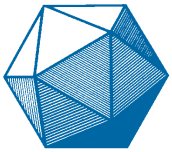
The Report of the
AMS, ASA, MAA and SIAM
Workshop on

Vertical Integration of Research and Education in the Mathematical Sciences

May 3–4, 2002

Hyatt Regency Reston Hotel,
Reston, Virginia



www.MAA.ORG

Contents

Preface

On May 3–4, 2002 a Workshop on the NSF's Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE) Program was held in Reston, Virginia. There were over 135 registered participants, including Phillipe Tondeur, the Director of the Mathematical Sciences Division of the NSF, and NSF's VIGRE Management Team. The organizations sponsoring the workshop were the American Mathematical Society (AMS), the American Statistical Association (ASA), the Mathematical Association of America (MAA), and the Society for Industrial and Applied Mathematics (SIAM). The workshop was funded by a grant from the National Science Foundation to the MAA, Grant Number DMS-0216549.

The goal of the workshop was to bring together representatives of mathematical sciences departments which currently hold NSF VIGRE Grants and those who are considering applying for a VIGRE Grant, and representatives of NSF's Division of Mathematical Sciences, to share information on the successes and challenges of the VIGRE Initiative and plans for the future. The first VIGRE programs began in 1999 and so the initial programs have now completed their third year. More than thirty departments currently hold grants and each of those departments was represented at this Workshop.

The program was designed to inform participants about existing VIGRE programs and to inform the VIGRE Management Team about the views of VIGRE that are held by mathematical scientists.

The program consisted of an overview of VIGRE by the VIGRE Management Team at NSF, sessions on exemplary practices in VIGRE programs, breakout sessions for discussion of the various components of VIGRE programs, experiences of VIGRE-supported postdocs, and a session on how VIGRE is perceived by the mathematical sciences community. There are reports in this document on all these parts of the program.

In addition there were special sessions not directly dealing with VIGRE but that were thought to be of interest to our community: Chris Golde of the Carnegie Foundation for the Advancement of Teaching on the Foundations Initiative on the Doctorate, Kathleen Bergin of the Education and Human Resources Directorate of NSF on the Mathematical and Sciences Partnerships Program, and Richard Proto, former chief of Research at the National Security Agency, and Douglas Arnold, Director of the Institute for Mathematics and its Applications at the University of Minnesota, on non-academic career opportunities for mathematical scientists. (The slides from Doug Arnold's presentation are available at `http://www.ima.umn.edu/~arnold/talks/industry.pdf`.)

The primary purposes of the Workshop were community building and dissemination. We think this workshop was successful in this regard and has laid a foundation for future workshops.

The website `http://www.math.psu.edu/VIGRE/` contains a list of Universities with VIGRE grants and links to their websites.

We wish to express our gratitude to Jim Maxwell of the AMS for his tremendous support and skill in organizing the workshop and in bringing these proceedings together.

Richard A. Brualdi
University of Wisconsin, Madison

Robert Greene
University of California, Los Angeles

Gary L. Mullen
Pennsylvania State University

Overview of the National Science Foundation Program Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE)

Henry Warchall

The Problem

Data on demographics in the mathematical sciences reveal worrisome trends. Between 1993 and 1999, the number of full-time U.S. graduate students in the mathematical sciences decreased by 27%. During the same time period, the number of junior and senior mathematics majors in the United States decreased by 23%. The percentage of recipients of doctoral degrees in the mathematical sciences who are U.S. citizens declined from over 70% in 1980 to under 50% in 2000.

Assessments

Several assessments of these phenomena were made:

- Report of the Senior Assessment Panel of the International Assessment of the U.S. Mathematical Sciences, March 1998. Chaired by Lieutenant General William E. Odom, former head of National Security Agency. (`http://www.nsf.gov/pubsys/ods/getpub.cfm?nsf9895`)

  "Based on present trends, it is unlikely that the U.S. will be able to maintain its world leadership in the mathematical sciences."

- Experiments in International Benchmarking of U.S. Research Fields, April 2000. National Research Council Committee on Science, Engineering, and Public Policy. (`http://www.nap.edu/books/0309068983/html/`)

  " ... the United States must cultivate its own mathematical talent to retain its leading stature in mathematical research."

- "FIVE QUESTIONS for GORDON E. MOORE; Technology Intensifies the Law of Change." Interview by Matt Richtel. New York Times, Money and Business/Financial Desk, Sunday, May 27, 2001. Late Edition - Final, Section 3, Page 4, Column 2. (`http://query.nytimes.com/search/abstract?res=F60B15FC34590C748EDDAC0894D9404482`)

  "We are in danger of exporting a lot of technological advantage because we are not training enough people here. Education, that's our Achilles' heel." – Gordon E. Moore (Intel Corporation founder)

- Road Map for National Security: Imperative for Change. The Phase III Report of the U.S. Commission on National Security/21st Century (Hart-Rudman National Security Report), February 15, 2001. (`http://www.nssg.gov/PhaseIIIFR.pdf`)

  "The harsh fact is that the U.S. need for the highest quality human capital in science, mathematics, and engineering is not being met... The nation is on the verge of a downward spiral in which current shortages will beget even more acute future shortages of high-quality professionals and competent teachers." "If the United States does not stop and reverse negative educational trends - the general teacher shortage, and the downward spiral in science and math education and performance - it will be unable to maintain its position of global leadership over the next quarter century."

Recommendations

Recommendations were formulated by the Senior Assessment Panel of the International Assessment of the U.S. Mathematical Sciences, which suggested that U.S. institutions of higher education:

- Broaden graduate and undergraduate education in the mathematical sciences by exposure to connections with other fields.
- Provide support for full-time graduate students at levels comparable with other sciences.
- Provide increased post-doctoral research opportunities.
- Encourage and foster interactions between university-based mathematical scientists and users of mathematics and statistics in industry, government, and other disciplines.
- Maintain and enhance the historical strength of the mathematical sciences in its academic setting as an intellectual endeavor and as a foundation for applications, sustaining the U.S. position and responsibility of world leadership.

NSF Response

In response to these observations and recommendations, the National Science Foundation Division of Mathematical Sciences (DMS) designed the program in Vertical Integration of Research and Education in the Mathematical Sciences (VIGRE). The objective of the VIGRE program is to significantly increase the number of well-prepared U.S. citizens, nationals, and permanent residents who pursue careers in the mathematical sciences. To accomplish this, VIGRE has the immediate goals of making the study of mathematical sciences more attractive for undergraduate and graduate students, and of making undergraduate, graduate, and postdoctoral training more effective and broadly applicable.

The first VIGRE awards were made in Spring 1999, and by Fall 1999 there were 11 operational VIGRE sites. In Fall 2000, 15 new sites were added; in Fall 2001, 5 new sites; and in Fall 2002, 4 new sites. The total investment in VIGRE in these 35 sites through 2002 will be approximately $64 million. Reports from VIGRE projects indicate:

- Dramatic increases in participation in Research Experiences for Undergraduates;

- Nationwide significant increases in numbers of mathematics majors;
- Increase in the number of undergraduates continuing to study mathematics; and
- Higher quality of educational experiences for U.S. graduate students.

To achieve its goals, the VIGRE program supports the three strategies of

- Enhancing undergraduate education through research experiences;
- Broadening graduate experience through research opportunities and multifaceted collaborations; and
- Enhancing postdoctoral experiences and opportunities.

Thus, VIGRE provides funds to Ph.D.-granting Departments in the mathematical sciences for undergraduate research stipends, graduate research traineeships, and increased post-doctoral research opportunities.

Institutions receiving VIGRE funds are required to carry out educational activities that result in:

(1) Integration of research with education at all levels;
(2) Enhanced interaction among students, postdoctoral fellows, and faculty members;
(3) Broadened educational experiences;
(4) Close mentoring of students and postdoctoral fellows; and
(5) Improvement of communication skills and teaching skills of students and postdoctoral fellows.

Many answers to questions about the VIGRE program are implicit in the observation that VIGRE activities are centered on the educational experiences of students and postdoctoral researchers. The following amplifications of the VIGRE activity requirements are not intended to be prescriptive or exhaustive.

VIGRE Requirements

Integration of Research with Education. It is believed that students should take a more active role in mathematics studies than has been traditional, and that effective education includes research activity. At the undergraduate level, Research Experiences for Undergraduates are meant to introduce students to the excitement of discovery. For DMS purposes, it is not a prerequisite for success that REU activity result in a published product. At the graduate level, early involvement in research activity fulfills students' desire to participate in new discoveries and provides students with strong motivation to fill gaps in their educational background through coursework and independent study. To be effective, such early involvement in research requires close guidance from faculty members. At the postdoctoral level, integration of research with education connotes the preparation of postdoctoral associates to take on and balance the entire spectrum of faculty duties.

Enhanced Interaction. The requirement that VIGRE activities result in enhanced interaction among students, postdoctoral fellows, and faculty members stems in part from the need of the more junior members of the community to observe and to emulate the activities of the more senior members, and for the more senior members to receive detailed and timely feedback on the effectiveness of educational activities.

Among activities that promote such enhanced interaction are:

- Research groups structured to include faculty, postdoctoral researchers, and graduate students, perhaps with selected undergraduates included.
- Postdoctoral fellows involved in team teaching with senior faculty and in mentoring graduate students and undergraduates.
- Graduate students involved in running seminars, in advising undergraduates, and in orientation programs for neophyte graduate students.
- Undergraduate students participating in research teams and acting as peer tutors for other undergraduates.

Mentoring. It is believed that students and postdoctoral fellows need close guidance in order to be efficient and effective scholars. For the purposes of the VIGRE program, the activity of mentoring includes providing guidance and feedback in such diverse areas as:

- teaching,
- applying to graduate school,
- preparing for qualifying exams,
- choosing a field of study and a graduate advisor,
- choosing research problems and pursuing the chosen research area,
- writing a dissertation,
- writing papers,
- writing proposals,
- preparing presentations for various venues,
- applying for postdoctoral positions, and
- seeking employment.

It is not suggested that students be coddled, but rather that successful VIGRE sites provide more than a "sink-or-swim" environment for their trainees.

Broadening of Education. The success of the mathematical sciences is dependent on their role as enabling disciplines, and their claim on public support is tied to this role. The VIGRE requirement for broadened educational experiences stems from the observation that narrowly trained mathematical scientists are neither competitive in the job market nor compelling as potential recipients of public funds. Among activities that can serve to broaden education are:

- Broadened formal programs of study;
- Interdisciplinary courses, and science courses in particular;
- Industry and laboratory internships; and
- Instruction in areas relating to career opportunities that are available to mathematical scientists.

As an illustration, consider two hypothetical resumes:

Curriculum Vitae #1

Courses:

- Theory of A (homework & exams)
- B Theory (homework & exams)
- C Theory & Applications (homework & exams)
- University Breadth Requirement (reading & exams)

Summer job: Fast food restaurant cook

Curriculum Vitae #2

Courses:

- Theory of A (homework & exams)
- Senior thesis / term project in B Theory
- Team research internship: Application of C Theory to Solve Important Industry Problem
- Minor in favorite Science Discipline (including laboratory courses)

Summer job: Statistical Analysis for local firm

Offering programs of study to facilitate, and guiding students toward, achievements similar to (2) rather than (1) is essential in VIGRE projects.

Improving Communication Skills. Effective communication is part of the job for professional mathematical scientists. Communication skills that are specific to the mathematical sciences can be improved by providing students and postdocs practice and feedback in, for example:

- presenting technical and non-technical material to various audiences;
- writing papers, resumes, grant proposals, referee reports, etc.; and
- teaching effectively.

Additional Considerations

The VIGRE program solicitation addresses additional considerations for VIGRE projects. Two important considerations are:

Recruitment and Retention of Students and Postdoctoral Associates. Increasing the number of U.S. citizens pursuing mathematical sciences careers requires thoughtful attention to getting potential students interested and keeping students engaged.

Among activities that can be aid in effective recruiting are:

- Sponsored campus visits for targeted students;
- Building partnerships with 4-year colleges; and
- Attention to under-represented demographic groups as sources of potential students.

Factors playing a role in retention of talented students and postdoctoral fellows include:

- "Bridge" courses for entering students who are talented but under-prepared in subject knowledge;
- Facilities available to students and postdocs (common room / lounge, group-study / conference areas, productive office space, telephones, computers, software);
- Student travel money;
- Departmental camaraderie, social affairs, food;
- Organized peer groups (Math Club, study groups, etc.).

Administrative Issues. Well-planned projects negotiate administrative issues (teaching release support, support for stipends after VIGRE funding ends, etc.) with upper levels of University administration before submission of the initial VIGRE proposal.

Mentoring Students and Postdocs

Richard Hain

One way to summarize the VIGRE program in one sentence is to say that its goal is to improve the training of mathematicians at all levels — graduate, undergraduate and postdoc. This entails improving retention, attracting underrepresented minorities to mathematics and helping them succeed, and also creating interest and opportunities in mathematics (increasing the number and quality of math majors etc.). VIGRE seeks effective new ideas for achieving these goals. Mentoring is a basic tool in these endeavours.

The following thoughts on mentoring are based on experiences in the Mathematics Department at Duke University.

Issues in mentoring. Since we are trying to improve the training of mathematicians in general, I suggest that, in as much as is possible, *all* students and postdocs be mentored in the same way — regardless of citizenship or involvement in other aspects of the VIGRE program. Doing this should help ensure the durability of the benefits of VIGRE. Of course, VIGRE funds can only be used to support citizens and residents of the US. Mentoring is also a valuable tool for all departments, not just those with VIGRE support.

Mentoring Undergraduates. Undergraduate research provides an ideal vehicle for mentoring, as well as an effective way of getting students interested in continuing their mathematical studies. Participating in a research project is a great way for undergraduates to learn to think creatively, and to write up and talk about their results. In order to be successful, this requires mentoring.

Supervising undergraduate research projects is an excellent way for postdocs to gain experience supervising research students. It is natural (and a good idea) for the postdoc to be mentored in this endeavour by a faculty mentor.

Undergraduates will take away much more from mentored research projects than just the mathematical skills they have developed during the project. Undergraduates are often unaware of opportunities in mathematics (and other sciences). They are often unaware that graduate students in mathematics are paid to study and teach. And they are frequently unaware of emerging areas, such as mathematical biology, in which there is likely to be considerable employment opportunities, both in and outside academia. Mentors can bring such opportunities to their attention.

At Duke, we try to recruit undergraduates into our REU program at the beginning of the junior year. The mentor can then direct students towards courses which will help provide background before the actual research is undertaken in the

summer between the junior and senior years. During the senior year, students typically continue their projects through reading courses and finish with a paper or senior thesis. Undergraduates involved in research projects give talks to each other at various stages of their research. The quality of presentations typically improves considerably over the course of the project.

Mentoring Graduate Students. Here it is a good idea to keep our goals in mind — decreasing time to degree, improving retention rates, broadening the education (and the opportunities) for graduate students, improving teaching and communication skills, including writing.[1] Many of these roles have traditionally been, and continue to be, filled by the thesis advisor. However, many places, including Duke, are finding it very useful to assign mentors to incoming students, whose role is to mentor students until they have a thesis advisor. They can help guide the student through the standard oral or written exam, and help the student think about possible areas of study and with the process of finding an advisor. They can also aid with the improvement of communication skills, oral and written by having the student present solutions to sample exam questions.

In addition, there are opportunities for group mentoring. For example, some funding agencies (such as the NIH) now require that graduate students and postdocs in departments that receive their funding be given ethics training. I will elaborate on this in the section on group mentoring below.

Mentoring Postdocs. In a broad sense, the mentoring of postdocs is to prepare them to be more effective faculty members, if they are headed to academia, or to guide them towards the kind of interdisciplinary research experiences valuable for those who intend to work in industry or government labs. Postdocs should be encouraged to show initiative in their research, teaching and service. Specific thoughts on mentoring postdocs include:

- Postdocs are in transition between being graduate students and full-fledged faculty members (or researchers in an industry or national lab). Some postdocs may need help in balancing their research and teaching responsibilities, especially early in their tenure as a postdoc.
- Postdocs often need help orienting their research programs. Intellectual growth in the first job is often important in obtaining a tenure track job. Mentors can help postdocs find new research problems and directions (such as interdisciplinary ones). They can also help students who want to work in industry gain valuable group research experiences by connecting them to researchers in other departments.
- Creative innovations in teaching can also help a postdoc obtain a tenure track job, as well as improve and broaden the training of undergraduates. It is a good idea to give postdocs the opportunity to teach courses where they can experiment a little. For example, postdocs who teach undergraduate algebra can introduce cryptography into the course, and computationally minded postdocs can help develop courses with a significant computational component. Mentors can help by nudging their postdoc to do this, and by being a sounding board for ideas. On the more mundane level, mentors can help postdocs when they have trouble in the classroom.

[1] Halmos' articles *How to write mathematics*, L'Enseignement Math. 16 (1970), 123–152, and *How to Talk Mathematics*, Notices of the Amer. Math. Soc., 21 (1974), are great aids.

- It is desirable that postdocs do some service. This should not be onerous. Some examples of how postdocs can contribute include running seminars, supervising undergraduate research, curriculum development, and outreach. Some of these can be done during the summer. Mentors can help postdocs find suitable ways to contribute by bringing various opportunities to their postdocs' attention and encouraging creativity.
- In Duke's VIGRE program, VIGRE postdocs are expected to contribute to the VIGRE program. There are many ways for them to do this, such as by supervising undergraduate research projects, helping high school teachers develop teaching materials, running seminars, running summer programs, but there is great flexibility in what the postdoc does.
- Obtaining a research grant also helps a postdoc establish a career. Mentors can help postdocs understand the grant writing process, especially what reviewers are looking for. This can be handled through a grant writing workshop for postdocs. Duke's model is described briefly below.

Group Mentoring. Some mentoring can also be done in groups. Here are two examples:

Duke's Ethics Workshop for Third Year Graduate Students. Since the Duke Mathematics Department receives NIH funds, we are required by the university to run an ethics workshop for all third year graduate students. These workshops are Duke's response to the concerns (or mandates) of the NIH and other funding agencies that students funded by them, or programs supported by them, receive training in the ethics of research practice.

The half-day workshop *Responsible Conduct in Research and Teaching* is run jointly with the Physics Department. It is a follow-up to a one-day workshop for all new graduate students in the sciences, mathematics, engineering, and some other departments, which is organized by the university.

There were two guest speakers. The first discussed plagiarism, emphasizing that plagiarism has a broad scope, while the second made a presentation on academic dishonesty among undergraduate students and how one can respond to it. There was a break-out session to consider case studies.

Grant Writing Workshop. Early last fall the Duke Mathematics Department ran a grant writing workshop for postdocs and other interested parties. (Some final year graduate students and junior faculty also participated.) It focused on submissions to the NSF, although making submissions to other funding agencies was also discussed.

There were two sessions, separated by one week. The first session consisted of several presentations followed by a panel discussion. The presentations covered topics such as: what grants pay for (and what they don't); funding agencies; how to apply; the structure of a proposal; budgets; the process; deadlines; where to get information. The panel, which consisted of four experienced reviewers, discussed the reviewing process and attempted to give some idea of what reviewers are looking for. Between the two sessions, participants prepared a draft proposal in consultation with their mentors. During the second session, the participants were divided into "review panels," each containing at least one experienced reviewer. The groups then collectively discussed all of the proposals in their area and gave constructive feedback.

Department of Mathematics, Duke University

Broadening in VIGRE

J.D. Meiss

Broadening the education of students in the mathematical sciences is one of the goals of the NSF-sponsored VIGRE program. In this note (based on my presentation at the May 2002 VIGRE meeting in Reston), I will outline some of the methods and strategies we have been using to accomplish this goal in Applied Mathematics at CU Boulder. The VIGRE effort in Boulder has been running for three years. Our department is relatively small (13 faculty, 15 postdocs, 67 majors and 60 graduate students), and consequently focused on a few selected areas of applied mathematics.

Our VIGRE program is organized around *tetrahedral* research groups. These are focused groups that involve each of the elements of the VIGRE grant—faculty, postdoctoral fellows, graduate and undergraduates (the vertices), who interact (the edges) and collaborate (the faces) both on research and educational activities. Under VIGRE, we support four tetrahedral groups in concentration areas of our department: nonlinear waves, dynamical systems, multigrid computation, and fast algorithms. Each VIGRE group fosters collaborative research, runs a seminar series that encourages interaction and discussion at multiple levels, and is involved in education both through multiple mentoring interactions (more about this below) and dissemination of research ideas into projects in our courses. The tetrahedral model has been so successful that it is spreading to the other areas of concentration of our faculty (statistics and applied analysis).

There are a number of ways in which we give our students experiences beyond those traditional to a mathematics education. Each undergraduate is essentially required to have a minor in an area with significant mathematical applications. Since our undergraduate major is in the College of Engineering this is often an engineering field, but it can also be in areas such as biology or finance. Similarly, each graduate student must complete a yearlong sequence of courses at the graduate level in some area of application. In many cases, this has led to graduate students doing research with an advisor in an outside department. To facilitate this, Applied Math has a list of nearly forty affiliated faculty who may lead a PhD thesis in areas ranging from Atmospheric and Oceanic Sciences to Business to Physics. We have repeatedly found that some faculty in technical areas use much more mathematics in their research than the students in their disciplines understand. Thus, these faculty are appreciative of mathematically sophisticated students and are delighted with the students we provide.

Under VIGRE, the Department has been emphasizing communications skills for our students at all levels—thus increasing their breadth of experience and skills. For

example our sophomore classes now require a series of projects that demand group interaction, often involve modeling or experimentation, and lead to well-constructed written reports. Many of our upper-division courses have a final project in which students apply what they have learned in the class and present their results orally, on paper, or both. Moreover, during the tetrahedral seminars students often give presentations on their research, and are encouraged to do so even at preliminary stages where discussion can help with the formulation of ideas and directions.

Computational skills are also an important component of what we do in the Department. Many of the projects in our lower division courses use computational tools (such as the Math Visualization toolkit that our JAVA initiative, discussed below, is developing).

Our newly developed modeling course, now offered both to advanced undergraduates and beginning graduates, is also focused around applying computational tools to physical problems.

By far the most visible short-term result of our VIGRE program has been the life-changing experiences for our undergraduates caused by the development of research skills . We have supported nearly thirty undergraduate projects in the first three years of VIGRE. The canonical model is for an undergraduate to begin a project with a tetrahedral group during the summer following the Junior year. This continues during the final year, leading to a capstone report along the lines of a senior honors thesis. In practice, we have supported students as early as their sophomore year, and some students have continued on projects for up to two years. Students are typically recruited for these projects from upper-division courses—which are taught either by our regular faculty or our postdoctoral fellows.

What is especially remarkable is that many of the undergraduate students that we supported did not even consider graduate school as an available or desirable option prior to their VIGRE experience. For example, one student said, "My old career plan led to sitting in a cubical as a programmer." After their research experience many now see things differently: "Now I see graduate school leading to a research career;" "I always thought I'd be a civil engineer, but suddenly I find myself getting a BS/MS in applied math and see a PhD as a possibility." Furthermore, engaging in the research process is a revelation to many students: "Working under the VIGRE grant taught me many valuable skills and changed my life plans. I now have an understanding of the methodologies used to undertake research in mathematics and I have learned a great deal about the preparation of articles for peer review." The abandonment of textbook exercises is also a fundamentally new experience for these students: "Incredibly, there is no book with the answers in the back."

The undergraduate program is centered around the development of successful projects and effective mentor/student relationships. We have found that a number of our VIGRE graduates and postdoctoral fellows are pleased to be involved in these activities, and find them useful in developing their skills as future advisors. Undergraduate research has led to publications in a number of cases, and has been helpful on the job market: "My experience as a mentor definitely helped get my tenure-track job." In some cases, graduate students have served as mentors on projects that are simpler versions of their PhD projects.

A manifestation of the verticality of our program is that some of the undergraduates have also become teaching assistants for our calculus courses. This

experience—certainly expanded beyond that of traditional undergraduate education—leads directly to improved chances for acceptance in a graduate program as well as giving the students the experience to be more effective in their first graduate school teaching assignment. Moreover, as one of our students said, "it is an eye-opening experience to have students sling questions at you right and left." As teachers who have to enlighten while trying to be entertaining, it can be heartwarming to have a student realize that "I now know how hard it is to convey mathematics well."

Internships form another broadening activity for all of our students. Boulder is fortunate to have a number of national laboratories (such as NCAR, NOAA, and NIST) and high technology companies (such as Sun, HP, and IBM) in the neighborhood. We have also fostered relationships with other laboratories (such as LLNL, LANL and Sandia) and other local companies. Over thirty of our students (graduate and undergraduate) have had internships—typically for a summer—at one of these institutions in the past three years. For graduate students this may be an interlude where their PhD project is put on hold, or it may inspire the development of a research area, or it can even lead to a thesis project itself. In some cases it has lead to a post-degree position.

Other breadth-related activities of our Department that are fostered by the support of the NSF-VIGRE program include the development of a 5 year BS/MS program, the creation of a joint MS degree with the Molecular, Cellular and Developmental Biology department, and the onset of a new MS/PhD Program that we call Computational Science and Engineering. In this latter program, a student will be simultaneously accepted into our Master's program and the PhD program in another department (departments that have signed on to this include Physics, Astrophysics, Aerospace Engineering; and Atmospheric and Oceanic Sciences). Finally we have developed a collaboration with Sun Microsystems to teach the JAVA programming language. To facilitate this a number of our students and postdocs have been trained by SUN and have become certified JAVA instructors. They now teach two JAVA courses for the Department.

It is natural for a department of applied mathematics to engage in some of these broadening activities; however, there are many ways in which we all can enhance the educational experience for our students and postdoctoral fellows. These activities, whether they include increased experiences in mentoring or the development of skills that are not directly related to a thesis, can lead to enhanced job opportunities for our students, as well as make them more effective colleagues. As such, even if they require extra effort, or a semester of extra time along the pathway to the PhD, they should be counted as well worthwhile.

Department of Applied Mathematics, University of Colorado at Boulder

Recruiting and Retention: Training Problem Solvers

Sastry G. Pantula

Recruiting

It is critical that we spend a considerable amount of time in recruiting outstanding undergraduate, graduate and postdoctoral students to the VIGRE program. Our faculty, staff, students and alumni enthusiastically participate in the recruiting process.

Our Director of Undergraduate Programs, Dr. William Swallow, spends a lot of time and energy in recruiting qualified undergraduate students. He visits several high schools and continues to be in touch with AP-Statistics and Mathematics instructors. He also spends time with the parents of prospective students educating them of the benefits of a statistics degree. He works also on transfer students from other programs on campus. He writes to the qualified students on campus encouraging them to enter an honors class that he teaches. The folklore is that the students can enter his office/class, but do not come out of the office/class without being excited about transferring to our undergraduate program in statistics. He sells the benefits of our VIGRE program and that of our accelerated BS/MS program. VIGRE trainees are selected from the pool of junior students. He gets them involved with research, especially through our environmental statistics practicum, statistical genetics journal club and the research workgroups. A good description of the environmental research our students are involved in can be found in a recent article in the May 2002 issue of the Amstat News.

Recruiting for graduate students is done from various sources. We do recruit some of our best undergraduate students through VIGRE traineeships and the accelerated BS/MS program. We also bring in undergraduate students for a summer research experience and encourage these summer trainees to consider graduate schools. We visit some undergraduate math programs and discuss the benefits of our graduate programs and the VIGRE traineeships. We make presentations about our research workgroups, VIGRE funding which also provides additional time to pursue research goals, our Preparing for the Professoriate Program and the industrial traineeship opportunities. Campus visits are critical to see VIGRE groups "in action." We have been participating in MathFest and MiniStatFest to especially recruit underrepresented students. At these conferences, we have given presentations on "How to Apply for Graduate Schools," "How to Succeed in Graduate Schools" and "Statistics at NC State." It is important to involve faculty, students, staff and alumni in recruiting good students to the program. Also, faculty members that

recommend students to our program are key to recruiting good students and it is important to appreciate the time they have put in writing letters for their students.

It has been difficult to recruit postdoctoral fellows in statistics. The job market has been excellent for doctoral graduates in statistics and hence, not many are interested in a postdoctoral fellowship. So, we have taken a targeted search for postdoctoral fellows. We look for students that are not sure about whether they would like to go into academia or industry. We look for good teachers that want to try research again. Also, we have looked for students that have an interest in learning a new area like our bioinformatics program. It is important to have a 3-year road map that includes research, teaching, grant writing and industry experience. Treating the postdoctoral fellows as colleagues increases the morale and in turn, helps in recruiting future students.

Retention

It is important to make retention the TOP priority. Retention helps in recruiting! At the graduate level, it is important to give additional time to gain a strong foundation in the core courses. Also, provide enough time to be involved with research workgroups. Communication with all students on a regular basis is very important. Mentoring by faculty and postdoctoral fellows is very critical. In addition, it is important to have peer-mentoring. We strongly encourage our VIGRE trainees to participate in skills workshops and attend professional meetings, which provide insights into: Preparing the Professoriate; Writing/Presentation skills; and Networking. Vertical integration provides a natural forum for mentoring. Postdoctoral fellows especially play an important role in retention. Also, seminars by faculty and our alumni in industry provide information regarding the benefits of a doctoral degree. These seminars especially help in retaining the MS level students. Focus on successes of the program and successes of the students breed success for the department.

We take pride in training problem solvers by providing a good blend of theory and application in our courses and by providing experience in research, teaching and statistical consulting.

Department of Statistics, North Carolina State University

The VIGRE Program at the University of Arizona

Michel Tabor and William McCallum

The VIGRE grant at the University of Arizona was awarded in the Fall of 1999. It is shared by the Department of Mathematics and the Program in Applied Mathematics. Although these are separate academic units with separate Ph.D. programs they have a long history of collaboration and this relationship is an integral part of the VIGRE program. In many ways the goals of the VIGRE program, as envisioned by the NSF, fit naturally with the culture at Arizona: the Mathematics Department has a record of teaching innovation and vertically integrated outreach activities, and the Applied Mathematics Program has a long tradition of interdisciplinary activities ("horizontal integration"). The Arizona VIGRE program has a variety of components at the graduate, undergraduate, and postdoctoral level. Here we describe some of the highlights in each category.

Graduate Training

A special feature of graduate training in both graduate programs is a system of **Research Tutorial Groups** (RTGs) for the first year students. One of the challenges of any graduate program is how to facilitate the students' transition from "consumer" (of course work) to "producer" (of research). The RTGs engage first year students in some form of (albeit modest) research activity in a tutorial group setting. Briefly, in the Fall semester the students are exposed to a variety of topics through blocks of seminars (essentially a hybrid between a "case study" and a mini-course), and in the Spring semester the students choose to pursue one of these topics with the faculty involved. The semester ends with all the students presenting their findings at a small research conference. This system is ideally suited to vertical integration since the research projects can be co-advised by postdocs and advanced graduate students. In some years they have also involved advanced undergraduates. The RTGs can sometimes lead to more advanced research projects in the second year, and they also provide a mechanism for unobtrusive evaluation of the students' progress - which is otherwise limited, for the most part, to assessment of their performance in the first year course work. A distinctive feature of the Arizona VIGRE program is that of **competitive proposal writing** by graduate students seeking continuing VIGRE support. Whereas many VIGRE sites offer students a long term commitment of VIGRE funds (usually apportioned over a number of years according to some formula) Arizona offers new students support only for their first year. For continuing funding students must submit a proposal laying out a clear plan of study, research, and vertical integration activities. A first draft of the proposal is reviewed by a faculty committee and an assigned faculty member then discusses the

proposal with the student making suggestions for appropriate changes based on the committee's recommendations. The student resubmits a revised proposal for final consideration. This scheme serves many valuable purposes: it makes the students think carefully about their plans, and provides a natural mentoring mechanism to train students in the writing of proposals. Not all proposals are funded and this too provides students with an invaluable foretaste of the realities of life as a professional mathematician seeking DMS funding!

Undergraduate Training

The VIGRE-funded UAMAZ program (Undergraduate Assistantships in Mathematics at Arizona) comprises both Undergraduate Research Assistantships and Undergraduate Teaching Assistantships. Undergraduate Research Assistants work with a faculty advisor on a research project, and Undergraduate Teaching Assistants learn about teaching mathematics by working with an instructor of a lower division course and meeting regularly as a group with a mentor. Summer funding for undergraduate research projects and travel support to undergraduate research conferences are also available. A list of research projects proposed by faculty members is posted on the department's undergraduate web site, and presented at a meeting of interested undergraduates each semester. In keeping with the practices of the graduate VIGRE program, undergraduate students who choose a particular project write a funding proposal, get a letter of support from the appropriate faculty member, and produce final reports suitable for posting on the web. Some examples are at `http://www.math.arizona.edu/~mcenter`. The success of the graduate RTGs has inspired an undergraduate version: an Undergraduate Research Seminar which leads undergraduates into research projects under the UAMAZ program. Each spring semester selected faculty and postdocs give series of lectures on the background to a project they have proposed, and assign mini-projects that give students a taste of the main one. Postdoctoral Training Arizona's VIGRE program supports up to four postdocs at any one time: two in Mathematics and two in Applied Mathematics. These Fellows can and do participate in a variety of vertical integration activities at both the undergraduate and graduate level. Here are some examples: (i) One of the VIGRE postdoc in Mathematics ran a Research Tutorial Group which, for one of the students involved, developed into research for a MS thesis which was co-advised by the postdoc. (ii) One of the Applied Mathematics postdocs developed a cross-disciplinary project on satellite control with faculty from Engineering, Space Sciences, and a local company. In the course of this project the postdoc co-advised 2 engineering students and several publications resulted. (iii) The other Applied Mathematics postdoc volunteered to help a group of graduate students prepare for their critical (and final) retake of their qualifying exams. As a result of his efforts all the students passed the exam.

General Comments

One general feature of the Arizona VIGRE program that we feel is worth highlighting is that of "natural" mentoring. Although it is easy to construct quite elaborate mentoring structures involving assigned faculty and senior students etc, our experience has been that better mentoring, and monitoring, of the students come about through meaningful activities in which the students and their mentors are intellectually engaged, such as the RTGs, or the competitive proposal writing.

Similarly with postdocs our feeling is that creating a user-friendly environment in which they can develop their own research and teaching identities is, in the longer term, more effective then imposing excessive direction. Finally, discussions with other VIGRE sites reveal that for some institutions, like Arizona, the "VIGRE culture" fits in naturally with the existing environment, whereas for others the fit is more stressful in terms of the pre-existing institutional structures and faculty commitment. Whereas a VIGRE grant does not necessarily "buy" a VIGRE culture it undoubtedly provides the essential time for students and faculty to benefit from it.

Program in Applied Mathematics, University of Arizona

Department of Mathematics, University of Arizona

VIGRE Workshop Mentoring Break-Out Sessions

Richard Hain and Joseph Rosenblatt

The break-out session on mentoring of graduate students and postdoctoral fellows met twice on May 4, each time for an hour and a quarter. The facilitators were Richard Hain (Duke University) and Joseph Rosenblatt (University of Illinois at Urbana-Champaign). Richard Hain had been one of the speakers on exemplary practices earlier in the meeting, on May 3; he talked about mentoring of graduate students and postdoctoral fellows at that time. His presentation and the break-out sessions addressed mentoring in general, but there was also a focus on the NSF VIGRE program and how it promotes and supports mentoring of graduate students and postdoctoral fellows.

During this break-out session, both Joseph Rosenblatt and Richard Hain gave short presentations about the VIGRE programs in their departments. Since the two departments are very different in size, but share common goals for research and teaching, the different schools and their VIGRE programs made for an interesting contrast. Both the University at Illinois at Urbana-Champaign and Duke University view mentoring as central to the success of their VIGRE programs. After these presentations there was a general exchange of information about mentoring of graduate students and postdoctoral fellows as it occurs in the departments represented by the participants.

Here is a short description of the NSF VIGRE program at the University of Illinois at Urbana-Champaign (UIUC) as it was presented at the break-out sessions. The majority of discussion was about the details of this program, the NSF VIGRE program at Duke University, and how these programs actually work. Many participants cited examples of similar practices at their own universities, both through NSF VIGRE activities and through the normal course of departmental life. The most interesting activity brought up is the successful Grant Writing Workshops at Duke University. This was suggested as a good mentoring practice to be employed by any department with postdoctoral and/or junior faculty members.

NSF VIGRE at UIUC

The Department of Mathematics at the University of Illinois at Urbana-Champaign is one of the largest mathematics departments in the world. It has currently about 100 mathematicians on its faculty, with 75 of them being regular faculty members and 25 of them being postdoctoral faculty members. They do research in many areas of mathematics and teach 10,000 students each year. The university's strength, particularly in engineering and the sciences, creates a huge demand for mathematics courses.

The NSF VIGRE program has had a very significant impact on the UIUC Department of Mathematics. See http://www.math.uiuc.edu/VIGRE for general information about this VIGRE program,

Mentoring occurs in the UIUC NSF VIGRE program in a number of different ways. At the UIUC, mentoring of graduate students and postdoctoral fellows is seen as vital to their success. In the existing advising structure, all undergraduate and graduate students have faculty advisors assigned to them to help with their course planning and career decisions. When a graduate student arranges with a faculty member to begin work under their supervision on a dissertation, that faculty member becomes the graduate student's advisor. Mentoring of the postdoctoral fellows comes through the faculty members who have been identified as most in contact with the research interests of the postdoctoral fellow.

Under supervision of the VIGRE administrative team, two types of peer groups have been formed to promote research and communication, the ALPs and the RAPs. Both types of groups provide a platform on which to carry out mentoring and interpersonal, professional support. The first type of group is Across Level Peers (ALPs); ALPs include undergraduate students, graduate students, and faculty of all types in groups to pursue wide-ranging agendas focused on topics in the mathematical sciences. The other type of group is Research Among Peers (RAPs). RAPs include graduate students, postdoctoral fellows and other faculty. These groups focus more on the specific research interests of the members, and provide a forum for consultation in the forming, presentation, and dissemination of research work.

Across Level Peers (ALPs)

These groups communicate how to look at mathematics, both in teaching and in research. They usually have a specific theme in mathematics as a focus. The central idea is to bring the undergraduate mathematics students into greater contact with mathematics graduate students and faculty. ALPs encourage such contacts on a very personal level; this type of small group interaction is vital for cohesiveness in the undergraduate education at such a large and multifaceted campus as UIUC. A postdoctoral fellow is often linked with an ALP. VIGRE postdoctoral fellows can in this way be in contact with more undergraduate students than they might meet otherwise. For further information about ALPs, see http://www.math.uiuc.edu/VIGRE/alp.html.

Research Among Peers (RAPs)

The core charge for the RAP groups is to provide a vertical integration structure among graduate students, postdoctoral fellows and faculty with similar interests. These groups form with the understanding that in them there will be an easy exchange of mathematics because the individuals are closer to being of similar career development and interests than those in an ALP. These groups are intended to be aligned as well as possible with targeted research goals. For further information about RAPs, see http://www.math.uiuc.edu/VIGRE/rap.html.

The VIGRE program at the UIUC also includes other practices that have significant mentoring opportunities. These include: Teacher Training for Undergraduates (TTUs), Research Experiences for Undergraduates (REUs), Graduate Student Seminars (GSSs), and the Math 500 Lecture Series.

Teacher Training for Undergraduates (TTUs)

The VIGRE Teacher Training for Undergraduates (TTUs) program is meant for undergraduate students who are interested in the teaching of mathematics. A faculty member mentors and supervises this activity. TTUs are focused around a course that the faculty member is teaching. The student's role will be to assist the instructor and learn more about how to present material in the course, how to arrange the material over the term, and how to test the class for their knowledge of the material. As the term progresses, the student will be given the opportunity to present sections of the material in class. By the end of the term, the Teacher Trainees will have prepared and conducted lectures on their own, participated in the writing of examinations, the grading of examinations, and the whole spectrum of issues arising in teaching of the course. For further information about TTUs, see `http://www.math.uiuc.edu/VIGRE/ttu.html`.

Research Experiences for Undergraduates (REUs)

There are two types of REUs sponsored by the VIGRE grant, academic year REUs and summer REUs. For further information about the UIUC VIGRE REUs, see `http://www.math.uiuc.edu/VIGRE/reu/`.

Academic year REUs. Each REU has a faculty supervisor. The supervisor and student agree together on a research activity, which involves independent research, possibly in conjunction with study of the existing literature. The undergraduate student is paid a stipend during an academic year REU. REUs are an excellent opportunity for students to gain insight into the nature of mathematical research.

Summer REUs. These research experiences are for undergraduate students. The summer REUs are planned as group activities with one or more faculty supervisors, and perhaps graduate students as assistants. These programs typically run for 8 weeks during the summer sessions at UIUC. NSF funds the undergraduate student with a stipend during a summer REU. The Department of Mathematics increased the stipend using its own funds. The students pay for their own travel, housing, and board out of this stipend.

Graduate Student Seminars (GSSs)

Graduate students are the ones who organize the Graduate Student Seminars with the advice a faculty member as a mentor. Typically the participants are mostly graduate students, but faculty members are often involved also. These seminars can focus on a variety of issues: background review for developing expertise in an area of graduate level mathematics, series of talks on graduate students work in a specific field, a joint enterprise to study a text or a group of research articles, and so on. See `http://www.math.uiuc.edu/VIGRE/gss.html` for information about these seminars.

Math 500 Lecture Series

The intention of Math 500 is to serve as a forum for advanced graduate students and postdoctoral fellows to deliver seminar talks geared toward an audience

consisting of graduate students who are at an early stage of their research. Explicitly, the lectures should give a broad picture of the research interests of the speaker, a sketch of the area that they are most interested in studying, and a compressed version of what the future holds for their field. For further information about this lecture series, see `http://www.math.uiuc.edu/VIGRE/math500.html`.

Department of Mathematics, Duke University

Department of Mathematics, University of Illinois at Urbana-Champaign

Broadening of Education of Students and Postdoctural Fellows

Dean Isaacson

The sessions on Broadening illustrated that there is no single definition of what it means to Broaden the Education of Students and Postdoctoral Fellows. Activities presented as broadening included colloquium talks, seminars, proposal writing, curriculum changes, interaction with K–12, assistantship duties, REUs and improving communication. There was also disagreement on whether the broadening should occur before or after a student wrote a dissertation. The purpose of this report is to describe the various views presented and not promote any activity as best. Participants did seem to agree that Broadening should mean different things to different programs so hopefully this list of options will give all departments an opportunity to provide some broadening experiences to Ph.D. students and postdoctoral fellows.

Departmental colloquia and seminars of several types were recommended as broadening experiences. If industrial mathematicians, or alumni are invited to speak to a mathematical sciences department, students, postdoctoral fellows and faculty will be exposed to new ways to use mathematics, applied mathematics or statistics. In order to get students actively involved in discussing research, it is good to establish a colloquium series run by graduate students and attended by only students (graduate and undergraduate). Students would speak on their research, REUs, or internships. Students might also present their work to working groups that meet in the Department.

A department can use the curriculum to encourage breadth in the educational process. One approach is to have students in the mathematical sciences take courses or even a second M.S. degree from another department. In some cases, breadth is obtained by having someone in pure math take courses in applied math, statistics or computer science. New courses in Mathematics and Medical Imaging and Mathematics of Finance are examples of courses that have been created as part of the broadening experience. Students should be encouraged to take courses outside their area of specialization through the curriculum or through departmental culture. Another way to use the curriculum to broaden the educational experience is to promote co-majors at the Ph.D. level for graduate students and double majors for undergraduates. In Statistics Departments, the Postdoctoral Fellows might have the Ph.D. degree in a subject matter science. Students and post-docs who have a second interest outside the mathematical sciences bring fresh ideas back to the working groups. They often bring faculty from the other department with them. This option is most likely to work for Departments of Statistics or Applied Math.

Some departments use interaction with K–12 students as a broadening experience. VIGRE trainees are given opportunities to visit high schools and present a lecture on an appropriate topic in the mathematical sciences. This forces the trainee to think about their subject at a new level as they interact with both high school students and teachers.

Duties performed as a graduate assistant or intern often broaden the perspective of a VIGRE trainee. In addition to teaching, some graduate assistants provide consulting services to faculty and graduate students from across the campus. This is especially true in statistics. Students taking internships with industry or government are usually exposed to an applied problem outside the mathematical sciences and they almost always expand their computing skills. Postdoctoral fellows also broaden their perspective through teaching, consulting and mentoring duties.

Undergraduate students can broaden their education through an REU or by taking a minor or second major in a subject matter science. The second major will look like extra work for the undergraduate, so it will take a good advisor to make it happen. Under a VIGRE program, some of this advising and mentoring could be done by VIGRE trainees or postdoctoral fellows. These assignments will broaden the perspective of the advisor and/or mentor.

The mentoring of graduate trainees can be done by postdoctoral fellows. At some programs, the postdoctoral fellows give presentations on how to survive in graduate school and how to apply for jobs upon graduation.

Participants in this session felt that strengthening communication skills is an essential part of broadening. Thinking about how they might effectively communicate their research problem to non-experts makes students or post-docs broaden their perspective. Presentations given to high school students, high school teachers, undergrads, and subject matter scientists force the speaker to think broadly about her/his research problem. One VIGRE program presents a course on math communication. Several programs present a course on grant writing. Asking all VIGRE trainees and fellows to develop a web page is another way to force them to think about how they should present their message to a broad audience. One participant asks trainees and fellows to prepare three talks on their research topic. The talks are to be of length three minutes, 12 minutes and 50 minutes. Deciding what to include in each is a broadening experience for the presenter.

Most participants agreed that broadening was valuable and it should be encouraged through some of the activities described above. The opinion was raised that promoting breadth will weaken depth and some see depth as more important. There was also some disagreement on whether the breadth should be sought early or late in the student's career. Some felt that it is optimal for the student to become "good" in some area as soon as possible. This will improve their confidence level so they will be comfortable branching out. Others felt that the time for breadth is early in the academic career. Whatever activities are selected to broaden the education of students and postdoctoral fellows, the participants agreed that they must be sustainable so the dependence on VIGRE funding should not be required.

VIGRE is designed to help colleges and universities produce Ph.D.s in the mathematical sciences who have a broad perspective of their research and the ability to communicate the importance and impact of their work. If the next generation of mathematical scientists does a better job of explaining the role of mathematics

and statistics in solving important problems in the world, the financial and public support for DMS will continue to grow.

Department of Statistics, Iowa State University

Recruitment and Retention of Students and Postdoctoral Fellows

Sastry Pantula and William Rundell

The two panel discussions on recruitment and retention were led by Sastry Pantula (Dept of Statistics, North Carolina State) and William Rundell (Dept of Mathematics, Texas A&M). In each session, both panel leaders gave a brief overview of the activities taking place at their VIGRE site relevant to the main discussion item. This initiated a question and answer time from the audience and a general deliberation on several subtopics developed.

On the recruitment of graduate students the consensus was that a successful department must, at a minimum, "do all the standard things". This includes; widely advertising the programs and fellowship/assistantship opportunities; having an easily navigatable web page containing relevant information for potential recruits; utilize individual faculty contacts; have regular "recruiting trips" to local universities and colleges that have sent students in the past. The need to at least offer an on-campus visit was considered very important. Many individuals reported that competitive stipends are essential since students at this stage in their career do not necessarily weight things from primarily an academic perspective, or do not have sufficient information to do so. Thus tangibles such as level of financial support can be a major factor in the decision. Professor Pantula reported that they have a main faculty advisor who "once a student enters his office, is hooked on entering a graduate statistics program". Indeed many in the audience echoed the fact that a charismatic departmental graduate chair who was willing to spend time with prospective students, was an extremely effective recruiting tool. This was particularly true for statistic departments who recruit heavily from the pool of local mathematics majors. This latter point, as well as the following one, brought up a discussion of whether it is prudent for the student's sake to recruit from amongst one's own undergraduates.

Several individuals mentioned the fact that their department had either initiated a combined bachelors/masters degree program or were considering doing so. It was pointed out that in some cases considerable institutional impediments exist to giving dual credit. However, those institutions who had such a program claimed that a large proportion of these students subsequently entered a doctoral degree program. SUch programs also offer an excellent mechanism to expose students to a research experience prior to entering a doctoral program as well as providing a stronger basis of core mathematical knowledge. Following this, there was discussion on whether VIGRE can have a positive effect on masters degree candidate recruiting, although this is not specifically part of the mandate for the VIGRE program.

It was pointed out that many departments often overlook A minus undergraduates as potential graduate degree recruits and these students, while perhaps not initially motivated to enter a doctoral program, may do so after a successful experience at the MS level. This was particularly true for statistics departments since often the student's previous exposure to the discipline is limited. There was broadly-held feeling that such A-minus students are an essential resource if we are to expand the recruitment base, for in many cases the "A students" actually recruited into the graduate program from smaller, and perhaps weaker, institutions are neither stronger nor better prepared.

On the issue of minority recruiting, Professor Pantula said that they routinely visit HBUs and bring faculty from such institutions into their department for a visit and they have found this to be very effective. Other avenues discussed to increase the minority pool was the utilization of Mathfest and REU programs. The need for bridge courses was noted.

There was considerable discussion on the recruitment of strong undergraduates. Rundell noted that for several years Texas A&M has been running a mathematics contest that attracts about 400 students from 30 high schools within a several hundred mile radius. The contest takes place on the College Station campus on a Saturday during the fall semester. The opportunity to expand this clearly exists, although logistics and the number of faculty required to participate, would then be a major factor. A significantly large proportion of the department's top undergraduates participated in the contest as high school students, showing its effectiveness as a recruiting tool. They key to the success of such an endeavor is the cultivation of good relations with high school teachers, and outreach programs such as AP workshops can play a key role here. Rundell also mentioned a practice of concentrating the best instructors into freshmen calculus courses for engineering students and providing additional help and support outside of the classroom for students in these sections. Such evangelizing has been quite effective in attracting very strong students into the mathematics program.

Retention issues were also discussed. Good mentoring and the fostering of a sense of community were considered extremely important and overall were the most effective means of retaining students in the program. The need to integrate the postdoctoral fellows into the life of the department was noted and mentoring here included not only help with the individual's research, but assistance in applying for funding, in finding the next position and with teaching. Rundell mentioned that Texas A&M had sheduled a brown bag lunch (provided for the postdocs) once each week during the fall semester where each of the approximately 20 postdocs (both VIGRE and non-VIGRE) gave a condensed 15/20 minute talk suitable for a general audience on their research. Each of the designated faculty mentors were asked to assist in the preparation of this talk, the content of which could provide an overview for a grant proposal or be used as part of the general departmental discussions a candidate faces during a job interview.

There was some discussion of whether the extra resources given to a VIGRE fellow broke with the more traditional system based entirely on proven merit and if this could have a negative impact on retention. This potentially effects both graduate students and postdocs. Some practices to offset this were noted and in some cases these included additional resources from the department or the university to give more support to the non-VIGRE fellows. Several members of the audience noted a problem with students initially entering the mathematics graduate program

but then switching at the first opportunity to another discipline with a higher job profile such as computer science. This was most noticeable from foreign applicants, in particular those from the PRC. One panel had an extensive discussion on a student's ability to change advisors and whether programs such as VIGRE or FRG made this process any easier.

Dept of Statistics, North Carolina State

Dept of Mathematics, Texas A&M

Report on Breakout Sessions on Exemplary Practices in Vertical Integration in VIGRE Programs

Rob Lazarsfeld and Michael Tabor

Two break-out sessions on Exemplary Practices in Vertical Integration were co-chaired by Rob Lazarsfeld (University of Michigan) and Michael Tabor (University of Arizona)

Both sessions started with a brief overview by Rob Lazarsfeld describing the VIGRE program at Michigan (the Arizona program had been described at an earlier presentation) who emphasized the decentralized design of their program, and explained how that encouraged wide faculty participation in one or another activity.

Participants then discussed aspects of the VIGRE programs at their own universities. Many features were common to most of the programs, e.g. seminars directed at VIGRE students, formal mentoring schemes and the like. An important goal for some of the programs was to bring less well-prepared incoming graduate students as quickly as possible to the point being able to engage in high-level work and research. These mechanisms took various forms at different VIGRE sites. For example, Chicago, UCLA, Indiana had various forms of summer programs for new students to attend before the begining of their first semester to help prepare them for their graduate courses; whereas Arizona had a system of first year Research Tutorial Groups to introduce students to research experiences.

Various VIGRE sites also reported on how the grants had enabed them to develop varous types of REU programs (both summer and term-time), including some that supported students outside the base mathematics department. These efforts all appear to have been succesful and, strikingly, often revealed a pent-up demand for undergraduate research opportunities among the local students.

One interesting difference that emerged among the various program is that some departments guaranteed several years of VIGRE support to incoming students, whereas others expected students to file some form of competitive propsals for VIGRE support after the first year. Among the advantages of the latter approach is that it encouraged students to think about how best to structure their programs and use any support that they got. The drawback appeared to be that it lessened the impact of VIGRE support as a recruiting tool. (The issue of the unavailability of VIGRE funds for foreign students was also discussed. Although this was a frequently expressed cause of concern by faculty, there were also indications that the students themselves were more accepting of this situation.)

Another question which arose is how different departments made up the shortfall in teaching strength resulting from the VIGRE teaching reductions. Several reported aggressive hiring of instructors from neighboring departments while others

made increased use of undergraduate course assistants. Some departments reported on the need to draw on adjunct faculty from local school districts and Community Colleges.

Finally, the question arose whether the benefits flowing from VIGRE could outlast the grant itself. Here it was stressed that while many of the cultural and curricular changes could become permanent, it was important to keep in mind that by far the main impact of VIGRE is to provide non-teaching support for students and postdocs. Obviously this would not outlast VIGRE unless other mechanisms for NSF support were put in place. Overall, the discussions revealed that for some Institutions the "VIGRE culture" fitted in naturally with the existing environment, whereas for others the fit was more stressful in terms of the pre-existing institutional structures and faculty commitment. Whereas a VIGRE grant did not necessarily "buy" a VIGRE culture it undoutably provided the essential time for students and faculty to benefit from it.

Department of Mathematics, University of Michigan

Department of Applied Mathematics, University of Arizona

A postdoc's experience with VIGRE at UCLA

Skip Garibaldi

UCLA has many programs associated with VIGRE that I was not personally involved with (e.g., bridge courses between lower- and upper-division and between undergraduate and graduate, summer REUs) or that I was only part of for a short time, so I won't discuss them here.

The VIGRE initiatives that I have been most involved with at UCLA are the "graduate participating seminars", which are listed as Math 296 in the course catalog. These courses typically involve graduate students, postdocs, and permanent faculty and can last from one term to indefinitely. This description makes them sound like normal seminar series! But many of these are somewhere between a traditional seminar and a traditional course.

For example, this quarter (spring 2002) I am running one where we are going through a mid-level graduate text on Galois cohomology. I designed the course outline, and the students — mostly in their second and third years — are doing all of the lecturing. For nearly all of them, this is their first time giving a talk on any material of this level of sophistication. Before they speak, they meet with me to discuss what results they need to cover, etc. I in turn consulted with my teaching mentor about the design of the course and continue to talk with him about various other aspects (e.g., course handouts written to address specific student questions). There are 9 graduate students enrolled, and each talk is typically also attended by a couple more students, two permanent faculty, and myself. Similar courses are also occurring this term on toric varieties (going through Fulton's book), local fields, ...

In a somewhat more traditional vein, my research advisor has organized an ongoing 296 since fall 2001 to present Voevodsky's recent proof of Milnor's conjecture. Again, there is a distinct arc of material, with a beginning and a destination. Because of the more advanced subject matter (and greater sophistication required because the results are scattered across various research papers and several books), roughly 2/3rds of the lecturing is being done by postdocs and 1/3rd by grad students. Although only 1 student is enrolled, 4 regularly attend, as well as 5 postdocs (3 of which are VIGREs), and 3 permanent faculty.

These courses — and the requirement that graduate students must take two of them in order to graduate — predate VIGRE. But before VIGRE, these courses were somehow just facades and not at all of the type I have just described. With VIGRE, the department has pushed faculty to organize 296s of this type and encouraged them with a 1/6th course release. Here are the numbers:

	before VIGRE (approximate)	this quarter
number of 296s	12	21
total number of students enrolled	13	61

The fact that there are 5 postdocs attending the seminar described above is a reflection of the large number of postdocs at UCLA: there are 64 permanent faculty and 26 postdocs (6 of which are VIGRE).

A major benefit of VIGRE for me was the $2500 per year for travel and expenses. As postdocs, we don't get startup packages, most of us do not have NSF grants, and UCLA has no departmental travel money for postdocs. This money gave me the freedom to attend many more conferences than I would have otherwise (e.g., I co-organized a special session at the AMS national meeting in January 2002 and I went to conferences in Baton Rouge; Duisburg, Germany; and Oberwolfach). Of course, one could always use more.

The other direct benefit of VIGRE is the course release. The usual postdoc load at UCLA is 2-1-1 and with VIGRE it is 1-1-1. During my first year at UCLA (before the department was awarded the VIGRE grant), I found that simultaneously teaching two different and entirely new courses left me very little time for research. Oddly, my research production seems to be greatest when I am teaching one course rather than none at all, so the VIGRE setup is ideal for me. Consequently, when Jean-Pierre Serre visited UCLA in winter 2001, I was in a position to take advantage of it. Now, he, my research advisor (Alexander Merkurjev), and I are writing a book to be published by the AMS. Since you can hardly ask for a wider spread in seniority amongst the authors, this seems like an ideal example of vertical integration.

Department of Mathematics, University of California, Los Angeles

A VIGRE Postdoc Experience at PSU

Jon Jacobsen

At the request of the organizers of the 2002 NSF VIGRE Workshop I have written the article below to describe how I have participated in and been affected by the VIGRE program.

1. Background

To put my experience in perspective, let me give some mathematical background. With the goal of becoming a high school teacher I entered the mathematics program at California Polytechnic State University, San Luis Obispo, CA in 1988. During an "early field experience" course in my junior year I quickly realized that high school teaching was no longer in my cards. I decided to stay at Cal Poly and obtain a masters degree to teach at the community college level. It was during my masters studies that I "saw the light" and realized I could not end my mathematical training at this stage. In 1999 I completed my graduate studies at the University of Utah. With a Ph.D. and seven years teaching experience I entered the academic job market.

2. Job Search

In 1999 I applied to approximately 25 positions, with a fairly even mix of tenure-track positions at liberal arts schools and postdocs at research universities. During the January AMS Meeting in San Antonio I had about 6 interviews. I was preparing for a phone interview with a liberal arts school in Wisconsin when I received a phone call from Gary Mullen at Penn State University offering an S Chowla Visiting Assistant Professorship, sponsored by the NSF VIGRE program. Although I was strongly interested in the tenure-track job in Wisconsin, the opportunity at Penn State was too enticing to pass up.

In contrast, the job search in 2001 was a completely different experience. I applied to approximately the same number of schools (tenure-track, equally split between research and liberal arts colleges). During the AMS Meeting I had approximately 15 interviews which led to several campus interviews at both research and liberal arts campuses. I had several acceptable options, and was extremely pleased to accept a tenure-track position at Harvey Mudd College.

3. The Postdoc Experience

Due to some technical difficulties, the title of the position was changed to S. Chowla Research Postdoctoral Fellow, and certain benefits originally offered were retracted (e.g., Dental and vision insurance, TIAA-CREF). Due to the nature of

the funding, the University was required to consider me a Postdoc instead of a Fixed Term I employee. The final details of the position are as follows: Academic Salary \$43,000 ($\times$ 3), Travel Fund \$2500 ($\times$ 3), Summer Support \$6500 ($\times$ 2), HMO Health care option, and an average of a 1-1 teaching load. During the second year the University added a dental and vision option for postdocs, although not equivalent to the dental plan offered Fixed Term I employees, it was better than no coverage. As I have a family of four these details were perhaps a bit more relevant.

My teaching profile during the appointment was split between advanced undergraduate and graduate courses:

Academic Year	**Fall**	**Spring**
'99-'00	Fourier Series & PDE	Fourier Series & PDE
'00-'01	Mathematical Modeling Nonlinear Analysis (Graduate)	No courses (see below)
'01-'02	PDE I (Graduate)	PDE II (Graduate)

During the Spring 2000 semester my colleague Andrew Belmonte and I noted that our PDE students were hungry for more analysis and applications of differential equations, but there was no non-graduate course to send them to. To combat this we designed a new course to introduce the art of mathematical modeling through experiment. We co-taught this course during the Fall 2000 term. Recently we were pleased that the course was approved by the faculty senate and is now an official part of the PSU curriculum. During the Fall 2000 term I also taught a graduate course in nonlinear analysis (degree theory, bifurcation theory, applications to PDE). Teaching two courses in the fall, I was able to arrange for no teaching duties during the Spring semester. This proved extremely valuable to my research. It was during this time I managed to complete three papers which have all since been accepted for publication.

The math department at Penn State tried to create an optimal research environment. Initially, due to space problems, there were three postdocs to an office. In the second year this was reduced to two per office for VIGRE postdocs. Additionally, each VIGRE postdoc was provided with their own Unix workstation (currently a SunBlade 100). Several departmental seminars (both formal and informal) and the W. G. Pritchard Fluids Laboratory, a well-established fully functioning experimental lab situated on the first floor of our building, provided a stimulating research environment. The opportunity to combine research in partial differential equations with the experiments they describe was an enlightening paradigm and I plan to continue this model in my research and teaching at Harvey Mudd College. Finally, the reduced teaching load, summer support, and minimal demands from the department allowed for ample time to pursue my research.

The bulk of my research funds were used for travel, with the major trips including:

1. Midwest PDE Seminar ('99)
2. Special Session talk (AMS January Meeting '00)
3. Visit FENOMEC, UNAM, Mexico City, Mexico (Summer '00)
4. Math Challenges of the 21$^{\text{st}}$ Century (UCLA) (Fall '00)
5. Oberwolfach (March '01)
6. Organized Special Session (AMS January Meeting '02)

The ability to travel was an extremely valuable component of the VIGRE postdoc. For instance, the January 2000 special session talk led to a new collaboration with Pablo Padilla (UNAM), which led to a visit and lecture in Cuernavaca which led to a survey paper on global implicit function theorems published in the conference proceedings. The Oberwolfach meeting was an excellent opportunity to discuss my research with some of the top researchers in differential equations from the international community.

4. Conclusion

The VIGRE postdoc at Penn State was an excellent opportunity. I had the chance to broaden my research interests and teaching skills at various levels which better prepared me for a career in mathematics.

Finally, I would like to recommend that departments consider having both a research mentor and a teaching/professional advice mentor. I was fortunate to have a research mentor who was equally interested in being a "professional life" mentor. However, I have seen several other postdocs struggle in this regard. The department should create a clear channel for postdocs to ask non research related questions that arise as a junior faculty member. This mentor can also help determine the postdoc's teaching interests and determine an appropriate teaching profile.

Department of Mathematics, The Pennsylvania State University

A summary of my involvement in VIGRE

Dan Knopf

1. Introduction

I received my Ph.D. in 1999 and am thus a first-generation VIGRE postdoc. In this brief report, I will do two things: describe my participation in the VIGRE program at the University of Wisconsin – Madison, and attempt to assess its professional impact on my career as a research mathematician. The reader is cautioned that these remarks are not intended to summarize all the activities of my fellow VIGRE postdocs at Madison, much less the entire UW program.

2. My participation in VIGRE

As a VIGRE postdoc, I was assigned a reduced teaching load of one course per semester, and had funds available to travel to conferences, bring in visitors, and visit collaborators to pursue joint research. I attended the math department's weekly or biweekly VIGRE seminars that bring together faculty, postdocs, and students to discuss topics such as research interests within our department and employment possibilities in mathematics. Together with other postdocs, I helped organize other opportunities for postdocs to meet with graduate students in less formal settings, to encourage frank conversations about academic and professional development. All of these experiences are probably typical of any VIGRE postdoc at Madison. Some of us also participated in special individual projects; for instance, Chris Raymond (also a first-generation VIGRE, but an applied mathematician) worked with a faculty member to develop a course on mathematical modeling.

What is unique to my experience is that I designed and implemented the undergraduate research component of the UW VIGRE program during the 2001–2002 academic year. This research project was informally called the *UW Minimal Surfaces Lab*. In terms of time and effort, this program composed the dominant component of my participation in VIGRE, so I will discuss it below. Before doing so, I wish to acknowledge the contributions of my fellow VIGRE postdocs Chris Raymond and Rebecca Field, who helped me to make it successful.

The project I designed had three main goals:

1. The primary goal was not for students to discover significant new mathematics, but rather to help them learn how to do research. They had opportunities to work in informal collaborative settings, to develop their creativity, to gain skills in communicating their problems and results, and to learn how to use computing and library resources effectively.

2. The second goal was to motivate the students to experience mathematics beyond the classroom. In order to accomplish this, I did present them with an authentic open problem — albeit one appropriately scaled to their level of mathematical development. In this way, they got a taste of the excitement and challenges of trying to discover new mathematics. By this means, I sought both to overcome their tendency to learn passively, and to attract them to pursue their studies at the next level.
3. The third goal was further to whet their appetites for advanced mathematics by exposing the students to mathematical concepts and techniques not often encountered by undergraduates. Then I attempted to help them begin to apply these tools through a process of guided discovery.

My own area of research is geometric analysis, so I endeavored to expose my students to this area of mathematics at a level appropriate for advanced undergraduates. As motivation, I presented them with a geometric problem in the guise of an engineering problem. After giving the students some preparation in differential geometry and the calculus of variations, I showed them how to cast the problem into some accessible questions about constant mean curvature surfaces. In turn, these questions led naturally to a family of nonlinear (but highly tractable) ODE. Finally, the students were helped to study these through a variety of analytic and computational means.

These topics are admittedly rather advanced for undergraduate students, so Rebecca Field, Chris Raymond, and I screened the applicants and ultimately selected five women and nine men, all of whom had completed the standard calculus sequence, together with various combinations of courses covering linear algebra, differential equations, and analysis. I met with the full group of students for four hours weekly, and scheduled time weekly for informal office hours. Rebecca and Chris also met with the students on occasion, in order to present a greater variety of mathematical viewpoints. There was some decline of student participation during the academic year, primarily due to competition from other academic commitments, but several students continued the project through the spring semester, until the end of the academic year.

What did I learn from this experience? It raised several issues which should be kept in mind by anyone designing a similar effort. Particularly with a problem as hard as the one I chose, there is a delicate balance between the need to teach students enough background, and the goal of giving them an opportunity for independent investigation. Too much structure risks turning the experience into a course; too little risks leaving the students foundering. There are also delicate questions of how much help to offer: give too little and students may become discouraged; give too much, and they can lose confidence in their capacity to contribute meaningfully. Finally, when running any sort of an undergraduate research project during the academic year, one has to address the obstacle of competition from classes in which students receive grades.

Nonetheless, the overall response was highly positive. Several students who participated are going on to graduate work in mathematics, and at least two found themselves to be seriously attracted to geometric analysis. I believe that the interest which the lab generated helped attract many of the twenty-two students who enrolled in the advanced undergraduate course in differential geometry that I taught

during the spring semester. Quotes from the undergraduate researchers themselves include the following:

> "...it was a great experience, one that has helped make the transition from intermediate to advanced mathematics easier."
>
> "Positives [were] interaction with peers and especially with professors [and an] opportunity to talk about subjects with guidance which would otherwise be merely mystifying."
>
> "The math club is neat, but this VIGRE program got us into an environment with a professor that allowed us to work together and learn from each other's strengths."
>
> "Learning how research can be done has helped me tremendously."

3. Its professional impact

How would I assess the professional impact of my VIGRE involvement? Without doubt, any postdoc who wants a career in research (as I do) should pursue 'vertical integration' in the sense of collaborating with senior faculty. So a more appropriate question to ask is: how did my experiences as a VIGRE postdoc differ from those of a typical non-VIGRE postdoc at UW–Madison?

By far, the way in which VIGRE helped my research the most was by giving me a reduced teaching load, together with the time and money to travel. I also received mentoring from senior colleagues at Madison, notably in the form of valuable advice and encouragement toward preparing grant proposals. I am happy to report that my individual research proposal in geometric analysis was recommended for funding by the NSF (DMS – 0202796). I am sure that the experience I gained by designing and implementing the undergraduate research project will be valuable in the future in terms of helping me give service to my department and my profession when I ultimately obtain a tenured (or at least tenure-track) position.

Here too there are delicate issues of balance that I would urge anyone involved in a VIGRE program to consider carefully. I am extremely grateful that Wisconsin released me from teaching during the fall semester so that I could develop the undergraduate research program. Without this release, the time this project demanded would certainly have had a substantial negative impact on my research productivity. I would also urge my fellow postdocs and those who mentor them not to let such participation create a false perception that their priorities lie in teaching rather than research. But if these factors are kept in balance, I think that VIGRE participation can be a valuable step in building a career as a research mathematician. I truly believe that I learned and benefited from my participation, particularly from the interactions it enabled with my colleagues in Madison.

Department of Mathematics, University of Wisconsin

VIGRE from the Perspective of the Mathematical Science Community

Dick Gross

Like the pill whose name it resembles, the purpose of the VIGRE grant is varied. Is it intended to increase the population, to restore strained relationships, or just to have more fun? In some cases, it does have a side effect of raising the blood pressure, as departments try to decipher ambiguous signals from the NSF. These ambiguities reflect some divisions in the mathematical community.

It was clear from the workshop that many departments have developed innovative and exciting programs, such as undergraduate research seminars, grant-writing workshops, and mentoring programs. Probably the main benefit from this grant has been the wealth of new ideas it has spawned in undergraduate education. But a large part of the funding is for graduate student support and post- doctoral fellowships. These are fundamental for the future of our discipline; our graduate students need time off from teaching, and our PhDs need jobs. Here I think the NSF has to make sure that they are not simply chasing innovation, but are funding the programs with the most promising graduate students and post-docs. The fact that three leading departments, Berkeley, MIT, and Stanford, are not supported by VIGRE grants is cause for concern.

I want to thank the organizers, and the sponsors, of this meeting for bringing us all together to discuss this. I think the DMS has done a fantastic job in increasing support for mathematics over the past few years, and by continuing to work closely with them, we can make a real impact.

Department of Mathematics, Harvard University

Reactions to VIGRE from the Trenches

Cal Moore

Introduction

I would like to offer some observations on the VIGRE program from my perspective as Chair of the Mathematics Department at UC Berkeley. We are a large department– over 60 faculty– in a large public university with a total campus enrollment slightly in excess of 30,000 students. I will comment both on the VIGRE program in general, and on the experience that Berkeley has had with VIGRE. These remarks are, of course, colored by that experience, by the nature and goals of the Berkeley Mathematics Department, and by those of the campus in which it is situated. They are also influenced by the goals and objectives that I set for myself when I became Department Chair six years ago, including the overriding goal of any Chair to gain resources for the Department.

It goes without saying all such goals have to be pursued within the unique structure of the institution and the patterns, traditions, and customs governing how resources flow within that institution. Not only do departments differ in their institutional context and competition for resources, but also in many other ways as well. One such is the kind of students that are both attracted to and sought out by the institution. In its undergraduate admissions process, Berkeley values students who have aggressively taken advantage of opportunities that were available to them and who have shown the ability to overcome obstacles in their education. The same is true at the graduate level as well. Students both at the undergraduate level and at the graduate level who have a degree of self-reliance and intellectual independence are attracted to Berkeley and are the kinds of students who do well at Berkeley. Other institutions may attract and seek students both at the undergraduate and graduate levels with somewhat different characteristics.

Another difference between graduate programs is in the range of preparation of their entering graduate students. The range at Berkeley is rather larger than at most of the institutions with which Berkeley competes. In addition to admitting a group of very highly talented students who have excellent credentials, Berkeley has for many years had a practice of admitting a number of students who appear promising and show determination, but who may not have the level of preparation and the background that the top-ranked students would present. The Department takes pride in this openness to a wide range of students, and has had notable success with most of them. Finally, graduate programs differ in the degree of flexibility of their curricula and in the role of applied mathematics in the university. Some

departments, such as Berkeley, have a continuum of pure and applied mathematics in one department with a free flow of ideas, students, and faculty interests, which at Berkeley extends into statistics, computer science, string theory, operations research, and mathematical economics. Other institutions may have separate departments of pure and applied mathematics that may have varying degrees of interaction between the two.

The VIGRE Program

Turning now more specifically to NSF and to the VIGRE program, let me begin by observing that the NSF is in the business of supporting the production of science and the production of scientists in the United States. The second part of this enterprise is one that is of great importance and is one that at this juncture commands our attention in the mathematical sciences. In my view, NSF's role should be to help individual scientists, groups of scientists, and institutions achieve their goals in these regards and to strengthen and maintain the necessary infrastructure. When proposing and implementing new initiatives, NSF should broadly engage the mathematical sciences community in discussion to ensure that the initiative is in concordance with these general goals. It is not clear that this has been the case with the VIGRE program.

I take the fundamental goal of the VIGRE program to be the laudable one of increasing the number of students studying mathematics and pursuing careers based on this training. However, it seems that NSF has decided in advance how to achieve this goal and has constructed a program that does not give sufficient recognition to the diversity of departments and institutional goals, and the diversity of programs and of the students enrolled in them. NSF puts forward a kind of mold for the way a department and its programs should operate. Even though the mold is not that well articulated - a circumstance that in fact compounds the problem – it is widely believed in the community that NSF through the VIGRE program is on a mission to reform mathematics education and professional training. One hears colleagues around the country discussing how they might pitch some aspect or characteristic of their program to NSF so as to meet the VIGRE guidelines or the VIGRE mold. This can only invite a degree of cynicism and dissimulation.

A second and related problem is that VIGRE guidelines call for changes in departmental programs, even when there is no reason for change or when some significant changes have already been made. Finally, and most important, there has been an absence of any broad engagement by NSF with the mathematical sciences community in a discussion of the goals and implementation of the VIGRE program and of the resulting problems just described.

I was on the original VIGRE panel that DMS Director Don Lewis convened in 1997 to advise DMS on the VIGRE program that was about to be born. It seemed that most things had been decided in advance and that this was a group called in at the last minute when there were few choices that remained to be made. The term "Vertical Integration" had been an ill-defined but popular expression at NSF that left many of us scratching our heads about what it meant. One supposition was that it was perhaps a general admonition to pay more attention to undergraduate education. The panel offered a general description of vertical integration as follows: "constructing undergraduate, graduate, and postdoctoral programs to be mutually supportive". The panel also offered a statement of purpose for VIGRE –"...[the]

purpose of the program is to provide quality experiences for undergraduate and graduate students, while also continuing professional development at the postdoctoral level". These two broad statements are sensible, and should have left a proper degree of latitude for implementation. However, in some respects, even the panel report goes too far in outlining some specifics. As the VIGRE program has been implemented, it has become encrusted and weighed down with many specifics that go far beyond the original intent, at least as I saw it. In addition, these specifics are not in any way consequences of the general goals, but rather represent choices made without broad consultation.

VIGRE at UC Berkeley

It is clear that attempts to increase the number of students studying mathematics have to start at least at the undergraduate level, particularly in attracting students to major in mathematics. One of the small number of problems that I decided to focus on as chair was that of increasing the number of undergraduate majors in mathematics. Four years ago we had 167 majors (this counts only juniors and seniors), and as of this week we had 556 declared majors. More than tripling the number of majors in four years was an aggressive goal, but one that I felt was achievable; moreover, it aligned very well with VIGRE goals that were subsequently put forward.

We improved our advising system and provided our majors with a feeling of belonging to the department, both intellectually and socially. We have a very successful peer-advising program where more advanced mathematics majors counsel and advise those who are just beginning or who are thinking of majoring in Mathematics. We also initiated systematic outreach activities to attract students. The introduction of our undergraduate research seminars, which was spurred by VIGRE, provided a significant incentive, especially to the very best students, to become math majors. In addition to providing stipends for students, we were able to use VIGRE funds to allow our majors to travel to conferences to present the results of their work not only in our own programs, but in other URE programs in which they had participated and where the URE program did not have sufficient funds to provide travel expenses. Many other disciplines in the sciences are able to provide such benefits and opportunities to their undergraduates, and our being able to offer them as well allowed us to compete more successfully for majors against these other departments. Finally, we have for many years encouraged double majors so that these majors have broad exposure to the applications of mathematics. This posture also allows us opportunities to recruit new majors. Right now some 30% of our majors are double majors.

Enrollments in our junior/senior level courses have more than doubled, but this also has had the downside that many of our core courses are running enrollments of 45 to 50. Exposing students to their first brush with real proofs in classes of this size is problematic. We are only able to offer at present 15-20% of our majors enrollment in an undergraduate research seminar because of faculty resource limitations. If VIGRE were to command that many or most majors have such an experience, we would not be able to comply, and it is not clear that every major would benefit from such an experience. There may be other kinds of experiences that we could design that would work. Thus, at the undergraduate level, we have been very successful with the assistance of VIGRE, and the relatively modest amount of VIGRE

funds invested at the undergraduate level has had a disproportionate impact. Nevertheless, there are problems that result, and we do not have the resources from the university to deal with them.

One of the other problems that I identified when I assumed the Chair in 1996 was that of improving the morale of our graduate students. This problem had been identified in a recent departmental review and was evident by comments and observations from many different sources. I wanted to bring the graduate students more fully into the life of the department socially and intellectually and to create a community of scholars. I wanted to ensure that the graduate students felt that the department was treating them well. At the same time, I devoted particular attention to making sure that women graduate students felt welcomed and supported by the department. The changes made involved minimal additional resources, but over time the climate and morale of the graduate students did improve. The evidence is part anecdotal, but the anecdotal evidence is consistent and extensive. In addition, exit surveys conducted by the Graduate Dean showed improvement, and a number of informal surveys that I commissioned showed improvements as well. Almost all of this had already been accomplished before VIGRE came along.

We arrange for several different kinds of mentoring of our graduate students– peer mentoring by more senior graduate students and mentoring by faculty advisors in the years before a student settles down with a dissertation supervisor. We also cultivate a degree of self-reliance in our students, a characteristic which we believe is essential for success as a mathematician. In the general spirit of our Department which has few stated requirements, such mentoring is not required, but is recommended and is readily available. Students ultimately have to make a decision for themselves. As judged from the reviews of our VIGRE project, this kind of approach appears not to be the correct mold for VIGRE.

We have about $5M in all forms of financial support for our graduate students, and our VIGRE grant, which was de-funded by NSF after three years, provided $250K, or about 5% of the total. This was an extraordinarily useful form of money, but ultimately its impact on the overall graduate program was not large. It provided fellowships for 10 out of a total of about 30 first-year domestic graduate students, who would have otherwise been supported by a teaching appointment. It no doubt bothered the VIGRE management team that their money was not having a more visible impact. In the course of our site visit, I was asked by the site visit team what would produce a significant impact at UC Berkeley. My response was that $1M in graduate fellowships would certainly have an impact– for instance 20 first-year fellowships and 20 "dissertation" year fellowships.

But there are catches here– first of all, VIGRE would never give us this kind of money, and second of all, I would not want it. My problem with it would be that we have to do long-term planning of our graduate enrollments and that requires a reasonably steady base of resources. From recent experiences, we would face the prospect of having $1M pulled out of our graduate student support budget essentially on a moment's notice. That would leave us in an untenable position, and being so dependent on one source would open the whole program up to all manner of subtle and not so subtle influences from the funding agency as to program structure and educational philosophy. Having $250 K pulled out when NSF de-funded the Berkeley VIGRE grant was bad enough, but was something we could deal with.

We will be able to replace it with other funds, and the main effect is that some of our first-year students will have to teach instead of having fellowship support.

The strongest and best-prepared graduate students who enter our program are either international students, or domestic students who come to us with NSF or other kinds of fellowships or are students that we can propose in the campus-wide competition for university fellowships and who will be successful in that competition. The fact is, the students supported on VIGRE at Berkeley are generally, but not always, the students who are among the least well-prepared and the ones most at risk. Thus the VIGRE students are not an elite group of the best students, as the NSF had perhaps imagined they would be.

I should add that for many years we have maintained a balance of about 25% international students, or about 10 entering each year. As noted, these students are among our strongest, and the cutoff for admission of international students is rather higher than for domestic students. The balance we strike here weighs on the one hand our responsibility as a government supported institution to provide opportunities for US citizens against the talent and the diversity of experience and background that international students bring to the program. The balance we have struck is a responsible and reasonable one. The citizenship requirement for VIGRE graduate fellowships is not a problem for us as long as it is understood where these students rank relative to other students in the program.

Conclusion

Let me conclude with some general observations flowing from these more specific comments. The VIGRE program it seems to me has created something of an adversarial relationship between the mathematics community and the Division of Mathematical Sciences at NSF for all of the reasons described above. A small group of program officers in Washington have become, in effect, inspectors general of mathematics education and training. Is this the proper role for NSF to be playing? The tendency to play this role was particularly evident from the presentations by NSF staff at the VIGRE conference in the Spring of 2001, at which NSF announced its new criteria for evaluation of VIGRE grants and described how the site visits would be conducted. Evidence from the first round of reviews of VIGRE sites indicates to many of us some serious problems with the current review process.

Mathematics departments in institutions such as UC Berkeley, MIT, and Stanford will continue to flourish with or without VIGRE grants, but it is evident that NSF through its decisions on VIGRE grants will end up picking and choosing winners and losers from among departments that are less well-established and without access to other resources. Again, is this a proper role for a group of program officers at NSF inside the beltway to be playing? These are questions that should be asked and discussed.

It is not clear what the goals of NSF are concerning overall graduate student support in the mathematical sciences and, in particular, what part of the total amount is planned to come through VIGRE and what part is planned to come through individual or small group grants. Likewise, it is not clear what the impact of having a VIGRE or of not having a VIGRE grant has on the ability of an individual investigator to obtain graduate student research assistantships on his or her grant. These questions have been raised by members of the mathematical community, and it is appropriate to raise them now. I do not know what the answers

are. Similarly it is not clear what the goals of NSF are with respect to support of postdoctoral scholars. What should be the proper balance between support of postdoctoral scholars through the Postdoctoral Research Fellowships (MSPRF), through support on VIGRE grants,and support on individual or small group grants. A case can be made for the superiority of the other two modes over VIGRE.

For the future, we need to find ways to move beyond the adversarial relationship that VIGRE has unfortunately created. One immediate step that should be taken by NSF is to conduct a thorough review of the VIGRE program. This review should engage the mathematical sciences community, should address questions about the proper role of NSF, issues of flexibility within general program goals, the balance of support for graduate students and postdoctoral fellows between VIGRE and other programs, and, most important, should address the mechanisms and process for review and evaluation of VIGRE projects. As the VIGRE program has stated goals concerning work-force issues, its effectiveness in advancing these goals should be assessed as part of the review.

Department of Mathematics, University of California, Berkeley