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# Value And Impact of Undergraduate Research In Chemistry:

# Lessons Gained From 45 Years of Experience at The University of Kansas

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## Abstract

The Department of Chemistry at the University of Kansas has a 45-year history of providing research opportunity to undergraduates via formal and informal programs. Since 1957 well over 600 students have engaged in research under the direction of its faculty. Participants have included its own undergraduates, many of them working on senior honors theses, as well as students from other colleges and universities. These students have been supported by the University's Undergraduate Research Award program, the National Science Foundation's URP and REU programs, industrial and departmental grants, the department and university, and individual faculty research funds. The combined involvement of all of these students has contributed significantly to the academic life of the department and the university. The climate favoring undergraduate research has had a major impact on undergraduate and graduate education, research productivity, and the overall university-wide research environment in the chemical sciences. Data obtained from surveys of students and advanced scientists, directors of research and research programs, and from personal histories and anecdotes will be presented. They point overwhelmingly to the value of research experience during the college/university years. Research participation has a record of producing young scientists with a clearer commitment to, and better preparation for, graduate education, along with a stronger understanding of career options in the chemical sciences. Research experience also adds an essential dimension to undergraduate science education, by providing a deeper understanding of and more positive attitude toward chemistry, by promoting personal and professional growth, and, finally, by contributing to the nation's research enterprise, the profession of chemistry, and the nation and society at large by leading to the production of more qualified and prepared chemical scientists for the coming generations.

## Introduction

For the past 15 years or so there has been increasing national discussion about the value and importance of undergraduate research. This debate has produced substantial action and support for the endeavor. Undergraduate research has been discussed and funded by the National Science Foundation such that the Chemistry Division, for example, now allocates 2-3% of its annual budget to its support. Primarily undergraduate institutions (PUIs) are more than ever expecting their faculty to engage in research and therefore to involve undergraduates . The Council of Undergraduate Research (CUR) was organized as early as 1974 by chemistry professors, then other natural science and math faculty, at undergraduate institutions to lobby for support for undergraduate research. CUR now is leading the way to encourage greater research involvement by faculty and students in the social sciences and humanities.

The debate about the importance of undergraduate research has been going on for a much longer time, however, both nationally and within colleges and universities. My own institution, the University of Kansas, has had an unusually strong and sustained history of supporting and promoting undergraduate research.

## Research-a critical component of the undergraduate experience.

*Education in the undergraduate major is incomplete without research experience.* I have believed this (known this) ever since my own involvement as an undergraduate--but have become ever more convinced during a professional career devoted largely to undergraduate education. I believe this to be true regardless of discipline, but to be especially true for science students, and certainly true for chemistry majors. I say this for several reasons, all having to do with the value and impact of undergraduate research experience-the theme of this paper. The first reason, discussed in this section, is that *research is an inherent component of the academic enterprise*, of scholarship in general, and certainly of chemistry. It therefore belongs in the undergraduate curriculum.

What is it we expect chemistry majors to take away with them as they emerge from their undergraduate years with a bachelor's degree? We expect a degree of mastery of *content* --a body of knowledge-- complete with facts, symbols, and concepts. This is commonly imparted in the lecture hall and the classroom. We also expect a degree of mastery of *process*-a body of methods-including the handling of equipment, the making of observations, and the collection and interpretation of data. This is commonly learned in the teaching-laboratory setting. Both of these are necessary, yet neither is capable of advancing what is, after all, a dynamic, experimental science. What is too often missing, I think, is the next step, namely *research*-the synthesis and application of content and process in order to discover, make, or do something new. Undergraduates can and should begin to engage in this dynamic aspect of their chosen major. In other words: ***research experience belongs in the undergraduate chemistry curriculum,*** just as do lecture courses in physical

chemistry or laboratory courses in organic methods.

This conclusion is, of course, neither original nor new. Many undergraduate chemistry programs require undergraduate research; many others strongly recommend it and make the opportunity available. Its importance is specified by the American Chemical Society's Committee on Professional Training. It was also the conclusion arrived at a decade ago by a group of NSF-REU (Research Experiences for Undergraduates) chemistry site directors:

"Chemistry is a dynamic experimental science for which research is an inherent component. Such a discipline requires "learning by doing," an inquiry approach, and an apprenticeship experience. A student's education in chemistry is incomplete without research experience." [Report on the National Science Foundation Workshop on Research in the Undergraduate Curriculum (held September 1990), Heinz F. Koch and K. Barbara Schowen, July 1991.]

and by a group of biological science REU site directors:

"...research not only serves as an important adjunct to the traditional classroom, but is absolutely essential in modern, quality, undergraduate science education." [National Science Foundation Site Directors Meeting (held August 1993) Final Report, C.C. Barney, B.A. Battelle, D. Bynum, R. Powell, and M. Stiassny.]

I see no reason why undergraduate research experience should be restricted to the basic or applied sciences, and believe that the arguments made above can and should be made for disciplines as widely disparate as history and social work. For the highest quality bachelor's-level degree programs, research should be part of the undergraduate experience of *all* students in *all* disciplines. In this context research is meant to be broadly defined-as producing a new or fresh discovery, creation, synthesis, analysis, or interpretation.

Let me make a few observations about what we might mean when we talk about undergraduate research in chemistry. First, we can distinguish between research *per se* and research *experience.* Ideally, undergraduate research should be "real," that is, it should be such that the student will, at least by the end of the experience, be working on an authentic project that will advance chemical knowledge and lead to publishable results. Ideally this work will be carried out in a well-equipped lab under the supervision of a knowledgeable faculty advisor. In this sense the activity may rightly be called research. However, since most genuine research projects-those encountered during graduate education, for example-take some years to carry to fruition, undergraduates most often are not able to work long enough to produce publishable work. It may be that what the student often is doing is getting a research *experience.* Again, I believe that what has just been said can apply to all disciplines.

Just how research is to be incorporated into the undergraduate curriculum is, of course, the problem. The most obvious problem is that of the unfavorable ratio of faculty advisors to students. For most institutions and most departments it simply will not be practical to *require* all undergraduates to experience research, and in some departments on-site research is not possible. There are a number of alternatives that could be considered, however. One alternative is to distinguish on the transcript or the diploma the fact that the student has a degree which included research. Precisely this is being planned at our institution to designate those students who have received an international experience or who have engaged in service learning, and a similar designation to document research experience is currently planned for discussion. Another alternative is to broaden the definition of research experience to include projects suggested by faculty members that could be done in one semester in a special course overseen by a dedicated instructor. Still another

alternative is to help students locate off-campus research opportunities at other campuses, industry, national labs and the like, and to give appropriate academic credit.

## Undergraduate research at the University of Kansas-a snapshot.

Several weeks ago, on March 2, 2002, a day with several inches of new snow on the ground and more coming down, a blustery day with a wind chill index below zero, 60 students gathered at the University of Kansas Memorial Union to present--by means of posters, talks, film, or performance--the results of their recent research. More impressive was the fact that 150 others braved the weather to attend the event, our annual Multidisciplinary Undergraduate Research Symposium. Although two-thirds of the presentations dealt with research in the natural sciences, engineering and mathematics, others were on topics in the social sciences, the humanities, and the arts--ranging from political theory, local history, a reinterpretation of the various versions of Shakespeare's Hamlet, a 50-minute documentary about a contemporary performing artist, to an original cello composition. Most of the presenters had received support for their research from the university's Undergraduate Research Award program and had conducted their research on campus. Some, however, had obtained their experience at particle accelerators or NASA sites, for example. The student presenters were enthusiastic and professional in every way. Many openly expressed gratitude for the opportunity, and seemed to recognize and appreciate its benefit. *Undergraduate research is thriving at the University of Kansas.*

Undergraduate research does indeed thrive at the University of Kansas-particularly in the natural sciences. Our faculty welcome students into their labs, and departments make available lists of faculty, research areas, and possible research projects. New students are often recruited to the university on the strength of our well-publicized undergraduate research opportunities. Last year a dozen or so of our incoming science and math majors began research as soon as they arrived on campus; many more began in their second or third years. Of our current chemistry seniors, most have participated in undergraduate research, and many of those started as sophomores. During this academic year there are about 45 students engaged in research in the chemical sciences (chemistry, biochemistry, medicinal and pharmaceutical chemistry), 85 in the biological sciences, 20 in physics and astronomy, and 8 in mathematics. Last summer, 15 of our chemistry students participated in research on or off campus, 45 in biochemistry and biological sciences, 12-15 in physics or astronomy, and 3-4 in mathematics.

Last year almost 60 undergraduates in all disciplines and all schools were recipients of competitive university awards which supported their summer or academic-year research pursuits. Another 114 were engaged in departmental honors research in the major, working on their bachelor's theses in every department of the College of Liberal Arts and Sciences, subsequently graduating from the university with honors.

Last summer there were three NSF-REU sites operating at our university (in the departments of chemistry, molecular biosciences, and ecology and evolutionary biology) along with self-sponsored programs in medicinal and pharmaceutical chemistry, and NSF-supplement research in mathematics. This coming summer an engineering site will join the others. About 50 students (40 from other colleges and universities) were directly supported by funds supplied

by these formal programs; another 50-60 of our own students participated side-by-side, most receiving funding from a variety of institutional sources. In my department, for example, of the14 chemistry majors doing summer research, three students were funded by an industrial grant, five by faculty research funds, three from the UGRA program (see below), and one was at another university. Others, part-time participants, worked for academic credit, but were also integrated into the formal programs. *In short, undergraduate research has a widely-recognized presence at KU.*

This presence has had important consequences. The existence of vibrant undergraduate research programs and a cadre of enthusiastic undergraduates, especially those in the summer programs, has proven to have an energizing effect on their labs and groups. This energy and enthusiasm spreads to the graduate students, postdoctoral researchers, and the faculty research directors themselves. The contributions of these students lead to a greater number of presentations, both on and off campus, and of publications, raising the overall visibility of the university's research enterprise. Moreover, the graduate students and postdocs gain experience in mentoring research, contributing to their own professional development in significant ways.

Finally, the existence of the summer research programs has had a significant effect on our graduate recruiting efforts. Since 1987, 2-3 students on average return the following year to enter the graduate program in chemistry. About 30 such students have received degrees in our department.

## The University of Kansas-45 years of advocating and facilitating undergraduate research.

Two years ago, our Provost addressed the annual faculty convocation with a proposal to make research part of the experience of every undergraduate. Our Center for Teaching Excellence has held meetings and produced a "white paper" devoted to this topic ["Undergraduate Research: Extending the Walls of the Classroom," T. Bengtson, A. Lieberman, K.B. Schowen, and F. Rodriguez, in *Reflections from the Classroom*, vol. 2, 1999, University of Kansas Center for Teaching Excellence.] and a task force charged with definition and implementation of this goal is soon to be underway. *These recent initiatives, impressive as they are, only build on what has been a tradition for almost 5 decades-a tradition of unusual, continuous and sustained support of undergraduate research.*

Undergraduate research as a formalized activity at the University of Kansas began in 1956 with the creation of what was then known as the College Honors Program. The students selected for this program were judged to be among the best in the state and had already demonstrated that they had mastered the basics. They were provided with faculty mentors, some special courses in certain disciplines (chemistry was one), unlimited access to the libraries, and a great deal of freedom in curriculum design. Central to the program was the expectation that these students would soon be ready for independent study in the major and would spend much of their last two years working on a senior thesis--doing research in their respective majors, something which developed into what we now call the *Departmental Honors Program.* Every department and program in the College has such an option variously called "departmental honors," the "bachelor's thesis," the "honors essay," or simply "honors research." Each department has a designated honors coordinator who acts as resource to the students and as liaison to the College. Students (who must also possess a requisite grade point average) apply for the program, take designated honors research courses in their department, conduct research with faculty oversight for a minimum of two semesters, write a thesis, and present the results to an

oversight committee. Completion of departmental honors is reflected in the commencement booklet and on the diploma: e.g., B. A. in History with Honors, B. S. in Chemistry with Honors. Last May 114 graduates of the College were so designated. Key to the success of this effort was the opportunity for students to apply for modest awards to help defray some of the costs of doing research. The *Undergraduate Research Award (UGRA)* has long been available to students for this purpose. It began in the very earliest days of the Honors Program, i.e., in the late 1950s, and was funded first by the Endowment Association and later from state allocations to the university's General Research Fund. The UGRA competition, administered by the University Honors Program, is open to any KU undergraduate in any discipline including those of the professional schools. Support is for the spring or summer terms. Funding is now provided by KU's Center for Research, Inc., and special grants from the central administration and the College of Liberal Arts and Sciences for a total of over $70,000 each year. Awards are competitive and students are required to have a faculty sponsor and to submit detailed proposals which are evaluated by a 21-member faculty committee. Successful applicants receive $500 for a semester of research and $1300 or more in the summer. Several years ago, inspired by faculty who had observed similar events at other universities, I started developing what has now turned into KU's annual *Multidisciplinary Undergraduate Research Symposium* described earlier.

## The Vital Role of the National Science Foundation

Almost immediately after its 1956 founding date, the Honors Program, which had begun with a Carnegie Foundation grant to the Dean of the College of Liberal Arts and Sciences, had achieved some degree of national recognition, in part because of the emphasis placed on independent research for undergraduates. It was perhaps no coincidence that an NSF site visitor to the Chemistry Department that same year visited with the Dean. Exactly what transpired at that meeting is not precisely known, but the net result was that the University of Kansas found itself involved in what amounted to a pilot project for an NSF undergraduate research initiative. The National Science Foundation was responding to what appeared to be a decline in the scientific and technological supremacy that had belonged to the United States following the Second World War. For the next year and a half 4-10 undergraduates were supported during the year and in the summer in undergraduate research at the University of Kansas in a variety of science disciplines including chemistry. The launching of Sputnik in October of 1957 made the urgency apparent to the entire nation.

A year later NSF launched the Undergraduate Research Participation Program (URP), the purpose of which was "accelerating and enriching the development of undergraduates majoring in the physical, biological, mathematical, and engineering sciences through direct participation in scientific research." The program evaluated proposals and provided funds to colleges and universities, private industrial sites, and the national labs. At KU, the College was the original recipient of funding and distributed awards directly to those students who were nominated by their respective science faculty. Students received $600-750 stipends for 10-12 weeks of summer research. They were also given $75 for supplies and expected to attend regular meetings and turn in a final report. Later, awards were made directly from NSF to individual departments. The Department of Chemistry enjoyed regular (although not continuous) NSF-URP support until the end of the program in 1981. For the first decade, participants were our own undergraduates. Starting in the late 1960s, however, the emphasis began to shift toward bringing in a few students from other, smaller colleges. I remember, for example, encouraging students from nearby Baker University (1000 undergraduates) where I was then on the faculty, to go to the University of Kansas for the summer. From 1972 to 1976, the Department of Chemistry had five years of funding for its 12-week summer NSF-URP site. The theme for some of these years was energy, not surprising considering the concerns of the time. Students were now receiving $900 in stipends, attending weekly

seminars and turning in journal-style final reports. By this time the cost to NSF was $1560 per student. In 1979-1981 we, along with the rest of the nation, enjoyed our last URP grants from NSF. Awards were for 10 weeks at $1000-1200 per student. Ten students, all from off-campus, participated; supply costs were $150 and all students attended twice-weekly seminars, gave oral reports and turned in final reports. The final year's award amounted to $1977 per student cost to NSF. I was co-PI on those last awards and remember that proposals needed to be more detailed, with more attention to the incorporation of students from small colleges, women and minorities into the program. It's worth mentioning that during these final years, four separate departments of the University of Kansas had URP sites in chemical science: Medicinal Chemistry, Biochemistry, Chemical Engineering, and our own Department of Chemistry.

The NSF-URP program was one of the most successful enterprises of the National Science Foundation. In 1965, for example, it supported the summer research of 6000 undergraduates, 2000 of whom were chemistry students, at a cost of $6 million, that is at an average cost of $1000 per undergraduate. By 1980, the funding had dropped to less than $2 million and the number of participants went down to 1000 of whom 420 were chemistry students. In other words, fewer than one-quarter of the number of chemistry students were receiving the benefit of research experience in 1980 as had done so 15 years earlier.

The URP program was abandoned in 1981, a decision NSF was forced to make because of severe budget cuts imposed by Congress. It did not take long, however, for the consequences of this cut to be noticed. In the mid 1980s, just a few years after the cessation of the program, it was observed that there was a severe "pipeline" problem developing, with an alarmingly small number of young people opting for careers in the natural sciences, mathematics and engineering. There was also abundant evidence that research experience is an exceptionally important factor as an undergraduate makes crucial career decisions. Disappointed with the lack of NSF funding, we nevertheless began a modest program of our own which ran during the summers of 1986 and 1987 for a few outside and some inside undergraduates. For many years under the leadership of Ted Kuwana and Cynthia Larive of our department we had an NSF site to provide research experience in bioanalytical chemistry to teams of undergraduates and college chemistry teachers.

In 1987, a new program was launched by NSF, one which has proven to be a superb successor to URP. The Research Experiences for Undergraduates (REU) program was similar in purpose to the former URP with the stated goal of ensuring an adequate supply of math, science, engineering professionals and attracting talented students into research careers, recognizing that the undergraduate years are critical. There was a particularly strong emphasis on those traditionally underrepresented in the sciences.

Starting with summer 1988, the Department of Chemistry at the University of Kansas has had an NSF-REU site in continuous operation, with this coming summer of 2002 being our fifteenth season. Each year we have brought in 10-14 students selected from an average of about 110 applicants from other colleges across the country who join about an equal number of our own undergraduates. They choose their research projects and advisor from information provided and almost always get matched with their first or second choice. Most of the research groups are large and active, so there is help for the students and they get to see the team and collaborative approach characteristic of so much of the way research is conducted. They are housed as a group in one of our residence halls. Participants are welcomed with an opening picnic, participate in weekly seminars, engage in two or three other scheduled social events, give an oral progress report and present a final poster. The poster session includes all undergraduates in the chemical sciences from across the campus in which close to 50 students report on their summer research. Over the past 15 years, the student

stipends have gone from $2500, to $2800, to $3000 for ten weeks of participation. Participants also receive room and board, tuition, and incidental fees. The supply allotment is around $500 per student.

During the late 1980s our programs averaged 39% women with an ever increasing percentage during the 1990s to where it now appears to be at a steady state of 50% or somewhat above. Over the past 15 years of summer undergraduate research programs, we have averaged close to 12% underrepresented minority students, although our range has been anywhere from 0 to 36%, not too surprising for our part of the country. A little less than one out of every two students has seen work appear in a publication in a respected journal; about the same number of students has presented research findings at major scientific meetings.

From our anonymous exit surveys we have learned that well over 80% of all 1988-2001 participants and almost 90% of the NSF participants said they were more inclined to plan for graduate study and careers in chemistry than before arriving. About 85% of our outside participants have gone on to (or are planning) Ph.D. or master's degree study in chemical science; the number is closer to 75% when we include our own majors.

***In summary, for the past 44 years (1957-2001), 333 students have been directly supported by formal NSF research programs in chemistry at the University of Kansas. Approximately 300 individual students have participated alongside in the summer or during the academic year, for a total impact of well over 600 students. About 330 of these students have been involved during the past 15 years.***

## Value and Impact of Undergraduate Research

Does undergraduate research make a difference? One needs to ask, of course, "for whom?" I believe the case can be made that not only does undergraduate research make a difference from the point of view of the discipline and to the intellectual life of the campus, as has already been discussed in the first sections of this paper, but also that it makes a difference to the individual student, the profession of chemistry, and the nation and society as a whole.

***Value to the individual student***. First, one might ask, has undergraduate research resulted in an increased understanding and appreciation of the major and of the discipline of chemistry? Has it helped in making career decisions? Has it helped make the decision to go to graduate school or to seek employment as a professional chemist? Has it helped define an area of interest for future study or work? If a student did go to graduate school, has it made adjustment easier? Did it increase retention? Much of the data that can answer these questions is anecdotal, gleaned from polling practicing scientists, graduate students, research advisors, and former undergraduate research participants.

In 1981 when funding to NSF was being curtailed, Professor Doug Neckers of Bowling Green University wrote to the current White House Science Advisor with a plea to continue the URP program. To support his arguments, he had solicited comments from former undergraduate researchers. Many of these were eloquent statements from senior industrial chemists or tenured faculty members who had participated in research in the 1950s, 1960s, and early 1970s testifying as to the impact and pivotal role early exposure to research had had on their careers.

From our own chemistry undergraduates I have heard comments such as

"I know I want to do research!"

and

"I want to do this for the rest of my life"

Our REU anonymous exit surveys have produced comments such as:

"This summer has maintained my interest in applying to graduate school. I want to obtain my PhD."

"This experience has definitely reinforced an already strong interest in research chemistry."

and

"This experience has given me the confidence...to pursue graduate research in chemistry and possibly a career in research."

"It has made me more interested in a research career because I now understand more what research is about."

Many would agree that the first two comments, while strongly pointing to the value of research experience, are not as compelling as the next two. The first two students may well have gone on to research careers anyway; the latter students are arguably the ones who benefitted the most.

In 1995, I conducted an informal mail survey of current chemistry graduate students and postdoctoral associates with the help of Professors John Hogg and Dale Hawley from two other chemistry departments, those of Texas A& M and of Kansas State Universities, respectively. A number of questions relating to those posed at the beginning of this section were on the survey. [The results of this survey have appeared in K.B. Schowen, "Research as a Critical Component of The Undergraduate Educational Experience" in the Report of the Workshop on Assessing the Value of Research in the Chemical Sciences organized by the Chemical Sciences Roundtable of the National Research Council held in September, 1997.] The total number of respondents was 129, with 110 (85%) of these having engaged in research during the undergraduate years. The response rate was 45% from KU, 40% from KSU, and 25% from A&M. Those completing the survey forms were 61% male, 39% female, 15% international, and about 5% members of recognized U.S. ethnic minority groups. All of them had been chemistry majors as undergraduates and 74% had earned B.S. degrees. Slightly more were graduates of four-year colleges(46%) than Ph.D.-granting universities (39%). Of these students 85% had engaged in research during the undergraduate years,

and 12% had done so for two years or more. Of those who had participated in undergraduate research, 95% had done so in the field of chemistry, 45% had worked in two or more different research groups, and 32% had been part of formal summer internship programs. About 23% had had their research experience only in the summer months, while almost half had done it mainly during the academic year at the home institution. More than half (58%) reported having received compensation for their work at one time or another. Most of the work was "wet" laboratory chemistry (87%) as opposed to computational or theoretical. Fifty-eight percent of the students had had at least one off-campus experience at a college or university, with an approximately equal distribution among the two kinds of institutions. Of the respondents as a whole, 93.5% were planning careers in the chemical sciences: 76% in research (20% academic, 40% industrial), and 13% reported planning careers in teaching with no significant research component. The great majority (84%) were going for the Ph.D. with 16% were planning to postdoc thereafter. The remaining students were divided between staying for the Master's degree only (5%) or changing out of chemistry altogether (3%). (Not all students responded to all questions).

For those students who reported an undergraduate research experience, the following observations were clear.

1. *fewer than 2% reported an unsatisfactory undergraduate research experience.* I have no information as to numbers of students with such negative experience who did not go on to graduate school, but the data indicate that of the 85% of students in graduate school with prior research experience, at least 97% of them had had a positive exposure.

2. *for 77% of the students, undergraduate research was a contributing factor in the decision to go to graduate school. For 44% it was the major factor.*

3. *Some 60% found that research experience helped in deciding where to apply to graduate school.*

4. *Almost 90% felt that the experience helped decide on a general area of research to pursue in graduate study.*

5. *Slightly more than two-thirds (67.4%) believed that prior research exposure helped them to "stay the course" and remain in graduate school.*

Among the comments received from the graduate students who turned in the surveys were the following:

*with respect to the contribution of undergraduate research to their education:*

"I participated in research at a major pharmaceutical firm, at a different university for a summer and worked in a lab at my university for three years. I consider the experience gained to be the most important part of my undergraduate experience."

*with respect to the decision to go to graduate school:*

"Undergraduate research allowed me to take a project from the beginning, all the way to completion. This, along with presentation/communication skills, was very important in deciding to go to graduate school."

"Even though I did some research at my small college prior to doing research at a big university, I had no idea what "real" research was like. The research work at the big university influenced >95% of my decision."

*with respect to professional contributions and associations:*

"My undergraduate research helped to integrate me with the chemistry faculty and resulted in two full papers which have since appeared in peer-reviewed journals."

*with respect to preparation for graduate school:*

"Undergraduate research helped me to develop skills used in doing undergraduate research, which also introduced me to instrumentation. I felt I had a head start on many new students."

"A research experience is critical to the decision process of selecting a division of study, and helping to decide whether a final goal of academic or industrial, teaching or research is desired."

Perhaps the most thoughtful and sophisticated insight was:

"I must...stress the importance of the research experience in making students an integral part of the department and converting them from bench warmers in class to productive, thinking scientists."

Interestingly, the responses from males and females showed no significant differences; no noticeable gender distinctions emerged from the data. The only instance where a difference was noticed was when asked about postdoctoral plans. The numbers of women wishing to proceed beyond the Ph.D. to a postdoc was much less than (almost half) that of the male students--at least at the time in the students' career that the question was asked. The number of minority respondents was so low that no meaningful patterns could be detected from their responses.

We should also be concerned with questions having to do with other, more intangible benefits accruing from undergraduate research experience.

"Honestly, this ten weeks has been the greatest time of my life. I loved working with my lab group...and the friendships I have made...are priceless."

Such intangibles may relate to the establishment of mentor and peer relationships and of networks of advisors, co-workers, collaborators and friends. They may equally relate to the personal growth and increased self-confidence developing from an experience of common endeavor, and perhaps of real accomplishment and productivity.

"This has been an absolutely great summer. The program was wonderfully organized and I am so fortunate to have been involved. Thanks."

***Value to science and the profession of chemistry***. I think it makes sense to argue that having more informed and prepared people entering graduate school and careers in chemistry as described in the previous section is beneficial to the nation's science enterprise. The data clearly point up the value of undergraduate research in making good career choices and in staying with a career in science.

***Value to the Nation and Society.*** Here we need to ask such questions as: Does undergraduate research experience help produce more informed scientists and citizens. Are more people emerging from the experience to become teachers, communicators, policy setters, problem solvers-and with positive attitudes about science? There is no question but that both science and society need people who have been trained to think independently. We need not only future researchers, but science teachers at all levels, science advocates, decision-makers, and a generally scientifically literate public.

## Value and Impact of Undergraduate Research-summary.

In summary, I believe we have seen that undergraduate research has impact on many levels. It

*1. provides an essential component of science education and therefore belongs in the undergraduate curriculum.*

*2. has a positive effect on individual research programs and the university's research enterprise.*

*3. contributes to the intellectual life of individual departments and the campus as a whole, raises the level of research activity, and helps recruit strong undergraduates, graduate students, and faculty.*

*4. allows graduate students and postdoctoral researchers to gain experience in mentoring research, enhancing their own professional competence, and the level of competence of the next generation of professional scientists.*

*5. provides students with a clearer understanding of career options in the chemical sciences.*

*6. produces more informed, committed and better prepared graduate students with greater potential for success in graduate programs.*

*7. gives students a deeper and more mature understanding and appreciation of chemistry and science in general.*

*8. contributes to personal and professional growth.*

*9. helps produce better prepared, and more qualified scientists for the coming generations.*

*10. Contributes to the development of people better able to teach and articulate the role of science to society.*