Undergraduate Education in the Mathematical and Physical Sciences:

Interim Report of the Joint Subcommittee of the NSF Education and Human Resources and Mathematical and Physical Sciences Advisory Committees

Respectfully submitted to the National Science Foundation
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Executive Summary

Undergraduate education in STEM disciplines is of vital importance to the nation. Within the mathematical and physical sciences (MPS), the core disciplines of mathematics, chemistry, and physics play a central role in producing baccalaureate degree recipients that support the graduate enterprise in these and related disciplines, that become K-12 STEM teachers, and that represent the entry-level technical workforce in many technically-based industries. The research and education frontiers of these disciplines are changing rapidly with important implications for the nature of modern professional practice, the preparation of new professionals, the creation of pathways that broaden participation, and the education of the U.S. citizenry in these areas. Assessing these implications in the context of undergraduate education in these disciplines is essential to ensure maintenance of a robust and dynamic undergraduate enterprise responsive to the scientific and technological needs of the U.S.

This study was undertaken at the request of the Education and Human Resources (EHR) and Mathematical and Physical Sciences (MPS) Directorates of the National Science Foundation (NSF) in order to assess the current state of affairs of undergraduate education of majors in the MPS disciplines, with a focus on the core disciplines of mathematics, chemistry, and physics, and to provide recommendations to EHR and MPS for activities that they might undertake to improve undergraduate education in these areas. Towards this end, a Joint Subcommittee on Undergraduate Education of the EHR and MPS Advisory Committees was formed and charged with conducting this study. This subcommittee has completed its first phase of data gathering from a series of focus group discussions conducted primarily with representatives of these disciplinary communities from academia.

Mathematics, chemistry, and physics are experiencing tremendous growth in research activity and opportunities at their interfaces with other disciplines. This explosion in the inter- and multidisciplinary nature of these research frontiers has fundamentally changed the skills and knowledge base needed by professionals in these areas. However, despite the significant changes manifest in modern professional practice, undergraduate education in these disciplines has not changed significantly over the past several decades. This disconnect between modern professional practice and undergraduate education in these disciplines is alarming, with potentially damaging consequences to the institutional structures (e.g. the graduate and K-12

STEM enterprises and U.S. industry) that depend on properly-prepared baccalaureate degree recipients in these fields if not redressed.

NSF can and should play a central role in stimulating and facilitating the changes in undergraduate education needed to rectify this situation. However, the most effective means for motivating these changes are not immediately evident. On the basis of these focus groups and discussions of the joint subcommittee, the preliminary recommendations below are offered as possible mechanisms for improving undergraduate education in these disciplines. Further elaboration of these recommendations and their justification can be found in the body of the report.

<u>Recommendations</u>

1) Issues and needs in undergraduate education in mathematics, chemistry, and physics can be quite distinct. The NSF EHR Directorate should experiment with discipline-specific programs that are developed with full integration of the expertise, insight into community culture, and understanding of the modern research frontier of the appropriate Division within the MPS Directorate.

2) Undergraduate reform efforts that engage the full range of faculty within a department and that seek to better infuse the current knowledge and modern professional practice of mathematics, chemistry, and physics into the undergraduate experience are likely to have the greatest positive impact on the education of majors in these disciplines. The development of a program to stimulate "department-level" reform in the undergraduate education of majors in these disciplines is recommended.

3) EHR and MPS should undertake activities to stimulate greater integration of two-year colleges with four-year colleges and universities in the preparation of undergraduate majors in mathematics, chemistry, and physics; experimental approaches to addressing professional development opportunities for two-year college faculty are needed.

4) EHR and MPS should undertake activities to facilitate better integration of "researchers" and "educators" in mathematics, chemistry, and physics within four-year institutions, between four-year institutions, and between four-year and two-year institutions.

5) Greater integration of research and education in all EHR and MPS funding activities is needed to change the existing disciplinary cultures that value research endeavors

significantly more than educational endeavors and for more effectively engaging research faculty in the undergraduate education of majors in mathematics, chemistry, and physics.

6) EHR and MPS should consider exploring changes in staff organization to better facilitate integration of relevant educational activities between these two Directorates. As an example, EHR and MPS might explore the establishment of a staff position/office charged with integrative educational activities between the two Directorates with dual reporting lines to the EHR and MPS Assistant Directors.

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History and Goals of Study

The NSF Mathematical and Physical Sciences Advisory Committee (MPSAC) and the Education and Human Resources Advisory Committee (EHRAC) have been engaged in efforts to promote more consistent and formal interactions for several years. A joint mini-symposium "Integrating the Science of Learning with the Learning of Science" involving both advisory committees was held in November 2002. Both committees expressed a commitment to continue to work together at that symposium. In discussing the outcomes of the joint symposium at its April 20003 meeting, the MPSAC endorsed efforts to further pursue enhanced interactions with the EHRAC. Shortly after this meeting, the MPSAC Chair, Dr. Joseph E. Salah, made a formal request to Dr. Ronald A. Williams, Chair of the EHRAC, and Dr. Judith A. Ramaley, Assistant Director of the NSF Directorate for Education and Human Resources, to put the discussion of further EHRAC interaction with the MPSAC on the EHRAC agenda for its May 2003 meeting. Along with this request, the MPSAC offered to send a representative to this meeting if desirable. Based on the enthusiastic response to this request received from Dr. Ramaley, Dr. Jeanne E. Pemberton of the MPSAC attended the EHRAC meeting in May 2003. As part of her presentation to the EHRAC, Dr. Pemberton proposed the creation of a joint subcommittee between the two Advisory Committees to study undergraduate education in the mathematical and physical sciences. The EHRAC endorsed this proposal unanimously. Shortly after that meeting, the subcommittee membership was established (Appendix A). The subcommittee is comprised of eight members representing both advisory committees (Drs. Robert L. Devaney, Yolanda Moses, Thomas N. Taylor, Ronald A. Williams [*ex officio*] from the EHRAC, Drs. Robert C. Hilborn, Claudia Neuhauser, and Jeanne E. Pemberton from the MPSAC) and a liaison from the BIOAC (Dr. Thomas E. Brady [*ex officio*]). In addition, three NSF staff (Dr. James H. Lightbourne from EHR, and Drs. Judith S. Sunley and Henry N. Blount, III from MPS) played critical roles in the activities of the subcommittee.

During the summer of 2003, Dr. Ramaley and then Acting Assistant Director for MPS, Dr. John Hunt, met with NSF staff to develop the details of the charge to this subcommittee (Appendix B), its initial membership and its initial workplan (Appendix C). Following his appointment as Assistant Director of MPS in October 2003, Dr. Michael Turner extended his support for the charge and initial workplan as well.

As stated in the charge, the goals of this study are:

- "Examining the ways their communities think about and describe the activities of research, professional practice, and education and how those definitions affect the nature of their activities;
- Exploring the commonalities and differences in approaches to integrating research, professional practice, and education and in defining successful integration; and
- Recommending types of activities that Directorate for Education and Human Resources (EHR) and the Directorate for Mathematical and Physical Sciences (MPS) might undertake, either together or in parallel, that would strengthen the preparation of the next generation of MPS professionals, broaden participation in the MPS disciplines, or create new pathways to MPS careers, either by building on existing programs, expanding them in directions that capitalize on commonalities of approach, or developing new programs that would promote innovative paradigms for the integration of research and education."

The charge further noted that in performing its work, the subcommittee should consider: the current state of the undergraduate enterprises in chemistry, physics, and mathematics and how they are changing, with an emphasis on the integration of research, professional practice, and education; EHR and MPS activities with impact on undergraduate education and their efficacy in promoting change; and past and current experiments in transcending the EHR-MPS boundary in carrying out these activities. The subcommittee initiated its work based on this charge in Fall 2003.

Introduction to Undergraduate Education in the Mathematical and Physical Sciences

The higher education system in the U.S. is internationally recognized for its excellence. Significantly, however, and in contrast to higher education in other countries, this excellence is achieved without sacrificing accessibility to the American public. Undergraduate education in the mathematical and physical sciences occurs within this broader landscape of modern higher education in the U.S. that is in the midst of significant change.

As we move into the 21st century, the burgeoning population and diversity of college-bound students in the U.S. have begun to place considerable stress on the higher education system. This stress is most noticeably manifest in greater institutional financial exigency and has led to enhanced public scrutiny of the higher educational system, with calls for greater accountability in ensuring the success of the educational process. In response to these concerns, a national discussion has ensued about the very nature of the higher educational process itself and how it might be improved to be both more engaging and inclusive, in recognition of the greater diversity of the student population, while at the same time, retaining appropriate rigor and depth. This discussion has made clear the fact that academic "business as usual", based on educational paradigms that date back to the early 1900's, is no longer sufficient to educate the student body of today.

Between 1980 and 2000, the minority population in this country grew by 88%[1] with the expected impact on the population of students attending college beginning to be evident. The college student population is becoming increasingly diverse, not only from a racial and ethnic perspective, but also from a socioeconomic perspective. The overall graduation rate from high school today is 88%,[2] and of these high school graduates, 75% undertake some level of postsecondary education within two years.[3] As of the year 2000, 42% of college students were enrolled in two-year colleges[4] with 51% of them indicating an intention to pursue a four-year degree[5] (although only about 30% of these students actually transfer with only about 10-15% of students who start their study at two-year colleges successfully completing a four-year degree.[6]) Minorities comprise 28% of college students today[2] and are estimated to represent approximately 50% of new students that will enroll in college within the next decade.[7] Moreover, as of 2002, 73% of the students enrolled in America's colleges and universities were non-traditional students.[8]

Students coming to college from the U.S. K-12 system are under-prepared, with only 47% having completed a college preparatory curriculum.[9] As a result, it is no surprise that 53% of students must undertake remedial course work upon entering college,[10] at great financial expense to institutions of higher education and to students.

Along with increased diversity in student population has come increased diversity in the possible modes of acquiring a college-level education. The mid-20th century model of an in-residence student attending one institution for an entire four-year undergraduate experience is no longer the norm. Tremendous growth in the number of two-year colleges, comprehensive universities, and even for-profit educational institutions attests to the expanding scope of the undergraduate educational landscape.

Today, 28% of undergraduates attend college only part-time.[11] Additionally, students are much more mobile: as of the early 1990's, 58% of bachelor's degree recipients attended two or more colleges on the way to receiving their degrees.[12] This figure is likely to be even higher today. Moreover, as college costs rise and the socioeconomic base of students attending college diversifies, more undergraduates today must work in order to finance their college education. In 1999, 74% of full-time undergraduate students worked.[13] Of these 46% worked at least 25 hours per week and 20% worked at least 35 hours per week.[13] Thus, the mid-twentieth century model of a college student wholly and singularly dedicated to their studies is no longer applicable to today's college students.

Students' modes of learning and their expectations for their educational experience have also changed relative to even a decade ago. Students are much less likely to be proficient at learning from a textbook or listening passively to a lecture. Instead, students today have become very adept at learning by finding information on the web and from interactive computer-based experiences. These changes are due in large part to developments in technology, the explosion in the availability of electronic information, and the tremendous advances in the use of this technology for entertainment in the form of computer games, animated presentations, digital music, and movies. These changes in learning mode have had a profound impact on student perception of their undergraduate educational experience. With all of this external intellectual stimulation, students have become increasingly disengaged from their educational endeavors with a significant fraction (>40%) reporting boredom in the classroom.[14]

In total, these demographic changes are seriously impacting the ability of higher education to produce bachelor's degree recipients in science, especially the mathematical and physical sciences. Although interest among entering freshmen in pursuing degrees in all areas of science and engineering remains at the level of about 25-30%,[15] fewer report an interest in pursuing degrees in the physical sciences. Less than 9% of entering freshmen today plan to pursue a degree in the physical sciences.[15] Given the relatively high attrition rate from science degree programs, only 1.3 % of all bachelor's degrees awarded in 1998 were in the physical sciences.[16] This figure is down from about 3% in the late 1960's.[16]

More specifically, trends in the production of bachelor's degrees in the mathematical sciences, chemistry and physics are reflected in the data of Figure 1 from the National Center for Education Statistics[17] that show degrees awarded between 1970 and 2001. Although each discipline exhibits its own patterns of rises and declines during this three decade period, degree production in mathematics clearly shows a substantial decline. Physics degree production over this period is down slightly but approximately flat, while chemistry degree production shows a slight decline. These trends are discussed more thoroughly in the next section.

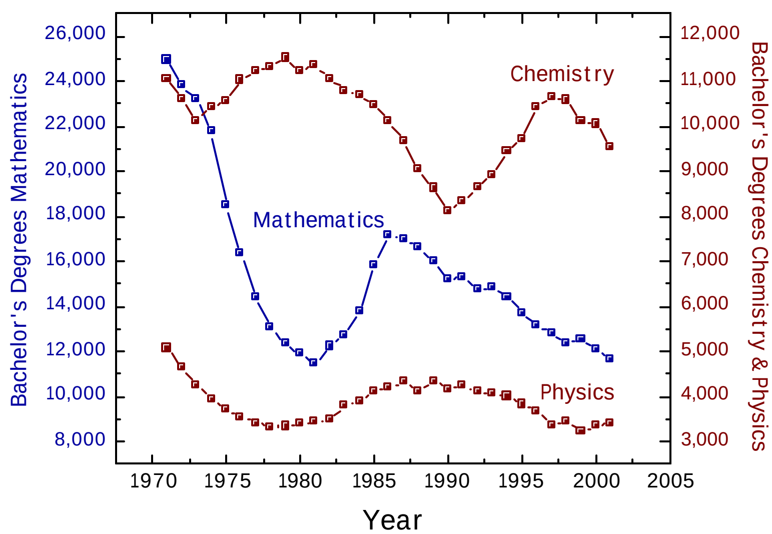

Figure 1. Bachelor's degree production in mathematics, chemistry, and physics.

The importance of undergraduate degree production in these disciplines, indeed in all of the STEM fields, cannot be overstated. The undergraduate enterprise in STEM provides the essential bachelor's degree recipients that drive graduate education efforts in STEM, that in turn, support the technological innovation in this country that forms the basis of U.S. economic competitiveness on a global scale, and the national defense and homeland security. Moreover, this graduate STEM enterprise is also responsible for the production of STEM faculty of both four-year and two-year colleges in the U.S. who, along with K-12 STEM teachers produced by the undergraduate enterprise, are required to properly prepare the continuing influx of students needed to keep the STEM pipeline full and healthy. Finally, the undergraduate enterprise in STEM sustains the production of the entry-level (i.e. bachelor's degree) technical workforce that is essential to many U.S. industries. Thus, undergraduate education plays a pivotal and central role in STEM activities of the nation

The subcommittee recognizes that it is within these broader contexts that the present study is undertaken and has attempted to remain cognizant of the influence of these broader contexts in assessing the current state of undergraduate education in mathematics, chemistry, and physics as described in the following sections.

Current State of the Undergraduate Education of Baccalaureate Degree Recipients in Mathematics, Chemistry, and Physics

The framework for the subcommittee's efforts in assessing the current state of undergraduate education in these disciplines is a model for undergraduate education as a platform based on four pillars as shown in Figure 2. These pillars represent the four essential elements of undergraduate education in the mathematical and physical sciences: content, pedagogy, infrastructure, and faculty capacity. This platform is built on the K-12 foundation and also serves as a pathway to a variety of post-baccalaureate pursuits that might include graduate school in the mathematical or physical sciences or related areas, further professional

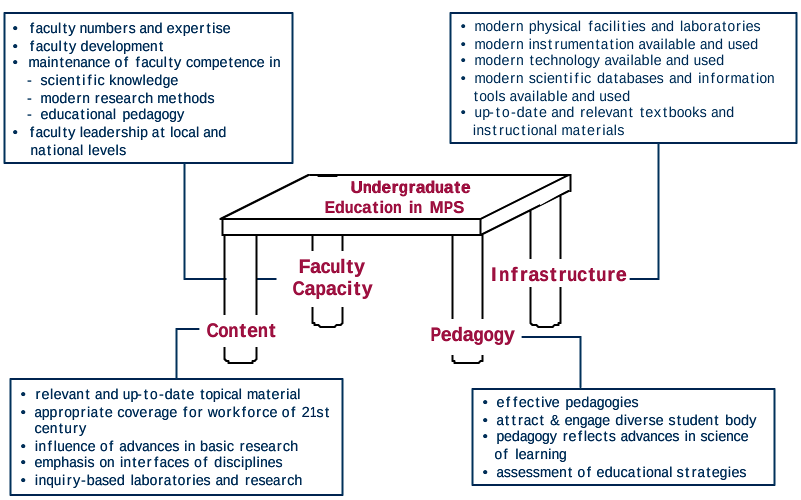

Figure 2. The four pillars of undergraduate education in the mathematical and physical sciences.

education such as medical or dental school, entry into the technical workforce, or simply as a step by which to become engaged in lifelong learning

The content pillar represents curricular aspects of the educational experience: Is the topical material covered relevant and up-to-date? Will this material result in adequate preparation of the next generation of mathematical and physical sciences professionals? Does the topical material covered incorporate the most relevant recent results from front-line research in a particular area? Is appropriate emphasis placed on emerging interfaces between disciplines? Does the educational experience incorporate research and inquiry-based laboratory exercises to reflect the way these disciplines are really practiced?

The pedagogy pillar represents the methodology utilized in the delivery of the content. Are effective pedagogies used to deliver the content? Are these pedagogies those that will successfully attract and retain a diverse student body to these professions that reflects the composition of the nation as a whole? Do the pedagogies used take advantage of the current understanding of the science of learning science? Are appropriate methods used to assess the extent and depth of student learning?

The infrastructure pillar represents the support structure for undergraduate education and includes the appropriate facilities and support staff necessary to offer a modern education in the mathematical and physical sciences. The necessary physical facilities can include classrooms and laboratories equipped with modern educational technologies, demonstration and laboratory preparation facilities, stockroom and chemical waste handling facilities, and the appropriately trained personnel to staff these facilities. Infrastructure also includes modern instrumentation and modern scientific databases and information resources that must be accessible to students and used in the delivery of the undergraduate curriculum. The relevance and currency of modern textbooks and other instructional materials is an additional essential element of infrastructure for undergraduate education in the mathematical and physical sciences.

Finally, the faculty capacity pillar represents the capabilities of the faculty as a unit including the appropriate numbers with the requisite skills and expertise, their ability to deliver the curriculum, and faculty development that allows them to maintain the currency of their knowledge base in their disciplines and in modern methods of research and pedagogy. Faculty capacity also includes the existence of appropriate leadership, within an institution and on a national level, to ensure the relevance and viability of undergraduate education in a mathematical or physical science discipline.

Mathematics

Much has changed in the discipline of mathematics in recent years. The computer has revolutionized what mathematicians see and how they compute things, as well as the mathematical topics that students need to know. In addition, many new areas are emerging in the mathematical sciences, including those related to the biosciences, mathematical finance, and economics, while traditional client disciplines such as physics are engaged in major reconsideration of the type of mathematics now important for their students to know. Mathematics will play a central role in all of these areas as they continue to evolve. Mathematics departments in most institutions are aware of these emerging areas and have begun to create or adapt existing programs to address these needs, but more efforts are needed along these lines, especially in the bioscience area. Thus, new course development will be a priority for mathematics departments as will enhancing interactions among mathematical scientists, biologists, and biomedical engineers, among others. Mathematicians will need to broaden their perspective and reach well beyond the traditional boundaries of the field in future years.

Most of the content in the first two years of the undergraduate mathematics curriculum is centered around calculus and driven by the needs of the traditional client disciplines such as engineering, physics, and chemistry. However, an increasing need for mathematics in such diverse disciplines as biology and computer science is emerging. Areas such as probability, statistics, and discrete mathematics are becoming increasingly important for these new clients of the mathematical sciences, and thus, opportunities exist for the development of alternative lower division curricula.

The traditional lower division undergraduate curriculum in mathematics has undergone significant modification in the last fifteen years. The calculus reform movement of the early 1990’s prompted many, but by no means a majority of, mathematicians to become involved in educational activities. Many departments, primarily at four-year colleges, undertook significant curricular reform at the introductory calculus level. In addition, the availability of computer algebra systems such as *Matlab*, *Maple*, and *Mathematica* has also changed the way many introductory courses are taught. These changes have been somewhat controversial, since many mathematicians oppose "updating" of the centuries-old calculus curriculum and object to the inclusion of technology as a computational tool. Indeed, many institutions have backed away from calculus reform and the use of technology in recent years.

The changes that have occurred in the freshman/sophomore level mathematics curriculum have not significantly impacted the more advanced courses in many mathematics departments. Indeed, many mathematics departments have not altered the courses they offer to their majors in the past several decades, despite the need for trained mathematical scientists in a much greater diversity of areas. Many mathematicians seem to be content to train their successors just as they were trained.

One consequence of this attitude has been a significant decline in the number of U.S. students entering the mathematical sciences in recent years (see Figure 1.) The number of bachelor's degrees awarded in mathematics is down by 32% since a peak in 1986 and down 53% since 1971. In addition, the number of domestic students entering graduate programs in the mathematical sciences has declined significantly in the past two decades. Although many reasons can be identified for this trend, including the technology boom of the 1990's and the appeal of the business sector during that same period, many students see the mathematics courses they take as irrelevant to what they wish to learn, a hurdle that they must overcome in order to get to the topics they perceive as more interesting in their chosen field of study.

Thus, one of the biggest challenges facing mathematics departments is the need to involve and excite undergraduates about modern mathematics. Undergraduates need to become involved in mathematical research projects early in their careers, or at least be exposed to contemporary ideas in the discipline and not just the standard fare of 17th-century calculus, 18th-eighteenth century analysis, and 19th-century algebra. Involving undergraduates in research early in their careers seems to be relatively common in other scientific and engineering disciplines, but it has only recently been recognized as a possibility in mathematics (due mainly to the NSF Research Experiences for Undergraduates [REU] program, and more recently, to the Interdisciplinary Training for Undergraduates in Biological and Mathematical Sciences [UBM] program). Clearly, more effort along these lines is needed.

One major initiative from the NSF Division of Mathematical Sciences in recent years that has had a positive impact in higher education in mathematics is the Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE) program. This program seeks to "vertically integrate" undergraduate and graduate students, postdoctoral researchers, and faculty to enhance the overall educational experience for all in a department and to provide broad training in the mathematics discipline. Universities that win these major awards are required to address both the research and educational needs of their students and postdoctoral researchers, integrating and intertwining these endeavors where possible. Many institutions with VIGRE awards include undergraduates in these activities, but this is not a major facet of this program. Some of the more recently established VIGRE awards more fully involve an undergraduate component, however. While the VIGRE program has detractors, it is clear that this program has had a profound effect on graduate student training at many institutions. Unfortunately, this program is currently limited to only about forty major research institutions in the country, although it should be noted that these are precisely the departments that are most in need of change in the educational arena. Nevertheless, NSF's vision in this regard is beginning to have an effect on how all faculty view their dual roles as researchers and educators.

Chemistry

The undergraduate education of chemists in the U.S. has historically been guided by the American Chemical Society's (ACS) undergraduate approval program through guidelines for high-quality undergraduate programs formulated by its Committee on Professional Training (CPT). The CPT was established by a resolution of the ACS Council in 1936, one year before the ACS Charter was issued by an Act of Congress, thereby significantly influencing the development of essentially all modern undergraduate chemistry programs in existence today at colleges and universities. Approximately 1050 institutions confer baccalaureate degrees in chemistry in the U.S., with about 630 of these holding formal ACS approval. Despite the fact that nearly 400 programs are not formally approved, the pervasive impact of the ACS approval program on their undergraduate chemistry programs is still evident, since virtually all faculty at these institutions encountered at least one approved chemistry program during the course of their undergraduate or graduate education. The indirect influence of the ACS approval program on chemistry education at two-year colleges is similar for the same reason.

Figure 1 shows baccalaureate degree production in chemistry since 1970. In 2001, slightly over 9500 bachelor's degrees were awarded in chemistry. When compared to degree production over the three decades shown, this number is 11% lower than the recent maximum in 1997 and 17% lower than the high in 1979. Typically, almost 50% of these baccalaureate degrees are awarded at institutions that offer doctoral programs in chemistry, another 15-20% are conferred at institutions at which the highest chemistry degree offered is a master's degree, with the remaining third being awarded at four-year colleges that offer only bachelor's degrees.[18]

It is instructive to explore recent trends in what students choose to do with baccalaureate degrees in chemistry. For many years, bachelor's degree recipients in chemistry were divided roughly into three equal groups in terms of post-baccalaureate pursuits with about 33% going on to graduate school in chemistry or closely-related disciplines, about 33% going directly into industry and the technical workforce, and about 33% going on to medical or dental school.[19] This trend was maintained up through the early 1990's. However, this pattern began to change during the mid 1990's for reasons that are not clear. In recent years, the percentage of bachelor's degree recipients going directly into the technical workforce has risen significantly to approximately 50% while only about 20-25% are pursuing graduate work in chemistry (including chemistry degree recipients who pursue graduate work in biochemistry.) The remaining 30% go largely to professional schools. Since the job market was not any better for chemists during this period than in previous periods of economic expansion, and since a greater fraction of the chemical workforce has Ph.D. degrees than 10-15 years ago,[20] this trend suggests that something fundamental has changed about the nature of students getting bachelor's degrees in chemistry or that their undergraduate training is somehow not generating in these students the desire for further study that it once did. Neither conclusion is particularly promising for the future health of the chemistry profession and provides the impetus for a deeper look at the undergraduate education of chemistry majors.

In terms of content, the undergraduate chemistry curriculum is fairly uniform in institutions of all sizes and types across the U.S. due largely to the influence of the ACS guidelines. Certain segments of the chemistry community have expressed the opinion that the ACS guidelines are somewhat too rigid for the diversity and complexity of today's chemistry. To address the growing level of activity in chemistry at the interfaces with other disciplines, CPT introduced a series of options for advanced undergraduate study into its guidelines in the late 1980's. Although these options allow the introduction of some level of interdisciplinary exposure in the undergraduate chemistry curriculum, they are built on essentially the identical chemistry core curriculum that was noted above to have been criticized as being too rigid. Given the central position of chemistry in many emerging interdisciplinary areas such as proteomics, nanotechnology and biocomplexity in the environment, this tension between core chemistry content and interdisciplinary exposure in the undergraduate curriculum will continue and is likely to stimulate fervent debate for years to come.

The service role of chemistry at the undergraduate level is substantial, and for this reason, the influence of this service function on the undergraduate chemistry curriculum for majors is worth considering in more detail here. Many undergraduate majors, including those in the biosciences, the health-related professions, engineering, agriculture, and the environmental sciences, require some exposure to chemistry. Students in these majors typically take one to two years of chemistry. The explosive growth of majors in the biosciences over the past decade and their requisite need for at least two years of chemistry, traditionally one year of general chemistry and one year of organic chemistry, has placed tremendous strain on the academic chemistry enterprise in the U.S. given the resource-intensive nature of undergraduate chemistry, particularly the laboratory component. In addition, however, the large numbers of students in these other majors needing exposure to general chemistry and organic chemistry early in their undergraduate careers has had the effect of holding the curriculum hostage for the much smaller number of chemistry majors, particularly at large institutions. The exposure to organic chemistry required on the Medical College Admission Test (MCAT) for pre-medical students has had a similar effect.

Although some recent efforts at curricular reform have been attempted or called for, the pervasive influence of the ACS guidelines has restrained significant nation-wide experiments in curricular reform for undergraduate majors. As a consequence, the chemistry curriculum of today is very similar to that of the 1970's and does not adequately reflect the interdisciplinary and multidisciplinary nature of modern chemical practice.

Despite limited efforts at curricular content reform, considerable efforts at reform in pedagogies used to teach chemistry at the undergraduate level have been undertaken. Much of the effort in this arena has taken place at the level of lower division chemistry (first two years) due to the emphasis placed on these in the NSF Systemic Changes in the Undergraduate Chemistry Curriculum initiative of the mid-1990's.

Undergraduate education in chemistry is strongly dependent on infrastructure due to its substantial laboratory component. As noted above, this infrastructure includes adequate classrooms, laboratory space, technology, chemical prep room and waste handling facilities, modern instrumentation, electronic forms of chemical information and the appropriate staff to operate and maintain this infrastructure. Recent advances in the power of modern chemical instrumentation for molecular structure determination and chemical and physical measurements on molecular systems have rendered such instrumentation essential for an increasing fraction of the undergraduate curriculum. Indeed, the pervasive nature of such instrumentation in all fields of modern STEM compels a preliminary exposure to modern chemical measurement tools even at the introductory chemistry level. Although significant inclusion of modern sophisticated instrumentation at the level of general chemistry is not yet very common, it is increasingly occurring at leading institutions. Given the large service role of undergraduate chemistry courses, particularly in the first two years, the increasing need for instrumentation translates to an enormous financial burden for chemistry departments. Moreover, this burden is likely to increase significantly in future years as the need for instrumentation at the lower division course level spreads from the elite four-year institutions to the more typical four-year institutions and to the two-year institutions.

Other aspects of infrastructure that are increasingly troublesome in terms of affordability include resources for maintenance of chemical instrumentation, chemical waste handling capabilities and costs, and access to critical chemical information resources such as *Chemical Abstracts*. This latter need is quickly becoming a critical issue for undergraduate chemistry programs due to the history associated with the development of *Chemical Abstracts* as a privately held and controlled database. The private status of the *Chemical Abstracts* database is in contrast to the major literature databases in the life and biomedical sciences that were developed with public funding, and therefore, are openly accessible. Despite its position as a private, commercial venture, *Chemical Abstracts* is the most important literature database in the physical sciences, and the

ACS has required approved institutions to maintain a current subscription to this database since the approval program began in the late 1930's. In recent years, *Chemical Abstracts* has become available electronically along with extremely powerful and versatile search engines that have put access to this database literally on the desktops of practicing chemistry professionals. However, this superb electronic resource comes only at relatively great expense. The unfortunate consequence of this cost for undergraduate education is that only the wealthier institutions can afford it[21] despite the expectation that well-educated chemistry undergraduates have used this modern tool. (Indeed, it is quite interesting to note that even the National Science Foundation has not yet subscribed to the desktop search version of *Chemical Abstracts*.) These thorny infrastructure issues for undergraduate chemistry education will not be easily resolved in the future and will most likely require funding from several sources in addition to that from NSF. However, these issues will cause increasing pain and damage to the undergraduate enterprise as the chemistry profession and higher education seek ways to rectify these problems.

Faculty capacity is another challenge that must be addressed in chemistry as in mathematics and physics. As the pace of discovery in modern chemistry and in the science of learning science accelerates, faculty at institutions of all sizes will struggle to maintain a current knowledge base in these areas. This challenge will obviously be the greatest at institutions with the fewest resources. The expanding number of higher education institutions in the U.S. at which chemistry is taught render this problem one of increasing complexity and difficulty.

Physics

The current state of undergraduate physics education has recently been surveyed in the report *Strategic Programs for Innovations in Undergraduate Physics* (SPIN-UP) produced by the National Task Force on Undergraduate Physics.[22,23] Here, the most important facts from this report are highlighted.

As shown in Figure 1, after a decade of steady decline in the 1990's, the number of students receiving bachelor's degrees in physics in the U.S. started moving upward in 1999 and has continued to climb. Although the number of degrees awarded is now about 3500, it is still substantially below the all time high of about 5000 in 1970. Also increasing is the fraction of bachelor's degrees in physics awarded to women. The latest statistics (tracked by the American Institute of Physics) indicate that this fraction is now about 25% and still growing. While this fraction is below the fraction of degrees going to women in chemistry and biology, the trend is upward. Unfortunately, the fraction of degrees awarded to ethnic minorities remains small even as the number of college-enrolled undergraduates from these groups grows.

Of the roughly 1400 four-year colleges and universities in the U.S., about 760 offer bachelor's degrees in physics. Many of those physics programs are small with only one or two faculty members. About half of the bachelor's degrees are awarded from four-year colleges; the other 50% are awarded from research universities. About 350,000 students take introductory-level physics in colleges and universities each year; about half of these take calculus-based physics. The number of students taking introductory physics courses has tracked the overall college population for many years. Only 2-3% of students that take introductory physics go on to take further physics courses. Thus, introductory physics is primarily a service course for other science, engineering, and mathematics majors. About 20-30% of the students who take college-level introductory physics do so in two-year colleges. Two-year college physics programs are currently being studied by the project SPIN-UP TYC through a grant funded by NSF.

Undergraduate physics curricula across the country show a surprising degree of homogeneity between institutions. This homogeneity is surprising, because unlike chemistry and engineering, the physics community has no approval or certification board for undergraduate programs. The SPIN-UP study did find an increasing number of physics departments developing more flexible programs for majors through various degree "tracks." For example, students could major in physics with an emphasis on biophysics, materials science, applied physics, or computational physics, to mention just a few of the more popular options. Overall, there seems to be a growing effort to connect (or perhaps reconnect) undergraduate physics to other scientific disciplines. In terms of careers, about 50% of undergraduate physics majors go on to graduate school, with about 30% continuing in physics and 20% in other scientific or engineering fields. The other 50% go directly to the workforce in a wide range of careers.

The SPIN-UP project also included a survey sent to all bachelor's degree-granting undergraduate physics programs in the U.S.; this survey was designed, distributed and analyzed with the assistance of the Statistical Research Division of the American Institute of Physics. This survey had a remarkably high response rate of 74%. A summary of the survey results can be found in Reference 22. When asked about their greatest strengths, 203 of the responding departments cited individualized faculty attention to students, 89 cited research opportunities, 79 pointed to excellent curricula, and 70 noted the quality of their faculty. When asked about the greatest challenges, 204 cited the need for more students, 73 pointed to the need for more faculty members, 41 indicated improved laboratory equipment and space, and 39 cited the need for increased funding. More than 60% of the responding departments reported that they had made "significant" curricular changes over the past decade. Most reported changes in both content and pedagogy. When asked about the source of funding for these changes, 60-70% reported using departmental funds (more so at research universities and less so at four-year colleges), 27% had other support from the college or university, 22% had funding from NSF or other federal agencies, and 9% had funding from private foundations (more often at four-year colleges than at universities).

The physics community has undertaken substantial reforms in undergraduate physics programs, particularly in physics pedagogy. (Reference 22 provides a summary of recent developments in physics pedagogy.) On the other hand, the content of the undergraduate majors' curriculum is largely unchanged over the past 20 years, with the exception of increased use of computers for computation, for data-taking and analysis, and more recently, for the gathering and dissemination of information via the Internet. No clear vision of how to change the overall undergraduate physics program has emerged. Many physics departments have begun to take serious action to reverse the decline in the number of undergraduate physics majors, and those efforts are beginning to show positive effects. At the same time, departments in institutions with engineering programs are often modifying their introductory courses to help the engineers meet the ABET 2000 criteria for undergraduate engineering programs. These beginning efforts to enhance undergraduate physics programs for both majors and non-majors are laudable; however, assessment of the effectiveness, pervasiveness, and sustainability of these new efforts is at least several years away.

Infrastructure needs vary greatly among different types of physics departments. All physics departments feel strained for personnel because of the large fraction of the teaching responsibilities devoted to introductory physics, which in almost all institutions are primarily service courses for other STEM majors. Many departments reluctantly rely on part-time instructors or adjuncts to handle introductory physics courses. Teaching the many laboratory sections that go along with these courses also presents substantial demands for personnel, equipment, and space. Four-year colleges often struggle to maintain up-to-date equipment for upper-level laboratory courses while many research departments are able, in many cases, to make use of equipment from research laboratories for teaching functions.

Faculty capacity issues are also manifest in many ways. Faculty in primarily undergraduate institutions worry about how they can keep up with new knowledge in their own subfields of research while simultaneously exposing students to the exciting new interdisciplinary efforts that are part of the current practice of physics research. Faculty at research institutions often express frustration in finding time (and rewards) for keeping up with the latest developments in curricular and pedagogy innovations in physics. All physics departments struggle with the issue of developing and rewarding the requisite faculty leadership needed for improvement of their undergraduate programs. It should be noted that, in terms of leadership development, the bi-annual physics department chairs meetings hosted by the American Physical Society and the American Association of Physics Teachers often focus on issues in undergraduate physics education. More recently, chairs of the "top-tier" physics research departments have also been meeting to discuss issues in undergraduate physics education, among other matters.

The Unique Role of Two-Year Colleges

No examination of undergraduate education in the mathematical and physical sciences is complete without a discussion of the role of two-year colleges. The American Association of Community Colleges (AACC) reported in 2000 that more than 1,100 community colleges across the country enroll 44% of all U.S. undergraduates, 46% of African American and Asian American undergraduates and 55% of Hispanic and Native American undergraduates.[24] The community college mission is threefold: to prepare students for transfer to baccalaureate institutions, to provide workforce training, and to offer continuing education. The diversity of the community college student population extends to age, background and goals. Students' reasons for attending community college vary widely, as do the duration and tenure of their attendance and their level of academic preparation.

One of the difficulties community colleges face is the extent of the need for remediation as a result of inadequate preparation in K-12. Placement tests help determine entering students' levels of ability in basic subjects, including mathematics. Depending on state policy, those who cannot demonstrate college-level proficiency in these areas are either advised or required to take remedial courses. National Center for Education Statistics (NCES) research shows that in 2000, 35% of entering freshmen at public two-year colleges enrolled in remedial mathematics courses.[25] Because remediation and retention are closely linked, the need for remediation is a significant barrier to graduation. Research indicates that the percentage of students needing at least one remedial course who continue their studies to a second year is much lower than that of the overall student population. NCES statistics also show that more than a quarter of community college students who are required to take remedial courses fail to complete their remedial coursework.[26] These statistics are significant, because a lack of proficiency in mathematics denies students the opportunity to move forward along pathways towards mathematics-dependent disciplines such as chemistry and physics. It also has implications for engineering and allied health and nursing pathways that also require a solid background in mathematics. This is especially significant in light of the fact that 65% of new healthcare workers receive their training at community colleges.[24]

Greater integration between higher education sectors is crucial. Students transferring to four-year institutions do not always find the transition smooth. Despite articulation agreements, there remain differential standards in performance expectations in science and mathematics courses between two-year and four-year colleges. The challenge is to ensure the success of transfer students in math and science programs at four-year institutions. Attention must also be paid to faculty development. If research is to be a driving force in undergraduate curricula in mathematics and the physical sciences, and if community colleges are to be charged with a role in providing research opportunities, this will be an additional burden on community college faculty. NCES figures show that more than half of the full-time faculty members at public community colleges already teach 15 hours a week or more, compared with 7.9% at public research institutions and 18% at public comprehensive institutions.[27] To remain current in their disciplines and focus more on research, additional time and support will be required for professional development opportunities.

One of the goals of strengthening undergraduate education in mathematics and the physical sciences is to increase the pool of domestic talent and, by extension, minority talent, in these fields. Census Bureau figures show that the Hispanic population in this country is projected to grow by 188% over the next 50 years, with the African American population increasing by 71%.[28] Yet both groups continue to be underrepresented in mathematics and the sciences. According to data tabulated by the National Science Foundation, in 2000, underrepresented minorities received only 5.9% of earned doctoral degrees in science and engineering. In contrast, non-US citizens with temporary visas received 68% of science doctorates earned in 2000.[29] Although we must continue to welcome foreign students and value their contributions, this trend is a cause for concern. Our ability to compete effectively in the global economy and to remain a world leader in research and development depends upon our success in recruiting more Americans into scientific and technical fields.

Enrollments at community colleges are forecasted to grow as the population of high school graduates increases.[30] With the number of college applications rising,[31] four-year institutions are becoming increasingly more selective. This trend, along with sharp tuition increases in higher education,[32] makes community colleges an affordable and accessible alternative for many students. Since community colleges educate a large proportion of undergraduates from minority groups, more effective methods for educating these students and encouraging their participation in fields related to mathematics and the physical sciences must be developed.

Community colleges face significant challenges in trying to educate students who are academically under-prepared for college-level courses. These institutions also require additional resources to provide faculty development opportunities in mathematics and the sciences. However, community colleges do have unique assets. Community colleges traditionally have strong teaching missions, with a concentrated focus on improving student learning. The AACC reports that community college faculty members spend 72% of their time teaching, whereas their counterparts at four-year institutions spend only 57% of their time on teaching.[33] This emphasis on teaching, combined with smaller community college class sizes, provides greater opportunities for individualized student attention and learning.

Community college faculty have all had experience with four-year institutions, but the reverse is not necessarily true. In order to ensure a fuller integration of goals and strategies, it is necessary for four-year college faculty to gain a better understanding of the community college sector. Greater collaboration between two-year and four-year institutions is needed to bolster teaching and research in mathematics and the physical sciences and to allow seamless transitions by students between the two sectors. Developing the intellectual capital of community college students and faculty will require creative approaches and the dedication of adequate resources.

Focus Group Findings

Focus group teleconferences were held on February 23-26, 2004 at NSF. Potential focus group participants were identified by subcommittee members and NSF staff. Invitations to participate in these focus groups were sent to almost 300 representatives of the mathematics, chemistry, and physics communities as well as to approximately 40 individuals representing areas that interface with these core disciplines. Along with receiving an invitation to participate in these focus group teleconferences, invitees were also given the option of providing written feedback in addition to or in lieu of participation in a focus group. Appendix E contains the list of focus group invitees, Appendix F contains a list of focus group teleconference participants and those who provided written input, and Appendix G contains a matrix of the focus groups, including subcommittee members and NSF staff from EHR and MPS who participated in conducting the focus groups. Despite the large number of invitations extended for these focus groups, only 49 individuals actually participated in focus group teleconferences, with most representing academic institutions. In addition, 14 individuals provided written input, five of them having also participated in the focus group teleconferences.

Although the absolute number of participants was relatively small, an excellent cross-section of each community was represented in these focus groups. Given the considerable redundancy in comments made during different focus group sessions, the subcommittee is reasonably confident that the most important issues in the undergraduate education of majors in these disciplines were articulated during these discussions.

Although the issues and problems facing mathematics, chemistry, and physics in the undergraduate education of majors are somewhat discrete, common themes emerged from these focus groups that transcend disciplinary boundaries. In addition to these general themes, the focus groups articulated issues and concerns specific to each discipline. These are detailed in separate sections below along with the insight into undergraduate education in these disciplines provided by interdisciplinary focus group participants.

Common Themes

In terms of modern research practice, disciplinary lines are blurring. Interdisciplinary and multidisciplinary research opportunities at the interfaces of mathematics, chemistry, and physics with other areas such as the biological sciences, materials, and environmental science are driving a paradigm shift in the modern practice of these disciplines. Researchers at academic institutions and in industry more frequently work in these interface areas requiring of mathematics and physical sciences professionals an ever-increasing working knowledge of allied disciplines. Moreover, at academic institutions, joint faculty appointments between traditional disciplinary departments are now quite common, reflecting the high intrinsic value of modern professional activity in these areas.

Graduate education of mathematicians, chemists, and physicists is being appropriately modified to reflect these changes in professional practice, motivated in part by NSF programs such as the Integrative Graduate Education and Research Traineeship (IGERT). In contrast, however, these changes in modern professional practice are *not* adequately reflected in the undergraduate education of majors in these disciplines in terms of curriculum content. Although some exposure to the inter- and multidisciplinary nature of modern professional practice in these disciplines is afforded by experiential learning opportunities such as research and industrial internships, in general, a significant disconnect exists between modern professional practice and the undergraduate preparation of professionals in these areas. Undergraduate curricula in these disciplines have been largely unchanged for at least several decades. Moreover, these traditional curricula are rigid and hierarchical and are not well-matched to the expansive opportunities available for professionals trained in these areas and severely limit pathways into majors in these disciplines. This disconnect may also contribute to the inadequate and declining number of domestic undergraduate majors in these areas.

Although improvements in pedagogy, such as the increased use of active learning strategies including discovery-based and inquiry-based laboratories, ameliorate the use of somewhat dated curricula, these pedagogies have most often been applied at the introductory course level and do not address critical upper division offerings wherein students first get a glimpse of the modern practice of a discipline. The magnitude of this disconnect between professional practice and undergraduate education in these disciplines provides a compelling argument for enhanced inclusion of experiential learning opportunities such as research and internships that convey a better sense of modern professional practice, into the undergraduate education of majors in mathematics, chemistry, and physics.

One additional shortcoming of existing curricula in these disciplines that was frequently cited in these focus groups was inadequate attention to the development of the so-called soft skills. In light of the increasingly inter- and multidisciplinary nature of mathematics, chemistry, and physics, professionals in these disciplines must possess the ability to communicate effectively (both oral and written), the ability to work in a multidisciplinary team, and critical thinking and problem-solving skills.

The increasingly important role of community colleges in providing entry-level (i.e. lower division) education in mathematics, chemistry and physics was frequently noted by focus group participants. As the undergraduate student enrollment in two-year colleges continues to grow, mechanisms for better integration of these institutions with four-year institutions are needed in order for students to be successful in making the transition from two-year to four-year institutions. This transition point is not only important in providing adequately prepared transfer students that have some hope of successfully completing a baccalaureate degree in mathematics, chemistry, or physics at a four-year institution, it is *critical* in order to tap the human resource potential represented by these institutions. In light of the lagging diversity of mathematics, chemistry, and physics relative to the population base of the U.S., efforts and innovative mechanisms to facilitate and enhance the connection between two- and four-year institutions in these disciplines are sorely needed.

Important problems at two other transition points related to undergraduate education in mathematics, chemistry, and physics were also frequently cited in focus group discussions. The transition point between K-12 and the undergraduate level strongly impacts the postsecondary pathways of students. K-12 under-preparation, especially in mathematics, is a pivotal deficiency that can deny students opportunities to pursue careers in science and technology-based careers by limiting pathways into majors in these areas at both two-year and four-year institutions. The under-preparation of undergraduates emerging from domestic programs in mathematics, chemistry, and physics that enter graduate programs in these areas relative to foreign students was also noted, although the effects of this difference in preparation usually disappear after a year or so of graduate study.

All focus groups noted the negative impact on undergraduate education in these disciplines experienced as a result of the increasing financial pressures on institutions of higher education. These financial pressures are reflected in difficulty in maintaining adequate infrastructure to support modern undergraduate programs at both four-year and two-year colleges, particularly in the infrastructure-intensive areas of chemistry and physics, and in issues related to faculty capacity.

An alarming increase in the use of part-time/temporary/adjunct faculty is evident at both two-year and four-year institutions. It is believed that this trend is being driven by purely financial considerations, since it is a practice generally agreed to be deleterious to undergraduate education in these disciplines. Although some participants argued that such individuals can have a positive impact on education given that their professional activities consist solely of teaching, most believe that the negative attributes of such appointments, including their vague and often transient attachment to a department, their relative isolation from the regular tenure-track faculty, and their lack of long-term commitment and buy-in to a particular institutional and/or departmental mission, far outweigh the positives of such appointments. Moreover, these part-time faculty members are often no longer active in research, and hence, are less able to convey to students the developments and excitement in contemporary research.

Faculty in mathematics, chemistry, and physics at both four-year and two-year institutions are working under enormous time pressures today. At research universities, the pressure to generate outside research dollars is increasing as these universities increasingly look to indirect cost return funds generated by these grants to offset declining support from other sources. At four-year institutions whose primary mission is teaching and at two-year colleges, faculty teaching loads are often creeping upwards as a mechanism to decrease expenses. All of these trends are negatively impacting faculty ability, and sometimes even desire, to effectively participate in the undergraduate education of majors. Moreover, these pressures are also driving professionals away from choosing academic career paths.

One consequence of these trends at large research universities is an emerging separation of faculty into “researchers” and “educators”, with a clear hierarchy of researchers as superior to educators. The subcommittee repeatedly heard from focus group participants at such institutions about the inclusion of faculty in their departments with expertise in mathematics education, chemical education or physics education. Implicit in their comments was oftentimes the sense that it was these faculty who bore the major responsibility for undergraduate education in their departments.

Indeed, faculty at research institutions are not well-informed about the modern state of or the broader problems facing higher education today, and a significant fraction of faculty at such institutions are not knowledgeable about recent advances in the science of learning science. Of perhaps greater concern is that a significant fraction of faculty in these disciplines express little sense of responsibility for improving the undergraduate education of their majors, and many faculty actively seek relief from their undergraduate teaching responsibilities through either direct buy-out or administratively-granted release upon acquiring research funding. NSF has actually contributed to this trend through increased funding for large group and center grants that require considerable faculty administrative oversight.

Thus, major changes in culture within these disciplines are needed in order to better engage faculty in the educational processes that create professionals in these disciplines. Such cultural change will only be successful with a concomitant institutional change in the reward structure for faculty attention to educational activities. Although such institutional changes are outside the scope of NSF control, NSF can greatly influence and facilitate such change by a further focus on the integration of research and education, particularly at the undergraduate level, in all funded activities.

Mathematics

In focus groups comprised mostly of members of the academic mathematics community, almost all from research universities, the following major issues were articulated during discussion:

- Many new areas are emerging in the mathematical sciences ranging from the biosciences to new areas in technology, from (mathematical) physics to math finance/economics. The mathematical sciences should play a major role in these areas as they evolve. Although mathematics departments are aware of these new areas and are creating or adapting existing programs to address these needs, new course development, particularly in interface areas related to the biosciences, is a high-priority need.

- One need in the discipline cited by multiple focus group participants is enhanced research opportunities for undergraduates earlier in their careers. Early engagement in research seems to be relatively standard in other scientific and engineering disciplines, but it has only recently emerged as a possibility in mathematics. While there is no agreement in the mathematics community about the ability of undergraduates to become productively involved in research, nor is there any concrete data that speak to the efficacy of such experiences in improving student learning or in the retention of majors, many REU programs have recently demonstrated that students can become effectively involved in interesting mathematics research during their undergraduate careers, given good mentoring and proper prior training. Moreover, these research experiences often lead students to choose careers in the mathematical sciences, an extremely important national need. An augmented REU program tailored specifically to the needs of the mathematical sciences would be a welcome program at NSF.

As one example of how the existing REU program might be improved, NSF should consider incentives for faculty to become involved in academic-year REU projects. Many students who come from financially disadvantaged backgrounds cannot afford to forgo summer salaries in order to participate in summer REU programs. Academic-year REU opportunities at their home institutions are much more viable for this cohort of students. In the current NSF environment, the only way faculty can finance academic-year REU students is by including their support on existing research grants. Unfortunately, most research faculty in mathematics departments do not have such grants and are therefore prohibited from providing such opportunities. Participants further felt that many faculty who are principal investigators on research grants are often not the best faculty to mentor undergraduates in research due to their commitment to their own research agendas. To address this need, NSF might fund small grants for individual researchers who do not have existing research grants to become more involved in mentoring undergraduate researchers during the academic year. Ideally, such a program might be jointly administrated and funded by the Division of Undergraduate Education (DUE) and the Division of Mathematical Sciences (DMS).

- More modern topics in mathematics must be incorporated into the undergraduate mathematics curriculum. Students regard mathematics as a "dead" discipline in which nothing of interest or relevance is being discovered. This perception has a negative impact on enrollments in undergraduate mathematics courses and is clearly linked to the decline in the number of people entering the mathematical sciences workforce. Mechanisms for the inclusion of modern mathematics topics in undergraduate curricula might be an additional appropriate topic for joint efforts between DMS and DUE.

  The mathematics curriculum is rigidly hierarchical in which the preceding course is used to lay the foundation for later courses. For example, many topics are covered in Complex Analysis I, because without coverage of these topics, those teaching Complex Analysis II would be handicapped. Many participants felt that it is much more important to stress the central ideas of mathematics rather than every single detail. In this way, some of the new and exciting material in the field could be incorporated into each course. NSF is the obvious agency to establish a program to accomplish this change in the undergraduate mathematics curriculum.

- Toward this end, focus group participants felt that a small grants program in which grants on the order of ~$25,000 were provided for activities such as new course development, undergraduate colloquia, undergraduate meetings, as well as REU opportunities might be an extremely effective use of NSF funds. NSF staff time might become an issue given the increased reviewing load that such a program would require; however, several participants advocated giving NSF staff the authority to hand out such small grants without extensive peer review (although not all participants supported this approach.)

- An obvious need to change the “culture” in mathematics exists. We need to "teach university faculty to teach" and to convince research university mathematics faculty that attention to undergraduate education in mathematics is vital in order to sustain the profession, and indeed, to sustain their own research agendas. The VIGRE program in DMS seems to be an excellent model for accomplishing this cultural change. Although aspects of this program are controversial, on the whole, VIGRE is seen as both visionary and beneficial. Moreover, recent changes to the VIGRE program should make it even more viable in stimulating the cultural change that is needed. A VIGRE program targeted towards predominantly undergraduate institutions might further enhance the impact of this program.

Chemistry

Chemistry focus group participants were largely from academic institutions, with about half from research universities and half from predominantly undergraduate institutions. Two focus group participants came from industry and one from a professional society. The following issues and concerns specific to chemistry were addressed by these focus groups:

- Despite the fact that many recent faculty in chemistry have been hired into joint appointments with other departments, the interdisciplinarity of the chemistry research frontier has not yet been fully expressed in undergraduate education in chemistry. In fact, very few institutions have begun to grapple with this challenge. This situation is in stark contrast to the state of graduate education in chemistry wherein programs such as IGERT have had a tremendous positive impact on enhancing interdisciplinary content.

- Focus group participants noted the pervasiveness of chemical measurements in all areas of modern chemistry and the concomitant need for modern instrumentation at *all levels* of undergraduate education in chemistry, from introductory to advanced. This need places a huge burden on the infrastructure for chemical education at four-year institutions, and increasingly, at two-year institutions.

- Costs associated with offering laboratory courses in chemistry continue to escalate placing enormous strain on chemistry departments. Given the very large service role of chemistry, the financial burden that this inflation places on the entire undergraduate enterprise is tremendous.

- Participants felt that the ACS guidelines for approved programs have provided an excellent framework for maintaining a uniformly-high level of standards in chemistry programs in the U.S. However, these guidelines have promoted traditional curricula defined in terms of the traditional sub-disciplinary areas of chemistry (analytical, inorganic, organic, and physical). Although a requirement for exposure to biochemistry has been recently added to these guidelines, overall, they may be too rigid for the interdisciplinary and multidisciplinary way in which modern chemistry is practiced.

- College students are under increasing time and financial pressures. Therefore, the chemistry curriculum cannot continue to simply add course requirements as the only viable means of adequately preparing professionals. The entire chemistry profession must reconsider what it means to be educated as a chemist today.

- Participants noted an increased emphasis on undergraduate research as a useful pedagogical tool and supported the enhancement of undergraduate research opportunities. It was noted that this might be one way to increase the number of domestic students getting bachelor's degrees in chemistry.

- Focus group participants noted serious needs in infrastructure including modern instrumentation and electronic chemical information. Although existing NSF programs address some level of need in this area, participants felt that the rather narrow definition of existing NSF programs prohibits greater proposal pressure to address these needs. Participants felt that definite tiers of institutions are emerging in terms of infrastructure and that critical infrastructure shortages are developing in these areas at second-tier institutions.

- Chemistry textbooks were noted to be a source of major inertia for curricular change.

- Faculty capacity is an issue at all types of institutions. Chemistry faculty at research institutions are not keeping up with advances in pedagogy or the science of learning science. Chemistry faculty at many small four-year institutions and two-year institutions at which teaching loads are high are struggling to stay current in their knowledge of modern chemistry research and education. Faculty development opportunities are difficult for faculty at all institutions. Funding sources for sabbaticals seem to be diminishing, even for faculty at research institutions, and funding for faculty sabbaticals at many four-year and two-year institutions is nonexistent.

Physics

The majority of focus group participants in physics were from academe, with approximately twice as many faculty from research universities as from primarily undergraduate institutions. In addition, two participants in physics were from professional societies. The following is a list of common themes that emerged from the focus group teleconferences with physicists:

- Many focus group participants cited the increasing importance of interdisciplinary activities in physics research. Biophysics, nanotechnology, and materials science were cited by many as rapidly growing areas of research activity in physics. However, none of the participants described any changes in the undergraduate physics curriculum, particularly at the introductory level, that reflect the interdisciplinary changes at the frontier of modern physics research.

- Physics programs have largely retained the "standard" curriculum established in the 1960's. Most physicists believe that physics students need a solid grounding in the core of the discipline and that interdisciplinary work is more appropriate at the graduate level. Many participants argued that the traditional undergraduate physics curriculum, particularly in introductory courses, is "boring" for students and disconnected with the practice of modern physics.

- Some departments have added degree "tracks" to allow students to combine interests in physics and in other science areas. However, in most cases, these tracks simply allow students to use courses in other science departments as part of their physics major program. The courses taught within the physics department have not changed significantly.

- The use of computers for physics majors is now taken for granted for computation, data acquisition, data analysis, and information gathering and dissemination. At the introductory level, computers may be used in laboratory courses, but otherwise their use is relatively limited.

- Undergraduate research participation is now widespread among undergraduate physics majors. Many participants supported increased funding opportunities for student participation in research earlier in their careers, even at the freshman level, as a mechanism for attracting more students to physics.

- Many participants noted the need to include training in "soft skills" as part of the undergraduate program: working in teams and written and oral communication both with other scientists and with the broader public.

- Participants thought that many academicians in the physics community do not yet see the need for change in undergraduate physics programs. Hence, the community lacks a clear and unified vision for how undergraduate programs should develop.

Focus group participants noted the following in response to the request for specific recommendations for NSF:

- Participants called for better dissemination of existing efforts to enhance undergraduate physics programs. Many faculty members do not know about what has already been done, what works where, and what funding opportunities are available to help support educational activities.

- Faculty development workshops would be helpful.

- Grants for departments to help support overall undergraduate program enhancement would be useful. Many pedagogical reforms require infrastructure support for new equipment or new (or renovated) space.

- Grants that encourage multi-institutional collaboration for curricular reform were suggested.

<u>Interdisciplinary Focus Groups</u>

Interdisciplinary focus group participants discussed the following ideas:

- Opportunities for graduates in mathematics, chemistry, and physics are steadily increasing, due in large part to an increase in interdisciplinary fields. Universities have quickly created new programs or research centers in materials science, chemical biology, biophysics, applied math, environmental science, etc. Undergraduate programs, however, have been slow to react to these changes due, in part, to the classical departmental structure and due to the service nature of many mathematics, chemistry, and physics courses. Translating the fruits of interdisciplinary research to the development of interdisciplinary courses has been difficult. Further problems are encountered in the creation of interdisciplinary courses when determining teaching loads, in tenure decisions, etc. for those involved in teaching such courses. NSF might consider development of a program at the undergraduate level analogous to IGERT to support the development of interdisciplinary undergraduate courses and research opportunities. Alternately, awards to multiple departments might be used to stimulate the development of interdisciplinary curricula and a greater number of interdisciplinary REU programs might be funded. Funds for collaborative Research at Undergraduate Institutions (RUI) projects could enhance interdisciplinary research opportunities at undergraduate institutions.

- As higher education becomes ever more expensive, many students enter through the community college system. Frequently, at urban and state-supported universities, a majority of undergraduates take introductory courses at community colleges. Greater interactions between two-year and four-year institutions are needed to ensure that students receive a comparable education and to facilitate a seamless transition for students that transfer.

- Mathematics, chemistry, and physics have historically done a poor job of attracting minority and disadvantaged students. With increasing numbers of minority and underserved minority populations and as the numbers of the traditional mathematics, chemistry, and physics professionals (i.e. white males) declines, it becomes increasingly evident that these communities must increase their efforts to attract and educate this population.

- Professionals in these disciplines who can adapt to a rapidly changing work environment are needed. Graduate schools and industry are increasingly seeking entrants who have learned the requisite "soft skills" (e.g. communication, problem-solving, critical thinking, teamwork, and the ability to find and synthesize data.) This is especially true in interdisciplinary fields. The challenge is to develop these skills within a more classical educational environment.

- Scientific and mathematical literacy of entering students is a problem that must be addressed at the K-12 level. Ensuring this literacy is dependent on the production of K-12 teachers who are mathematics-, chemistry-, and physics-literate. It is imperative that educational institutions take greater responsibility in the production of science and mathematics-literate teachers. Increasingly, a disciplinary degree in mathematics, chemistry, or physics is required in order to teach these subjects at the secondary level. However, as these disciplines shift toward greater interdisciplinary emphases, a change in the way secondary education is structured may be required as well. The existing NSF

Research Experiences for Teachers (RET) program might be effectively used for enhancing the interdisciplinary knowledge of in-service secondary teachers.

Preliminary Recommendations for NSF

The focus groups provided considerable insight into the current state of undergraduate education in mathematics, chemistry, and physics and stimulated extensive discussion within the joint subcommittee that led to the recommendations below for appropriate and specific actions that should be undertaken by the EHR and MPS Directorates to improve the undergraduate education of majors in these disciplines. These recommendations are made with a view of higher education as a *dynamic, evolving institution* in the U.S., one for which no singular standard of practice is necessarily appropriate. Given the intrinsic dynamism of higher education, *ensuring that the forefront of undergraduate science education evolves as an experimentally-based body of knowledge requires a long-term, indeed permanent, commitment for financial support.* Finally, the recommendations below are made with the perspective that there is no "one size fits all", or even best, solution to undergraduate education in the mathematical and physical sciences that is simply waiting to be uncovered; multiple approaches will be contextually successful in different disciplines and in different institutions. The central challenge faced by NSF is to articulate a rational process for experimental and evidence-based discovery of these approaches. It is within this spirit that the following recommendations are made.

1) Issues and needs in undergraduate education in mathematics, chemistry, and physics can be quite distinct. The NSF EHR Directorate should experiment with discipline-specific programs that are developed with full integration of the expertise, insight into community culture, and understanding of the modern research frontier of the appropriate Division within the MPS Directorate.

The discussion contained within the sections above portrays an undergraduate education landscape that is different for each discipline in terms of current practice and deficiencies. The approach of developing programs with uniform guidelines for all disciplines is inadequate for addressing existing needs of these communities in the undergraduate education of majors. For example, the most significant need within the mathematical sciences is modernization of the undergraduate experience through more frequent exposure to research activities in order to infuse a sense of the relevance and frontiers of modern mathematics into the education of majors and to better engage research-active faculty in the undergraduate education process. Such research opportunities would provide appropriate balance to the centuries-old core mathematical topics that must also be necessarily covered in the undergraduate mathematics curriculum.

In contrast, some of the most pressing needs within chemistry and physics are in the areas of overall curriculum development, infrastructure and faculty development. Existing curricula in these disciplines must be made more flexible to support the increasingly diverse scientific interests and career pathways of professionals in these disciplines and to modernize course content to better reflect the increasing interdisciplinary nature of these fields. Infrastructure for the undergraduate education of majors in these areas must be enhanced to provide access to modern instrumentation and electronic tools throughout all levels of the undergraduate experience. Faculty development opportunities are sorely needed to facilitate better dissemination of recent advances in educational practice in these areas, particularly to faculty at research institutions and two-year colleges, and to allow faculty at small four-year colleges and two-year colleges to maintain their currency in recent advances in research in these disciplines.

Finally, programs for undergraduate education in the mathematical and physical sciences should be developed with full utilization of the expertise, insight into the community culture, and understanding of the modern research frontier that can be provided by the relevant Divisions within MPS working cooperatively with EHR. In addressing the existing needs in undergraduate education in these disciplines, the subcommittee strongly recommends more extensive collaboration and integration of effort between these two Directorates.

2) Undergraduate reform efforts that engage the full range of faculty within a department and that seek to better infuse the current knowledge and modern professional practice of mathematics, chemistry, and physics into the undergraduate experience are likely to have the greatest positive impact on the education of majors in these disciplines. The development of a program to stimulate "department-level" reform in the undergraduate education of majors in these disciplines is recommended.

The four pillars that support undergraduate education in MPS must not only be established but also sustained and nurtured in order for excellence to be attained in undergraduate education in a scientific discipline. Too often, past attempts to improve the undergraduate experience have focused exclusively on only one of these key ingredients such as the acquisition of new instrumentation or the development of new laboratory experiments or new courses. Although improvements in certain aspects of the undergraduate experience can be realized through such changes, this approach neglects the essential interdependence of these pillars that supports the foundation of an undergraduate education in a scientific discipline.

Given that the academic department is the functional unit of educational change, fundamental systemic change in the quality of an undergraduate experience at a given institution must be undertaken at the department level with attention to each of the pillars supporting the vertical development of students' knowledge. This holistic view of educational reform presents unique opportunities for innovation in restructuring the undergraduate experience in a scientific discipline that could be manifest in the development of new curricula and the pedagogical means for its delivery, in the development, management and utilization of infrastructure, and in the management and development of faculty resources.

An NSF program for department-level reform in the undergraduate education of mathematics, chemistry, and physics professionals could stimulate the development of new and innovative models for education that better equip graduates to contribute to and professionally thrive within the scope, rate of change, and practice of modern science when compared with existing educational paradigms. The focus on department-level reform is not meant to diminish the importance of inter- and multidisciplinarity that are the hallmarks of modern science. Rather, this focus merely appropriately recognizes the academic department as the unit of functional control and change around which the majority of academic institutions are organized.

The overarching goal of a department-level reform program would be to engender broad faculty engagement in the delivery of a quality experience for all undergraduate majors in a given department. The appropriate components of such an experience are likely to differ between disciplines or even between departments within a given discipline. Thus, the nature of activities to be undertaken as part of a departmental-level reform effort may differ vastly between disciplines but may include changes in curricular structure and content, development or improvement of infrastructure, enhancements in faculty capacity or the utilization of faculty resources, the development or improvement of undergraduate research activities, or the development or improvement of enhanced mentoring and/or advising activities.

It should also be noted that, insofar as the systemic changes envisioned typically stimulate broader changes in education throughout a department, improvements in the undergraduate experience for majors are also likely to result in significant improvements in the education of non-majors within a given discipline.

Finally, in order for such a program to stimulate systemic change in undergraduate education in these disciplines, it must be developed in such a way as to be attractive to the top-tier institutions, both research universities and four-year colleges, in each discipline. Without buy-in to the need for improvement in the undergraduate education of majors by such institutions, changes in practice are likely to remain isolated and of limited overall impact.

3) EHR and MPS should undertake activities to stimulate greater integration of two-year colleges with four-year colleges and universities in the preparation of undergraduate majors in mathematics, chemistry, and physics; experimental

approaches to addressing professional development opportunities for two-year college faculty are needed.

The increasing importance of two-year colleges in undergraduate education in STEM disciplines is undeniable. Moreover, the student demographics of such institutions indicate that they represent a diverse and largely untapped pool of talent from which minorities under-represented in STEM disciplines could be drawn. Despite articulation agreements, the integration of the two-year college system with the four-year higher education system remains relatively poor, and additional programs to facilitate and enhance this integration are sorely needed. Over the long term, such programs would not only contribute to greater success for students in making the transition from two-year colleges to four-year colleges and universities, but could also substantially improve faculty capacity at two-year institutions.

Specifically, the development of programs that provide enhanced research opportunities for two-year college students and faculty are recommended. For students, such "bridge" programs have been effective in enhancing the success of two-year college students in the life sciences. For faculty, research experiences represent critical faculty development opportunities to maintain currency in modern research practice in a discipline and to sustain vitality among the faculty ranks at two-year institutions.

One new program that has the appropriate essential characteristics of integration of two-year and four-year institutions that address this recommendation is the Undergraduate Research Centers program recently introduced by the Division of Chemistry within MPS. Expansion and broadening of this concept to mathematics and physics should be explored as one mechanism for enhancing the integration of two-year and four-year institutions.

4) EHR and MPS should undertake activities to facilitate better integration of "researchers" and "educators" in mathematics, chemistry, and physics within four-year institutions, between four-year institutions, and between four-year and two-year institutions.

The communities of "researchers" and "educators" in mathematics, chemistry, and physics, and their cultures, remain very separate entities with inadequate integration and communication and with deleterious effects on the undergraduate education of majors in these disciplines. Too often, researchers exhibit a surprising lack of knowledge about advances in cognitive science and science education related to the learning of science, and have difficulty even understanding the language of these fields. Educators in these disciplines are often not knowledgeable about significant advances in modern research in these areas, since their day-to-day efforts are far removed from their disciplinary research frontiers. Thus, despite the increasingly prevalent practice within research universities over the past decade of adding faculty colleagues with expertise and scholarly activities in science education, these two communities remain decidedly discrete. To a certain extent, the separation of EHR from the research Directorates within NSF has sustained and perpetuated this division. Undergraduate education of majors in these areas has suffered as a result.

In the development of undergraduate programs in mathematics, physics, and chemistry, the subcommittee recommends that EHR and MPS foster greater cooperation between these communities and require the participation on grant awards of appropriate individuals from both the research-based and education-based sectors of these disciplines. Such individuals may come from within a single institution or might appropriately come from multiple institutions and institution types. Moreover, better integration of these two communities can be facilitated within EHR and MPS through the inclusion of experts from both communities in the panel review of grant proposals to both research-based and education-based programs in mathematics, chemistry, and physics.

5) **Greater integration of research and education in all EHR and MPS funding activities is needed to change the existing disciplinary cultures that value research endeavors significantly more than educational endeavors and for more effectively engaging research faculty in the undergraduate education of majors in mathematics, chemistry, and physics.**

As noted above, the communities and cultures of the research and education communities in these disciplines are distinct. Of particular concern is the decreasing engagement of researchers in the undergraduate education of majors. Certain recent practices of NSF have contributed to this trend. Specifically, as more funding opportunities are made available in the form of large center or group grants that carry a significant administrative burden, some of the most research-active faculty involved in such programs seek relief from the time consequences engendered by these administrative burdens through release from teaching responsibilities. Removal of some of the most successful and engaged top-flight research faculty from the undergraduate classroom is clearly to the detriment of undergraduate education in these disciplines. Indeed, what is needed is *greater* engagement of these faculty in the undergraduate experience, since these researchers are typically at the forefront of their fields and can bring the excitement and enthusiasm of these disciplines into the classroom. Therefore, it is recommended that NSF expressly disallow teaching release as a mechanism for institutions to provide relief to faculty for these administrative responsibilities, and encourage instead the exploration of alternate mechanisms for relief through provision of additional staff or infrastructure support. When administered workloads of faculty are considered, participation in undergraduate education should be retained as a high-priority responsibility.

Use of Merit Criterion II for broader impacts of a funded research grant should also be explored by EHR and MPS as a way to facilitate greater integration of research and education, particularly for grants to faculty at research institutions. For example, requiring grant awardees at academic institutions to have a component of their broader impact efforts targeted towards undergraduate education in their discipline might be one way to facilitate greater engagement of research faculty in the undergraduate educational process in these disciplines.

6) EHR and MPS should consider exploring changes in staff organization to better facilitate educational activities between these two Directorates. As an example, EHR and MPS might explore the establishment of a staff position/office charged with integrative educational activities between the two Directorates with dual reporting lines to the EHR and MPS Assistant Directors.

The partial separation of research and education functions within NSF, although necessary as policy in order to provide an appropriate home for educational and human resource functions that fall outside the normal scope of responsibility of the research Directorates, creates somewhat of a disconnect in function for education at the postsecondary level. In terms of EHR and MPS specifically, although excellent efforts at formalizing regular communication between the two Directorates have been undertaken, these have only infrequently led to the successful development of jointly conceived and sponsored programs in a way that takes advantage of the expertise in research and education existing within both organizations. One reason for this sporadic record of truly integrative activity between the Directorates is the absence of a clearly identifiable staff line or office explicitly responsible for this function that reports to both Directorates. By analogy to the highly successful Office of Multidisciplinary Activities (OMA) within MPS, one mechanism for improving the integration of these two Directorates with respect to educational activities in the MPS disciplines is to establish a staff position charged with this integrative function with dual reporting responsibilities to both Assistant Directors.

The function of the OMA within MPS is to serve as a facilitator for MPS-relevant programs of intrinsic interdisciplinary or multidisciplinary nature that cross traditional divisional boundaries within MPS or that cross Directorate boundaries within the Foundation. At the inception of the Office, the interpretation of multidisciplinary was principally of discipline-crossing research collaborations. Over time and with the emphasis on Merit Criterion II, OMA has reinterpreted the original scope to include additional collaborations with an educational mission. As facilitator, the OMA interprets its role as that of a venture capitalist, co-investor, and good steward. This includes assisting in the initial funding of high-risk but potentially high-return projects, providing seed resources to bring experimental new programs on line in a timely way that would otherwise miss a critical opportunity, and supporting programs that offer a new paradigm in approach to research, education, or diversity. An office or position charged with similarly integrating research and educational activities across the EHR/MPS Directorate boundary, and funded from both Directorates, could broker the existing missions and expertise of these two Directorates in a way that significantly enhances the positive impact of the NSF investment in undergraduate education in the MPS disciplines.

Plans for Future JSAC Activities

Although considerable progress has been made to date by the EHR/MPS Joint Subcommittee on Undergraduate Education in meeting its charge, much work remains to be done. Specifically, data gathering to date has primarily focused on the four-year academic communities of mathematics, chemistry, and physics. The subcommittee believes that these communities can only provide part of the picture of the current state of undergraduate education and the needs of these disciplines for improving the undergraduate education of majors. One perspective that is critical to assessing the appropriate direction for change in undergraduate education in these disciplines, but that is noticeably absent from the information gathered by the subcommittee to date, should come from a broader cross-section of the workforce that hires postsecondary degree recipients in these fields. In the view of the subcommittee, this workforce is broadly defined to include industry and government laboratories in addition to the K-12 education system that hire teachers in these disciplines. In addition, input from a greater number of two-year college faculty is needed to more fully understand the needs of this very important segment of the undergraduate education base in mathematics, chemistry, and physics. Pending endorsement of further subcommittee activity by the MPSAC and the EHRAC at their spring 2004 meetings and with the permission of both Assistant Directors, the subcommittee would plan to conduct additional focus groups during the summer of 2004 targeted towards these sectors.

Once these focus groups were complete, the subcommittee would plan to meet one additional time in early fall of 2004 to consider the information obtained from these focus groups and to formulate final recommendations to the NSF EHR and MPS Directorates. Following this, the subcommittee would decide on the contents of the final report with a target completion date of mid-October 2004. The final report would then be presented to a joint session of the MPSAC and the EHRAC at their November 2004 meetings. Once approved by both Advisory Committees, the final report would be submitted to the Assistant Directors for EHR and MPS with a target date of November 2004.

Insofar as this joint subcommittee was originally constituted and empowered to be a continuing effort of the two Advisory Committees, its future status and activities could be decided by these bodies at their November 2004 meetings.

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Appendices

Appendix A: Membership of the EHR/MPS Joint Subcommittee of the Advisory Committees

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Appendix B: Charge to the EHR/MPS Joint Subcommittee of the Advisory Committees

Education and Human Resources
Mathematical and Physical Sciences

Joint Subcommittee of the Advisory Committees
on
Undergraduate Education in the
Mathematical and Physical Sciences Disciplines

Purpose:

EHR and MPS and their Advisory committees are creating this joint subcommittee as one aspect of a broader effort to work together toward common goals. These common goals include: preparing the next generation of MPS professionals; broadening participation in MPS disciplines; and creating pathways to MPS careers.

The joint subcommittee will advise MPS and EHR on how they can cooperate in improving undergraduate education, using as context the development of a coherent vision and approach toward strengthening undergraduate majors in MPS disciplines that emphasizes linking study in a field with its practice.

Charge:

Undergraduate education is a pivotal point both for improving professional education and broadening participation in the disciplines and for enhancing STEM understanding in the broader public. The subcommittee will explore NSF's role in addressing these issues, as well as opportunities and challenges for leverage and synergy in existing investments in the two directorates and in exploration of possible new directions.

Background: The research frontier in MPS disciplines and related interdisciplinary areas is moving rapidly, with both the new knowledge and new approaches to research and education having implications for both nature of professional practice and the preparation of the next generation of researchers and practitioners in these fields. Addressing these implications requires input from the broader research, education, and professional practitioner communities concerned with these areas. Both within the scientific communities and within NSF, it has proven difficult to address the issues in concert. The joint subcommittee will aim for an integration of views from these communities that aims toward an integration of research and education activities.

Charge: On behalf of the EHR and MPS Advisory Committees, the joint subcommittee is charged with

- Examining the ways their communities think about and describe the activities of research, professional practice, and education and how those definitions affect the nature of their activities;
- Exploring the commonalities and differences in approaches to integrating research, professional practice, and education and in defining successful integration; and

- Recommending types of activities that EHR and MPS might undertake, either together or in parallel, that would strengthen the preparation of the next generation of MPS professionals, broaden participation in the MPS disciplines, or create new pathways to MPS careers, either by building on existing programs, expanding them in directions that capitalize on commonalities of approach, or developing new programs that would promote innovative paradigms for the integration of research and education.

The two advisory committees expect preliminary recommendations on new or expanded activities for the directorates at their Spring 2004 meetings.

In the course of this effort, the joint subcommittee may need to look carefully at

- The current state of the undergraduate enterprise in MPS disciplines and how it is changing, with emphasis on integration of research, professional practice, and education;
- NSF activities with impact on undergraduate education and their efficacy in promoting change; and
- Past and current experiments in transcending the EHR/MPS boundaries in carrying out these activities.

The joint subcommittee will report regularly to the parent advisory committees on the status of their response to this charge. The advisory committees and joint subcommittee, in consultation with NSF staff in the two directorates, will determine the best way to convey the results of the review and any recommendations arising from it to the relevant scientific and academic communities.

Composition:

The joint subcommittee will consist of an appropriate number of active members from each advisory committee and any appropriate ad hoc members as determined and appointed by the advisory committee chairs. EHR members will have connections to MPS disciplines, where possible. Chairmanship of the joint subcommittee will alternate between MPS and EHR annually.

Staff:

Staff members from each directorate will work synergistically in support of the work of the subcommittee.

Appendix C: Initial Workplan for the EHR/MPS Joint Subcommittee of the Advisory Committees

Education and Human Resources
Mathematical and Physical Sciences

Joint Subcommittee of the Advisory Committees
on
Undergraduate Education in the
Mathematical and Physical Sciences Disciplines

INITIAL WORK PLAN

The Joint Subcommittee on Undergraduate Education in the Mathematical and Physical Sciences Disciplines is charged with

- Examining the ways their communities think about and describe the activities of research, professional practice, and education and how those definitions affect the nature of their activities;
- Exploring the commonalities and differences in approaches to integrating research, professional practice, and education and in defining successful integration; and
- Recommending types of activities that EHR and MPS might undertake, either together or in parallel, that would strengthen the preparation of the next generation of MPS professionals, broaden participation in the MPS disciplines, or create new pathways to MPS careers, either by building on existing programs, expanding them in directions that capitalize on commonalities of approach, or developing new programs that would promote innovative paradigms for the integration of research and education.

Initial Membership

Jeanne Pemberton, MPSAC (Chair)
Robert Devaney, EHRAC
Robert Hilborn, MPSAC
Yolanda Moses, EHRAC
Claudia Neuhauser, MPSAC
Thomas Taylor, EHRAC

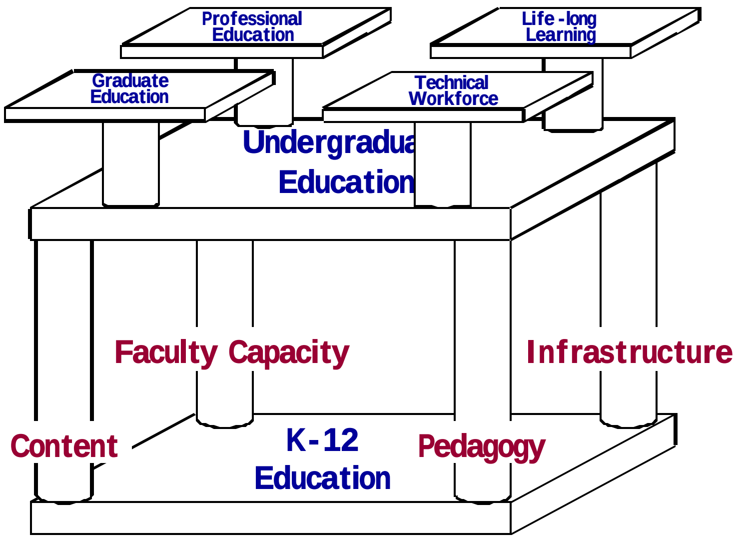
Plan for Responding to the Charge

In carrying out its charge, the joint subcommittee will look carefully at

- The current interplay of research, professional practice, and education in the undergraduate enterprise in MPS disciplines and how it is changing;
- EHR and MPS activities with impact on undergraduate education and their efficacy in promoting integration of research, professional practice, and education; and
- Past and current experiments in transcending the EHR/MPS boundaries in carrying out these activities.

It will use the “Four Pillar” approach developed by its chair, Dr. Pemberton, for discussion with the EHR Advisory Committee as illustrated in the graphic below in addressing these issues.

The Four Pillars of Undergraduate Education in the Mathematical and Physical Sciences



Within each of the categories represented by the four pillars – content, pedagogy, faculty capacity, and infrastructure – the subcommittee members will develop, refine, and respond to a set of key questions that will form the basis for speaking to their charge. The questions will elicit information about how different communities understand research, professional practice, education and their interplay; how those understandings are expressed in the undergraduate experience and in plans to change the experience in MPS disciplines; and the role of the research, education, and professional practitioner communities in the change process. The subcommittee will explore in parallel fashion how MPS and EHR approach their responsibilities for improvement of undergraduate education in MPS disciplines, how these approaches have evolved over time, and how they might be more effective.

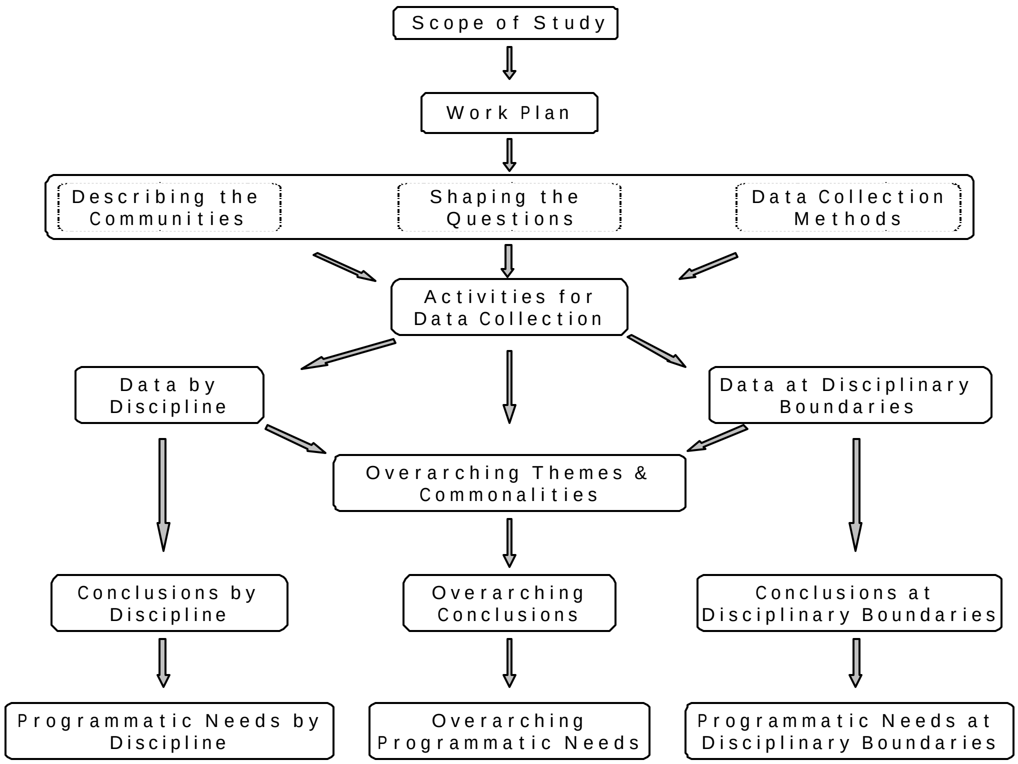
In carrying out its work, the joint subcommittee will focus on elements that

- Reflect the changing nature of science (including emerging interdisciplinary areas) in MPS disciplines in the preparation of MPS professionals;
- Help define the integration of research and education in the preparation of MPS professionals;
- Connect out-of-class research experiences for undergraduates or related opportunities such as internships or community service with academic programs;
- Enhance the research base on learning in MPS disciplines; and
- Increase the capacity for change.

Activity Work Flow

The joint subcommittee held its first meeting in September 2003 to refine its plan of action. It agreed to use the following flow of work.

EHR/MPS Joint Subcommittee on Undergraduate Education in the Mathematical & Physical Sciences Disciplines: Activity Flowchart



Timing

To initiate the phase of describing communities, shaping questions, and determining methods, the joint subcommittee formed three subgroups. The first subgroup consists of members who will focus on the three disciplinary communities – math, chemistry, and physics, developing appropriate sets of contacts and questions. The second will focus on the broad range of improvement efforts in the undergraduate education arena. The third will focus on the intersection of undergraduate education and the community of professional practitioners (e.g., employers).

This stage of activity will take place during October 2003. Following a discussion with the parent advisory committees in November 2003, the joint subcommittee will implement its plan through FY 2004. The current plan is to complete data collection by the end of January 2004. The parent advisory committees expect a report on preliminary findings and recommendations in spring 2004. They will use these preliminary materials to advise the directorates on initiating new or expanding existing cooperative efforts in FY 2005.

The joint subcommittee will complete a draft report for the advisory committees for the November 2004 meetings. Over the following winter, the subcommittee will finalize their product for submission to the advisory committees and the Assistant Directors for EHR and MPS in the spring of 2005.

In the process of implementing its plan, the joint subcommittee will ask for significant input from relevant communities. The relevant divisions within both MPS and EHR, professional societies, employers of

MPS baccalaureates, graduate and professional programs to which MPS baccalaureates might go, and others, including students themselves, will have the opportunity to participate in the effort. To facilitate the actions of the joint subcommittee, MPS will maintain a web site that contains core information on which the activities will draw.

Meta-Level Questions for the Review

In the course of addressing the specifics of its charge, the joint subcommittee may want to explore some of the following questions.

- To what extent does undergraduate MPS education reflect or emphasize the *current body of knowledge* within a discipline? The most recent additions to that body of knowledge?
- To what extent does undergraduate MPS education reflect *"current practice"* and/or employer needs of disciplines?
- To what extent is undergraduate MPS education receptive to *variable and diverse pathways to STEM careers*? To what extent does it facilitate the progress of those who need such pathways?
- What are *essential elements of "highly successful" models* of undergraduate MPS education in the context of integration of research and education.
- What *essential elements* of undergraduate MPS education are not addressed by current NSF activities?
- What are *anticipated essential elements* of undergraduate MPS education that should be addressed by future NSF activities?
- What are *essential elements of "highly successful" joint MPS/EHR activities* in undergraduate MPS education?

Appendix D: Focus Group Questions

Question Set I: Related to Changes in the Disciplines

<u>Level I Disciplinary Questions</u>

Answer this set of questions in the context of

- current and anticipated changes in the frontiers and methods of disciplinary and educational research, and in educational and professional practice, in chemistry, physics, and mathematics
- intersection points of these frontiers and methods with other disciplines (e.g. biology, materials, education, etc.)
- professional pathways for chemistry, physics, and mathematics degree holders
- demographics of
  - o population (and hence, college & university student bodies)
  - o higher education institutional types (e.g. research universities, four-year colleges, two-year colleges, etc.)
- anticipated labor needs

Sublevel A

1. What are the key changes taking place in your discipline today?
2. How do these changes affect the nature of the professional activities of practicing professionals in your discipline?
3. How do professionals in your discipline maintain currency in research, education, and professional practice frontiers and methods both within your discipline and at the boundaries of your discipline?

Sublevel B

4. How do these changes affect the nature of the overall professional activities of faculty at all types of institutions of higher education in your discipline?
5. How do faculty at all types of institutions of higher education maintain currency in research, education, and professional practice frontiers and methods both within your discipline and at the boundaries of your discipline?

<u>Level II Disciplinary Questions</u>

Within the framework of your answers to the Level I questions, answer these questions in the context of undergraduate education in your discipline

1. What are the implications of these changes for preparing the next generation of professionals in your discipline?
2. What changes/enhancements in undergraduate education are needed to address these implications for preparing the next generation of professionals in your discipline?
3. What resources are needed in each of the “four pillar” areas (content, pedagogy, infrastructure, faculty capacity) to implement and sustain these changes/ enhancements?
4. What are the challenges in implementing and sustaining these changes/ enhancements?

5. How do these changes either encourage or discourage broadened participation in your discipline? How do these changes impact the creation of pathways to careers in your discipline?
6. What activities or programs can you suggest for either the Education and Human Resources Directorate or the Mathematical and Physical Sciences Directorate of the National Science Foundation to improve the undergraduate preparation of professionals in chemistry, physics, and/or mathematics?

Question Set II: Related to Undergraduate Reform in Institutions

Level I Institutional Questions

Answer this set of questions in the context of

- undergraduate education reform in academic institutions
- current and anticipated changes in the frontiers and methods of disciplinary and educational research, and in educational and professional practice, in chemistry, physics, and mathematics
- intersection points of these frontiers and methods with other disciplines (e.g. biology, materials, education, etc.)
- professional pathways for chemistry, physics, and mathematics degree holders
- demographics of
    - population (and hence, college & university student bodies)
    - higher education institutional types (e.g. research universities, four-year colleges, two-year colleges, etc.)
- anticipated labor needs

Sublevel A

1. What are the key changes taking place in (your) institution(s) today?
2. How do these changes affect the nature of the educational activities of faculty in chemistry, physics, and mathematics at all types of institutions of higher education?
3. To what extent are faculty involved in initiating or implementing these changes? To what extent are they reactive? Where do they go for advice and guidance?
4. What are the benchmarks for accountability of these changes (e.g. number of majors, increase in graduate school admissions, feedback from employers, etc.)?

Sublevel B

5. How do these changes affect the nature of the overall professional activities of faculty in chemistry, physics, and mathematics at all types of institutions of higher education?
6. How do faculty in chemistry, physics, and mathematics at all types of institutions of higher education maintain currency in research, education, and professional practice frontiers and methods in light of changes in the institutional environment?

Level II Institutional Questions

Within the framework of your answers to the Level I questions, answer these questions in the context of undergraduate education in MPS disciplines.

1. What changes/enhancements in undergraduate education are needed to better prepare the next generation of faculty in chemistry, physics and mathematics?
2. What are the challenges in implementing and sustaining these changes/ enhancements?
3. What changes/enhancements in undergraduate education are needed to broaden participation in chemistry, physics, and mathematics? To create/enhance pathways to careers in these disciplines?
4. What resources are needed in each of the "four pillar" areas (content, pedagogy, infrastructure, faculty capacity) to implement and sustain these changes/ enhancements at the institutional level? Who should provide/develop these changes?
5. What activities or programs can you suggest for either the Education and Human Resources Directorate or the Mathematical and Physical Sciences Directorate of the National Science Foundation to improve the undergraduate preparation of professionals in chemistry, physics, and/or mathematics?

Question Set III: Related to Changes in Demands of the STEM Workforce

Level I Workforce Questions

Answer this set of questions in the context of

- Changes in demands of the STEM workforce
- current and anticipated changes in the frontiers and methods of disciplinary and educational research, and in educational and professional practice, in chemistry, physics, and mathematics
- intersection points of these frontiers and methods with other disciplines (e.g. biology, materials, education, etc.)
- professional pathways for chemistry, physics, and mathematics degree holders
- demographics of
    - population (and hence, college & university student bodies)
    - higher education institutional types (e.g. research universities, four-year colleges, two-year colleges, etc.)
- anticipated labor needs

1. What are the key changes taking place in the workplace today?
2. How do these changes affect the nature of activities undertaken by chemistry, physics, and mathematics professionals?
3. How do these changes in professional practice affect your expectations for new hires in chemistry, physics, and mathematics in subject knowledge, in technical skills, in communication and collaboration skills? How do they affect your expectations for the undergraduate experience of these incoming professionals?
4. How do professionals in chemistry, physics, and mathematics maintain currency in research, education, and professional practice frontiers and methods in light of changes in the workplace environment?
5. How do these changes in professional practice impact broader participation in chemistry, physics or mathematics? How do they impact the creation of pathways to careers in these disciplines?

Level II Workforce Questions

Within the framework of your answers to the Level I questions, answer these questions in the context of undergraduate education in chemistry, physics, and mathematics.

1. What changes/enhancements in undergraduate education are needed to better prepare the next generation of professionals in chemistry, physics, and mathematics?
2. What partnerships do you cultivate to implement and sustain these changes/ enhancements?
3. What are the challenges in implementing and sustaining these changes/ enhancements?
4. What activities or programs can you suggest for either the Education and Human Resources Directorate or the Mathematical and Physical Sciences Directorate of the National Science Foundation to improve the undergraduate preparation of professionals in chemistry, physics, and/or mathematics?

Appendix E: Focus Group Invitees

NAME	INSTITUTION
Mathematics	
Dr. Michael Aschbacher	California Institute of Technology
Dr. Richard Askey	University of Wisconsin
Dr. Thomas Banchoff	Brown University
Dr. William Barker	Bowdoin College
Dr. Peter Bates	Brigham Young University
Dr. Jonathan Bell	University of Maryland – Baltimore County
Dr. Thomas Berger	Colby College
Dr. James Berger	Duke University
Dr. Mary Ellen Bock	Purdue University
Dr. Jerry Bona	University of Illinois – Chicago
Dr. Sylvia Bozeman	Spelman College
Dr. Sadie Bragg	CUNY - Borough of Manhattan Community College
Dr. Ann Brandwein	Baruch College
Dr. David Bressoud	Macalester College
Dr. Felix Broroder	Rutgers University
Dr. Robert Bryant	Duke University
Dr. Carlos Castillo	Cornell University
Dr. Sun Yung Chang	Princeton University
Dr. Fan Chung	University of California – San Diego
Dr. George Cobb	Mt. Holyoke College
Dr. Amy Cohen	Rutgers University
Dr. Michael Crandall	University of California - Santa Barbara
Dr. Peter Duren	University of Michigan
Dr. David Eisenbud	Brandeis University
Dr. Wade Ellis	West Valley College
Dr. Susan Forman	Bronx Community College
Dr. Avner Friedman	Ohio State University
Dr. Ramesh Gangolli	University of Washington
Dr. Andrew Gleason	Harvard University
Dr. Bonnie Gold	Monmouth College
Dr. Carolyn Gordon	Dartmouth University
Dr. Daniel Goroff	Harvard University
Dr. Judith Grabiner	Pitzer College
Dr. Ronald Graham	University of California – San Diego
Dr. Philip Griffiths	Princeton University
Dr. Kenneth Gross	University of Vermont
Dr. Thomas Hales	University of Pittsburgh
Dr. William Haver	Virginia Commonwealth University
Dr. William Hawkins	University of District of Columbia
Dr. Terry Herdman	Virginia Polytechnic Institute and State University
Dr. Aparna Higgins	University of Dayton
Dr. Robert Hogg	University of Iowa
Dr. Frank Hoppensteadt	Arizona State University
Dr. Mary Ann Horn	Vanderbilt University
Dr. Roger Howe	Yale University
Dr. Freeman Hrabowski	University of Maryland – Baltimore County
Dr. Rhonda Hughes	Bryn Mawr College
Dr. Fern Hunt	NIST

Dr. Arthur Jaffe	Harvard University
Dr. Raymond Johnson	University of Maryland
Dr. Iain Johnstone	Stanford University
Dr. Svetlana Katok	Pennsylvania State University
Dr. Barbara Keyfitz	University of Houston
Dr. Nancy Kopell	Boston University
Dr. Irwin Kra	SUNY – Stony Brook
Dr. Steven Krantz	Washington University
Dr. Philip Kutzko	University of Iowa
Dr. Susan Landau	Sun Microsystems
Dr. Eric Lander	Massachusetts Institute of Technology
Dr. Gregory Lawler	Cornell University
Dr. Carl Lee	University of Kentucky
Dr. Joan Leitzel	University of New Hampshire (retired)
Dr. Suzanne Lenhart	University of Tennessee
Dr. Jim Lewis	University of Nebraska
Dr. Roger Lewis	University of Alabama - Birmingham
Dr. Johnny Lott	University of Montana
Dr. David Lutzer	William and Mary University
Dr. Bernie Madison	University of Arkansas
Dr. Daniel Maki	Indiana University
Dr. William McCallum	University of Arizona
Dr. Dusa McDuff	SUNY – Stony Brook
Dr. Robert Megginson	University of Michigan
Dr. James Milgram	Stanford University
Dr. Kenneth Millett	University of California - Santa Barbara
Dr. Richard Millman	Knox College
Dr. Calvin Moore	University of California - Berkeley
Dr. David Moore	Purdue University
Dr. Frank Morgan	Williams College
Dr. John Morgan	Columbia University
Dr. David Morrison	Duke University
Dr. David Mumford	Harvard University
Dr. Deborah Nolan	University of California - Berkeley
Dr. John Osborn	University of Maryland
Dr. Ira Papick	University of Missouri
Dr. Arnold Pizer	University of Rochester
Dr. John Polking	Rice University
Dr. Louise Raphael	Howard University
Dr. Chris Rasmussen	Purdue University - Calumet
Dr. Fred Roberts	Rutgers University
Dr. Ron Rosier	Georgetown University
Dr. Hugo Rossi	University of Utah
Dr. Paul Sally	University of Chicago
Dr. David Sanchez	Texas A&M University
Dr. Peter Sarnak	Princeton University
Dr. Richard Scheaffer	University of Florida
Dr. James Sethian	University of California - Berkeley
Dr. Lance Small	University of California – San Diego
Dr. Donald Small	U.S. Military Academy
Dr. Linda Sons	Northern Illinois University
Dr. Richard Stanley	Massachusetts Institute of Technology
Dr. Michael Starbird	University of Texas - Austin
Dr. Gilbert Strang	Massachusetts Institute of Technology
Dr. Jean Taylor	New York University
Dr. Alan Tucker	SUNY – Stony Brook

Dr. John Tyson	Virginia Polytechnic Institute and State University
Dr. Karen Uhlenbeck	University of Texas – Austin
Dr. William Velez	University of Arizona
Dr. Karen Vogtman	Cornell University
Dr. Russell Walker	Montana State University
Dr. Judy Walker	University of Nebraska
Dr. Fred Wan	University of California - Irvine
Dr. Ginger Warfield	University of Washington
Dr. Ann Watkins	California State University - Northridge
Dr. Carol Wood	Wesleyan University
Dr. Susan Wood	J. Sargent Reynolds Community College
Dr. Margaret Wright	New York University
Dr. Hsuing Wu	University of California - Berkeley
Dr. James Yorke	University of Maryland
Dr. Robert Zimmer	Brown University
Dr. Paul Zorn	St. Olaf College

<u>Chemistry</u>

Dr. Paul Anderson	Bristol-Myers-Squibb
Dr. Robert Angelici	Iowa State University
Dr. Shenda Baker	Harvey Mudd College
Dr. Mark Banszak-Holl	University of Michigan
Dr. Clarita Bhat	Shoreline Community College
Dr. Paul Bohn	University of Illinois - Urbana-Champaign
Dr. John Brauman	Stanford University
Dr. Ronald Breslow	Columbia University
Dr. Diane Bunce	Catholic University of America
Dr. James Burke	Rohm & Haas (retired)
Dr. Daryle Busch	University of Kansas
Dr. Michele Bushey	Trinity University
Dr. Charles Casey	University of Wisconsin - Madison
Dr. Anna Cavinato	Eastern Oregon University
Dr. Orville Chapman	University of California - Los Angeles
Dr. Sibrina Collins	Claflin College
Dr. Graham Cooks	Purdue University
Dr. Melanie Cooper	Clemson University
Dr. Brian Coppola	University of Michigan
Dr. Norman Craig	Oberlin College
Dr. Fleming Crim	University of Wisconsin - Madison
Dr. Michael Doyle	University of Maryland
Dr. Randy Duran	University of Florida
Dr. Luis Echegoyen	Clemson University
Dr. Arthur Ellis	National Science Foundation
Dr. Mostafa El-Sayed	Georgia Institute of Technology
Dr. Leonard Fine	Columbia University
Dr. George Flynn	Columbia University
Dr. Robert Ford	Southern University and A&M College
Dr. Marye Anne Fox	North Carolina State University
Dr. Joseph Francisco	Purdue University
Dr. Larry Friedman	Bayer Corporation
Dr. Jean Futrell	Pacific Northwest National Laboratory
Dr. Cornelia Gillyard	Spelman College
Dr. Joseph Gordon	IBM Almaden Research Division
Dr. David Gosser	City University of New York

Dr. Joseph Grabowski	University of Pittsburgh
Dr. Harry Gray	California Institute of Technology
Dr. Thomas Greenbowe	Iowa State University
Dr. Carlos Gutierrez	California State University - Los Angeles
Dr. John Hall	Morehouse College
Dr. Dudley Herschbach	Harvard University
Dr. Chris Hollinshed	DuPont Company
Dr. Jani Ingram	Northern Arizona University
Dr. Nancy Jackson	Sandia National Laboratory
Dr. Robert Kennedy	University of Michigan
Dr. Lon Knight	Furman University
Dr. John Kozarich	ActivX Biosciences
Dr. Cynthia Larive	University of Kansas
Dr. Moses Lee	Furman University
Dr. Nancy Levinger	Colorado State University
Dr. Eileen Lewis	University of California - Berkeley
Dr. Nathan Lewis	California Institute of Technology
Dr. Carl Lineberger	University of Colorado at Boulder
Dr. George Lisensky	Beloit College
Dr. Gary Long	Virginia Polytechnic Institute and State University
Dr. Tobin Marks	Northwestern University
Dr. George McLendon	Princeton University
Dr. Thomas Meyer	Los Alamos National Laboratory
Dr. Nancy Mills	Trinity University
Dr. Jerry Mohrig	Carleton College
Dr. Richard Moog	Franklin & Marshall College
Dr. John Moore	University of Wisconsin
Dr. Royce Murray	University of North Carolina - Chapel Hill
Dr. Mary Nakhleh	Purdue University
Ms. Cathy Nelson	American Chemical Society
Dr. Larry Overman	University of California - Irvine
Dr. Eli Pearce	Polytechnic University
Dr. Dale Poulter	University of Utah
Dr. Mark Ratner	Northwestern University
Dr. Kenneth Raymond	University of California – Berkeley
Dr. Elsa Reichmanis	Lucent Technologies
Dr. David Reingold	Juniata College
Dr. Geraldine Richmond	University of Oregon
Dr. Jeffrey Roberts	University of Minnesota
Dr. Debra Rolison	Naval Research Laboratory
Dr. Barbara Sawrey	University of California - San Diego
Dr. Steven Schultz	Diné College
Dr. Joel Shulman	University of Cinncinati
Dr. Richard Smalley	Rice University
Dr. James Spencer	Franklin & Marshall College
Dr. Brock Spencer	Beloit College
Dr. Angelica Stacey	University of California - Berkeley
Dr. Peter Stang	University of Utah
Dr. John Stevens	University of North Carolina - Asheville
Dr. Joanne Stewart	Hope College
Dr. Nicholas Turro	Columbia University
Dr. Pratibha Varma-Nelson	Northeastern Illinois University
Dr. Mark Walter	Oakton Community College
Dr. Sylvia Ware	American Chemical Society
Dr. Isiah Warner	Louisiana State University
Dr. Ed Wasserman	DuPont Company

Dr. Gabriela Weaver	Purdue University
Dr. Paul Weiss	Pennsylvania State University
Dr. Thomas Wenzel	Bates College
Dr. Jodi Wesemann	American Chemical Society
Dr. George Whitesides	Harvard University
Dr. Bobby Wilson	Texas Southern University
Dr. John Wright	University of Wisconsin - Madison
Dr. David Yaron	Carnegie Mellon University
Dr. John Yates	University of Pittsburgh
Dr. Ed Yeung	Iowa State University
Dr. Richard Zare	Stanford University
Dr. Theresa Zielinski	Monmouth State University

<u>Physics</u>

Dr. Rama Bansil	Boston University
Dr. Robert Beichner	North Carolina State University
Dr. Truman T. Bell	Exxon Mobil
Dr. Dawn Bonnell	University of Pennsylvania
Dr. Giovanni Bonvicini	Wayne State University
Ms. Marjorie G. Bordeen	Fermi National Accelerator
Ms. Phyllis S. Buchanan	DuPont Company
Dr. Bruce Carney	University of North Carolina – Chapel Hill
Dr. Peggy Cebe	Tufts University
Dr. Wolfgang Christian	Davidson College
Dr. Robert Clark	Brigham Young University
Dr. Dan Clemens	Boston University
Dr. Ruth Chabay	North Carolina State University
Dr. Eugene Commins	University of California - Berkeley
Mr. Isadore T. Davis	Raytheon Corporation
Dr. Leonard Feldman	Vanderbilt University
Dr. Paul Fleury	Yale University
Dr. Anthony French	Massachusetts Institute of Technology
Dr. S. James Gates	University of Maryland
Dr. Sean Gavin	Wayne State University
Dr. Howard Georgi	Harvard University
Dr. John Ginder	APS Committee on Careers & Professional Development
Dr. Susan Ginsberg	American Physical Society
Dr. Gary Gladding	University of Illinois
Dr. Henry Glyde	University of Delaware
Dr. Francis Halzen	University of Wisconsin
Dr. Jack Hehn	American Institute of Physics
Dr. Eric J. Heller	Harvard University
Dr. Kenneth Heller	University of Minnesota
Dr. David O. Hestenes	Arizona State University
Dr. Charles Holbrow	Colgate University
Dr. Ruth Howes	Marquette University
Dr. Christopher Impey	University of Arizona
Dr. John G. King	Massachusetts Institute of Technology
Dr. Bernard V. Khoury	American Association of Physics Teachers
Dr. Priscilla Laws	Dickenson College
Dr. Cathy Mader	Hope College
Dr. John Marko	University of Illinois - Chicago
Dr. Eric Mazur	Harvard University
Dr. Lillian McDermott	University of Washington

Dr. Robert D. McKeown	California Institute of Technology
Dr. Laurie McNeil	University of North Carolina - Chapel Hill
Dr. Jose Mestre	University of Massachusetts
Mr. James A. Mitchell	Casio Inc.
Dr. Alfred Moye	Hewlett Packard
Dr. Philip Nelson	University of Pennsylvania
Dr. John Neumeier	Montana State University
Mr. Roger Nozaki	General Electric Foundation
Dr. Thomas O'kuma	Lee College
Dr. Marjorie Olmstead	University of Washington
Dr. Bruce Partridge	Haverford College
Dr. Helen R. Quinn	Stanford University
Dr. Edward Redish	University of Maryland
Dr. Alex Rimberg	Rice University
Dr. Richard W. Robinett	Pennsylvania State University
Dr. Randal C. Ruchti	University of Notre Dame
Dr. Gregory J. Salamo	University of Arkansas
Dr. Bruce Sherwood	North Carolina State University
Dr. Harry Shipman	University of Delaware
Dr. Timothy Slater	University of Arizona
Dr. Daniel Stinebring	Oberlin College
Dr. Gregory R. Snow	University of Nebraska
Dr. Peter Taborek	University of California - Irvine
Dr. Joseph H. Taylor	Princeton University
Dr. Michael Teitelbaum	The Alfred P. Sloan Foundation
Dr. Robert Thorne	Cornell University
Dr. Barrett Wells	University of Connecticut
Dr. Carl Wieman	University of Colorado
Dr. William J. Willis	Columbia University
Dr. James J. Wynne	IBM Yorktown
Dr. Dean Zollman	Kansas State University

Interdisciplinary		Discipline
Dr. Viola L. Acoff	University of Alabama	Materials
Dr. James B. Adams	Arizona State University	Materials
Ms. Jill H. Andrew	California Institute of Technology	Materials
Dr. Robert P.H. Chang	Northwestern University	Materials
Dr. Jay Dubner	Columbia University	Materials
Dr. Marni Goldman	Stanford University	Materials
Dr. Fiona Goodchild	University of California – Santa Barbara	Materials
Dr. Lee Makowski	Argonne National Laboratory	Materials
Dr. Miriam Rafailovich	SUNY – Stony Brook	Materials
Dr. William A. Sibley	Oklahoma Center for the Advancement of Science & Technology	Materials
Dr. Charles G. Wade	IBM Research Center Almaden	Materials
Dr. Reudi Aebersold	University of Washington	Biology
Dr. James Beach	University of Kansas	Biology
Dr. A. Malcolm Campbell	Davidson College	Biology
Dr. James P. Collins	Arizona State University	Biology
Dr. James M. Gentile	Hope College	Biology
Dr. Raymond E. Goldstein	University of Arizona	Biology
Dr. John Hopfield	Princeton University	Biology

Dr. John Marko	University of Illinois	Biology
Dr. Roger Nisbet	University of California – Santa Barbara	Biology
Dr. Harry Noller	University of California – Santa Cruz	Biology
Dr. Margaret A. Palmer	University of Maryland	Biology
Dr. John Pastor	University of Minnesota	Biology
Dr. Bradley M. Tebo	University of California – San Diego	Biology
Dr. Neal Woodbury	Arizona State University	Biology
Dr. John C. Wooley	University of California – San Diego	Biology

Dr. Jillian F. Banfield	University of California - Berkeley	Environmental
Dr. Karen S. Bartels	Northeastern Illinois University	Environmental
Dr. Laura J. Crossey	University of New Mexico	Environmental
Dr. Benjamin E. Cuker	Hampton University	Environmental
Dr. Donald Dabdub	University of California - Irvine	Environmental
Dr. Pamela A. Eibeck	Northern Arizona University	Environmental
Dr. John M. Hayes	Woods Hole Oceanographic Institute	Environmental
Dr. Kyle D. Hoagland	University of Nebraska Lincoln	Environmental
Dr. Charles E. Kolb	Aerodyne Research	Environmental
Dr. Patricia A. Maurice	University of Notre Dame	Environmental
Dr. Anthony F. Michaels	University of Southern California	Environmental

Professional Organizations

Dr. Mark Cardillo	Camille and Henry Dreyfus Foundation
Dr. Wendy Katkin	SUNY - Stony Brook/Reinvention Center
Dr. Andrea Leskes	Association of American Colleges & Universities
Dr. Jeannne Narum	Project Kaleidoscope

Appendix F: Focus Group Participants

Teleconference Participants

Dr. Michael Crandall	University of California - Santa Barbara	Mathematics
Dr. Carolyn Gordon	Dartmouth University	Mathematics
Dr. Frank Hoppensteadt	Arizona State University	Mathematics
Dr. Roger Howe	Yale University	Mathematics
Dr. Nancy Kopell	Boston University	Mathematics
Dr. Joan Leitzel	University of New Hampshire (retired)	Mathematics
Dr. Johnny Lott	University of Montana	Mathematics
Dr. Louise Raphael	Howard University	Mathematics
Dr. Richard Scheaffer	University of Florida	Mathematics
Dr. Lance Small	University of California – San Diego	Mathematics
Dr. Donald Small	US Military Academy	Mathematics
Dr. Alan Tucker	SUNY – Stony Brook	Mathematics
Dr. William Velez[†]	University of Arizona	Mathematics
Dr. Charles Casey	University of Wisconsin - Madison	Chemistry
Dr. Melanie Cooper	Clemson University	Chemistry
Dr. Fleming Crim	University of Wisconsin - Madison	Chemistry
Dr. Michael Doyle	University of Maryland	Chemistry
Dr. Joseph Gordon	IBM Research Division Almaden	Chemistry
Dr. Cynthia Larive[†]	University of Kansas	Chemistry
Dr. Nancy Mills	Trinity University	Chemistry
Ms. Cathy Nelson	American Chemical Society	Chemistry
Dr. Dale Poulter	University of Utah	Chemistry
Dr. Jeffrey Roberts	University of Minnesota	Chemistry
Dr. Barbara Sawrey	University of California - San Diego	Chemistry
Dr. Joel Shulman	University of Cinncinati	Chemistry
Dr. Brock Spencer	Beloit College	Chemistry
Dr. John Stevens	University of North Carolina - Asheville	Chemistry
Dr. Joanne Stewart	Hope College	Chemistry
Dr. Thomas Wenzel	Bates College	Chemistry
Dr. Richard Zare	Stanford University	Chemistry
Dr. Susan Ginsberg	American Physical Society	Physics
Dr. Jack Hehn	American Institute of Physics	Physics
Dr. Kenneth Heller	University of Minnesota	Physics
Dr. Charles Holbrow	Colgate University	Physics
Dr. Ruth Howes	Marquette University	Physics
Dr. Priscilla Laws	Dickenson College	Physics
Dr. Cathy Mader	Hope College	Physics
Dr. John Marko	University of Illinois - Chicago	Physics
Dr. Laurie McNeil	University of North Carolina - Chapel Hill	Physics
Dr. Jose Mestre	University of Massachusetts	Physics
Dr. Philip Nelson[†]	University of Pennsylvania	Physics
Dr. Bruce Sherwood	North Carolina State University	Physics
Dr. Gregory R. Snow	University of Nebraska	Physics
Dr. Robert Thorne	Cornell University	Physics
Dr. Carl Wieman	University of Colorado	Physics
Dr. Marni Goldman	Stanford University	Materials
Dr. William A. Sibley	Oklahoma Center for the Advancement of Science & Technology	Materials
Dr. James P. Collins	Arizona State University	Biology
Dr. John Pastor[†]	University of Minnesota	Biology

Written Comments Received

Dr. Clarita Bhat	Shoreline Community College	Chemistry
Dr. David Bressoud[†]	Macalester College	Mathematics
Dr. Daryle Busch	University of Kansas	Chemistry
Dr. Amy Cohen	Rutgers University	Mathematics
Dr. Arthur Ellis	National Science Foundation	Chemistry
Dr. Fiona Goodchild	University of California – Santa Barbara	Materials
Dr. Wendy Katkin	SUNY – Stony Brook	Reinvention Center
Dr. Cynthia Larive[†]	University of Kansas	Chemistry
Dr. Royce Murray	University of North Carolina – Chapel Hill	Chemistry
Dr. Philip Nelson[†]	University of Pennsylvania	Physics
Dr. John Pastor[†]	University of Minnesota	Biology
Dr. Helen R. Quinn	Stanford University	Physics
Dr. Linda Sons	Northern Illinois University	Mathematics
Dr. William Velez[†]	University of Arizona	Mathematics

[†] These individuals both participated in the focus group discussions and provided written comments.

Appendix G: Focus Group Matrix

EHRAC/MPSAC Joint Subcommittee on Undergraduate Education

Final Focus Group Matrix – Monday 23 – Feb - 04

9:30 AM - 10:30 AM: Stafford I - 1005.11
JS, HB, JL, JP Status Update; Finalize NSF staff assignments

10:30 AM - 12:00 Noon: Stafford I - 130
JSAC meets with JS, HB, JL, reviews schedule, finalizes methods for conducting group sessions, finalizes JSAC assignments, and resolves questions.

12:00 Noon - 1:00 PM: Neighborhood
Lunch on your own

1:00 PM - 2:30 PM: Stafford I - 130; Stafford I - 220
Focus Groups IM1300; MM1300

2:30 PM - 2:45 PM: Stafford I - 130; Stafford I - 220
Focus Groups IM1300; MM1300 Summarize

3:00 PM - 4:30 PM: Stafford I - 130; Stafford I - 220; Stafford I - 1005.19
Focus Groups CM1500; IM1500, MM1500

4:30 PM - 4:45 PM: Stafford I - 130; Stafford I - 220; Stafford I - 1005.19
Focus Groups CM1500; IM1500, MM1500 Summarize

5:00 PM - 5:30 PM: Stafford I - 1005.19
Short debriefing; Sharing of Monday data

JSAC	NSF
TB: Tom Brady	JS: Judy Sunley
BD: Bob Devaney	JL: Jim Lightbourne
BH: Bob Hilborn	HB: Henry Blount
YM: Yolanda Moses	CK: Carol Korzeniewski
JP: Jeanne Pemberton	CW: Calvin Williams
TT: Tom Taylor	HR: Hal Richtol
RW: Ron Williams	TH: Ted Hodapp
	SH: Susan Hixson
	JD: John Dwyer

1:00 PM - 2:30 PM

Focus Group IM1300
Stafford I - 130
Call: 1-877-410-1072
Leader Code: 425073
Passcode: 246087

Casey, Charles	C
Collins, James	I
Holbrow, Charlie	P
Snow, Greg	P
BH TT YM JP	JSAC
CK TH	NSF

Focus Group MM1300
Stafford I - 220
Call: 1-877-407-5717
Leader Code: 147573
Passcode: 224446

Gordon, Carolyn	M
Hoppensteadt, Frai	M
Howe, Roger	M
Velez, Bill	M
BD TB RW JS	JSAC
CW	NSF

3:00 PM - 4:30 PM

Focus Group CM1500
Stafford I - 130
Call: 1-877-410-1072
Leader Code: 425073
Passcode: 246087

Lewis, Nate	C
Poulter, Dale	C
Roberts, Jeff	C
Zare, Dick	C
TT BH JP	JSAC
HR SH JD	NSF

Focus Group IM1500
Stafford I - 220
Call: 1-877-915-0919
Leader Code: 434715
Passcode: 609209

Goldman, Marni	I
Partridge, Bruce	P
Pastor, John	I
TB JP	JSAC
CK	NSF

Focus Group MM1500
Stafford I - 1005.11
Call: 1-877-407-5717
Leader Code: 147573
Passcode: 224446

Small, Lance	M
BD YM	JSAC
CW JS	NSF

Update: 14-Apr-04

EHRAC/MPSAC Joint Subcommittee on Undergraduate Education
Final Focus Group Matrix – Tuesday 24 – Feb - 04

8:30 AM - 10:00 AM: Stafford I - 130
JSAC meets to debrief Monday, review remaining schedule, adjust assignments, identify needed input on workforce issues and discuss how to obtain

10:30 AM - 12:00 Noon: Stafford I - 130; Stafford I - 220
Focus Groups IT1030; PT1030

12:00 Noon - 12:15 PM: Stafford I - 130; Stafford I - 220
Focus Groups IT1030; PT1030 Summarize

12:15 PM - 1:00 PM: Neighborhood
Lunch on your own

1:00 PM - 2:30 PM: Stafford I - 805
Focus Group IT1300

2:30 PM - 2:45 PM: Stafford I - 805
Focus Group IT1300 Summarizes

2:45 PM - 3:45 PM: Stafford I - 1005.11
Debrief for Tuesday; review progress to date, plan for seven Focus Groups on Wednesday, adjust strategy, tactics, and assignments as appropriate

JSAC	**NSF**
TB: Tom Brady	JS: Judy Sunley
BD: Bob Devaney	JL: Jim Lightbourne
BH: Bob Hilborn	HB: Henry Blount
YM: Yolanda Moses	CK: Carol Korzeniewski
JP: Jeanne Pemberton	RT: Rich Taber
TT: Tom Taylor	TH: Ted Hodapp
RW: Ron Williams	JD: John Dwyer
	CD: Connie Della-Piana

10:30 AM - 12:00 Noon

Focus Group IT1030
Stafford I - 130
Call: 1-877-410-1072
Leader Code: 425073
Passcode: 246087

Crim, Fleming	C
Kopell, Nancy	M
Nelson, Cathy	C
Shulman, Joel	C
TT TB RW JP	JSAC
RT JD JL	NSF

Focus Group PT1030
Stafford I - 220
Call: 1-877-407-5717
Leader Code: 147573
Passcode: 224446

Ginsberg, Susan	P
Hehn, Jack	P
Mader, Cathy	P
Nelson, Philip	P
Stewart, Joanne	C
BH YM	JSAC
TH CD CK HB	NSF

1:00 PM - 2:30 PM

Focus Group IT1300
Stafford I - 805.11
Call: 1-877-407-5717
Leader Code: 147573
Passcode: 224446

Gordon, Joe	C
Marko, John	P
Sibley, Bill	I
Wenzel, Tom	C
TB YM BH TT JP	JSAC
CK RT	NSF

Update: 14-Apr-04

EHRAC/MPSAC Joint Subcommittee on Undergraduate Education

Final Focus Group Matrix – Wednesday 25 – Feb - 04

8:30 AM - 10:00 AM: Stafford II - 585; Stafford II - 565
Focus Groups CW0830; MW0830

10:00 AM - 10:15 AM: Stafford II - 585; Stafford II - 565
Focus Groups CW0830; MW0830 Summarize

10:30 AM - 12:00 Noon: Stafford II - 565; Stafford II - 585
Focus Groups MW1030; PW1030

12:00 Noon - 12:15 PM: Stafford II - 565; Stafford II - 585
Focus Groups MW1030; PW1030 Summarize

12:15 PM - 1:00 PM: Neighborhood
Lunch on your own

1:00 PM - 2:30 PM: Stafford I-130; Stafford I-220; Stafford I-1005.19
Focus Groups CW1300; MW1300; PW1300

2:30 PM - 2:45 PM: Stafford I-130; Stafford I-220; Stafford I-1005.19
Focus Groups CW1300; MW1300; PW1300 Summarize

3:00 PM - 4:00 PM: Stafford I - 1005.19
Final Debriefing and Planning

JSAC	NSF
TB: Tom Brady	JS: Judy Sunley
BD: Bob Devaney	JL: Jim Lightbourne
BH: Bob Hilborn	HB: Henry Blount
YM: Yolanda Moses	CK: Carol Korzeniewski
JP: Jeanne Pemberton	ED: Elizabeth Dorland
TT: Tom Taylor	DM: Duncan McBride
RW: Ron Williams	LZ: Lee Zia
	JD: John Dwyer
	CD: Connie Della-Piana
	SH: Susan Hixson
	JJ: Joe Jenkins

8:30 AM - 10:00 AM

Focus Group CW0830
Stafford II - 585
Call: 1-877-915-0919
Leader Code: 434715
Passcode: 609209

Cooper, Melanie	C
Doyle, Mike	C
Larive, Cindy	C
TB JP	JSAC
ED JD CD	NSF

Focus Group MW0830
Stafford II - 565
Call: 1-877-407-5717
Leader Code: 147573
Passcode: 224446

Leitzel, Joan	M
Schaeffer, Richard	M
Small, Don	M
BD BH	JSAC
CK LZ JJ	NSF

10:30 AM - 12:00 Noon

Focus Group MW1030
Stafford II - 565
Call: 1-877-407-5717
Leader Code: 147573
Passcode: 224446

Crandall, Michael	M
Tucker, Alan	M
BD JP	JSAC
LZ CK JJ	NSF

Focus Group PW1030
Stafford II - 585
Call: 1-877-410-1072
Leader Code: 425073
Passcode: 246087

Heller, Ken	P
Howes, Ruth	P
McNeil, Laurie	P
Thorne, Robert	P
Wieman, Carl	P
BH TB	JSAC
JL DM	NSF

1:00 PM - 2:30 PM

Focus Group CW1300
Stafford I - 130
Call: 1-877-915-0919
Leader Code: 434715
Passcode: 609209

Mills, Nancy	C
Sawrey, Barbara	C
Spencer, Brock	C
Stevens, John	C
TB YM JP	JSAC
CK ED SH	NSF

Focus Group MW1300
Stafford I - 220
Call: 1-877-407-5717
Leader Code: 147573
Passcode: 224446

Lott, Johnny	M
Raphael, Louise	M
BD	JSAC
LZ	NSF

Focus Group PW1300
Stafford I - 1005.19
Call: 1-877-410-1072
Leader Code: 425073
Passcode: 246087

Laws, Priscilla	P
Mestre, Jose	P
Sherwood, Bruce	P
BH JS	JSAC
DM	NSF

Update: 14-Apr-04