of California, Berkeley, CA, **1985**.

37. Wenzel, T. J., Controlling the climate in your classroom, *Anal. Chem.*, **2003**, *75*, 311A-314A.

38. Hall, R. M., Sandler, B. R., *The Classroom Climate: A Chilly One for Women?*, Project on the Status of Education of Women; Association of American Colleges: Washington, DC, **1982**.

39. Sander, B. R., Silverberg, L. A., Hall, R. M., *The Chilly Climate: A Guide to Improve the Education of Women*, National Association for Women in Education, Washington, DC, **1996**.

40. Sadker, D., Sadker, M., *Promoting Effectiveness in Classroom Instruction*, Final Report, No. 400-80-0033, National Institute of Education, Washington, DC, **1984**.

41. *The National Survey of Student Engagement 2000 Report*, http://www.iub.edu/~nsse/acrobat/report-2000.pdf

42. American Chemical Society, American Chemical Society, Committee on Professional Training, http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=education%5Ccpt%5Cindex.html

43. Undergraduate Professional Education in Chemistry: Guidelines and Evaluation Procedures, Spring **2003**, American Chemical Society Committee on Professional Training, www.chemistry.org/portal/a/c/s/1/general.html?DOC=education\cpt\guidelines.html

44. For one example, see Hanks, T. W., Wright, L. L., Techniques in chemistry: the centerpiece of a research oriented curriculum, *J. Chem. Educ.*, **2002**, *97*, 1127.

45. *Chemical and Engineering News*, August 25, **2003**, *81*, 46-52.

46. Craig, N.C., The joys and trials of doing research with undergraduates, *J. Chem. Educ.*, **1999**, *76*, 595.

47. Pladziewicz, J.R., Factors important to the maintenance of undergraduate research programs, *J. Chem. Educ.*, **1984**, *61*, 515.

48. Mills, N.S., Undergraduate research from the perspective of a young faculty member, *J. Chem. Educ.*, **1984**, *61*, 513.

49. Scalzi, F.V., Kovacic, P., An undergraduate-graduate research collaboration program, *J. Chem. Educ.*, **1973**, *50*, 205.

50. American Chemical Society, Petroleum Research Fund, Undergraduate Faculty Sabbatical Program, http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=prf\prfgrant.html

51. National Science Foundation, Discovery Corps Fellowships Program, Postdoctoral Fellowships and Senior Fellowships, NSF 03-596, http://www.nsf.gov/pubsys/ods/getpub.cfm?nsf03596

52. Research Corporation, http://www.rescorp.org/

53. National Science Foundation, Collaborative Research in Undergraduate Institutions Program, NSF 03-514, http://www.nsf.gov/pubs/2003/nsf03514/nsf03514.htm

54. The Camille and Henry Dreyfus Foundation, http://www.dreyfus.org/

55. National Science Foundation, Research in Undergraduate Institutions Program, NSF 00-144, http://www.nsf.gov/pubsys/ods/getpub.cfm?nsf00144

56. National Institutes of Health, Academic Research Enhancement Awards Program, http://grants1.nih.gov/grants/funding/area.htm

57. National Science Foundation, Major Research Instrumentation Program, NSF 04-511, http://www.nsf.gov/pubsys/ods/getpub.cfm?ods_key=nsf04511, The December 2002 issue of the *CUR Quarterly* features articles on writing successful REU proposals, http://www.cur.org/Quarterly/dec02/dec02toc.pdf

58. National Science Foundation, Course, Curriculum, and Laboratory Improvement (CCLI), Adaptation and Implementation (A&I) Track, NSF 03-598, http://www.nsf.gov/pubs/2003/nsf03598/nsf03598.htm#toc, The March 2002 issue of the *CUR Quarterly* features articles on writing successful REU proposals, http://www.cur.org/Quarterly/mar02/mar02toc.pdf

59. Council on Undergraduate Research, http://www.cur.org

60. National Science Foundation, Nanotechnology Undergraduate Education Program, http://www.nanofab.psu.edu/education/nsf-nue-program.htm

61. The Fulbright Program, http://www.cies.org/about_fulb.htm

62. Project Kaleidoscope, http://www.pkal.org/

63. The June and September 2002 issues of the *CUR Quarterly* are on Undergraduate Research Celebration days, including sessions for state legislators, http://www.cur.org/Quarterly/jun02/jun02toc.pdf

64. Shi, D. E., Reflections on excellence in science education, *Council on Undergraduate Research Quarterly*, ***2001***, *22*, 21.

65. Wenzel, T. J., What is an appropriate teaching load for a research-active faculty member at a predominantly undergraduate institution?", *Council on Undergraduate Research Quarterly*, **2001**, *21*, 104.

66. Lichter, R.L., A modest question: What does it mean to be a professor?, *J. Chem. Educ.*, **1999**, *76*, 1610. For a responding Letter to the Editor, *J. Chem. Educ.*, **2000**, *77*, 1559.

67. American Chemical Society, *47th Annual Report on Research Under Sponsorship of The American Chemical Society Petroleum Research Fund*, Washington, DC, **2003**.

68. For more information on ACS PRF grant programs, visit http://www.chemistry.org/prf

69. *Teaching Chemistry to Students with Disabilities: A Manual for High Schools, Colleges, and Graduate Programs 4th ed*; Miner, D.L. et.al. Eds.; American Chemical Society: Washington, DC, **2001**; ISBN 0841238170

70. Woods, M., *Working Chemists with Disabilities, Expanding Opportunities in Science*; Blumenkopf, T.A. et. al, Eds.; American Chemical Society: Washington, DC, **1996**; ISBN 0841235023

71. Lang, H.G.; Meath-Lang, B., *Deaf Persons in the Arts and Sciences: A Biographical Dictionary*; Greenwood Press: Westport, CT, **1995**.

72. Rouhi, A. M., A blind man's vision, *Chemical and Engineering News*, **2002**, *80*, 36-37.

73. Seal, B.C., Wynne, D., MacDonald, G., Deaf students, teachers, and interpreters in the chemistry lab, *Chemical and Engineering News*, **2002**, *79*, 239-243.

74. Wilkinson, S. L., Approaching a workplace for all, *Chemical and Engineering News*, **2001**, *79*, 55-59.

75. A further description of the Interdisciplinary Laboratory may be found in Van Hecke, G. R., Karukstis, K. K., Haskell, R. C., McFadden, C. S., Wettack F. S., An integration of chemistry, biology, and physics: The interdisciplinary laboratory, *J. Chem. Educ.*, **2002**, *79* 837-844.

76. For more detail, see http://www.haverford.edu/kinsc/

77. National Science Foundation, Grant Opportunities for Academic Liaison with Industry (GOALI), NSF 98-142, http://www.nsf.gov/home/crssprgm/goali/start.htm