## Meeting the Purposes of the Program

The Department of Mathematics at the University of Chicago has an educational mission consisting of five interrelated components: first, the training of its graduate students as high quality researchers in areas of pure and applied mathematics; second, the careful training of these students as educators in mathematics and as communicators of mathematical ideas at all levels; third, the training of undergraduate mathematics majors in preparation for further advanced study in mathematics or related technical areas and for future development as educators, researchers, or scientists; fourth, the communication of serious and important mathematical ideas to the entire undergraduate student body of the University; fifth, outreach programs to people in the community at large who are not necessarily directly connected to the University. The last includes programs for gifted pre-college students, for students from traditionally under-represented groups, and for Chicago public school mathematics teachers.

Underlying our approach to accomplishing these missions is a principle that we feel is of basic importance: all of these goals, as well as the advancement of mathematical research and knowledge, are interrelated, and the most effective way of advancing all of these goals is the presence of a coherent fabric of research, communication, and education at a variety of levels, by a variety of persons, and to a variety of audiences. It is exactly this type of fabric that we have striven to create at the University of Chicago and which we feel is an essential ingredient in the success we have attained. We believe it provides a perspective that is important to the long-term health of national mathematics education and research. Two important features of this fabric are the communication of the goals of excellence in research and education at all levels, and the incorporation of representatives from traditionally under-represented groups in the process.

One of the essential components of this fabric is the community of graduate students in the

department. Our goals in training these students are several: to impart broad based mathematical knowledge; to foster their research capacities; to train them as educators; and to offer students opportunities in the educational outreach programs of the department. Our intention in doing this is to produce mathematicians and educators who will function with excellence at a variety of levels and in turn transmit the importance of mathematical ideas to a broad audience. In these ways, our training of graduate students plays an important role in achieving the national goals of excellence in scientific research, and a long term strengthening of the fabric of national mathematics education and research.

In this proposal, we are applying for 5 GAANN Fellowships to be awarded to graduate students in the Department of Mathematics. Our goals are to provide support to graduate students to enable them to complete, within a five or at most six year period, the training in mathematical research and educational perspective that we can offer them. We do this with the following measurable objectives:

a) To increase the number of American students in general, and those from traditionally under-represented groups in particular, who complete the PhD. program at Chicago, which includes the completion of a doctoral dissertation and the satisfactory completion of a multi-year carefully supervised program of training and experience in teaching. Given the traditionally high quality of our graduate students, and the nature of the programs we offer them, this is an optimal way to support mathematics research and education nationally.

b) Specifically, we propose to increase our numbers of students from the current 83 to up to 90 while maintaining our record of negligible attrition. With our new faculty appointments, discussed below, we now have the faculty resources to expand while simultaneously enhancing the quality of education we offer.

c) To continue to build an infrastructure of education and research that will provide intense educational support, especially as needed for those from traditionally under-represented groups, and to increase the numbers from such groups entering mathematics research and education. The nature of our program, which is built on intense personal interaction and communication and incorporates the principles outlined above, provides an excellent environment for fostering the abilities of these students. This shall be discussed in detail later in this narrative.

d) To continue to encourage more American students to enter the areas of mathematical research and education, and to provide them the opportunity to learn in an institution of outstanding quality. There are numerous American students of outstanding ability in small colleges or in branches of large state universities, many of whom are women or members of minority groups and many of whom have no family tradition of higher education. Often the mathematical background of these students is not as strong as that of those coming from more research oriented undergraduate programs. We have traditionally made an effort in our recruitment of graduate students to seek out students in this category who we feel can do well in our program. Again, the nature of our program and the perspective on which it is based are extremely well suited to success in this direction, and we make special efforts to help these students develop. This too shall be discussed later in the description of the overall structure of our program. These efforts have been very successful and it is our objective to be able to continue and expand our efforts in developing this pool of talent.

Our admission and recruitment procedures, which we discuss in detail later, involve the careful examination of students' past performance and the context in which this performance has taken place. We seek students of outstanding ability, and admit only those who are seeking to obtain a Ph.D. (An exception is made in the case of a separate departmental master's degree

program in financial mathematics. GAANN fellowships, however, will not be given to master's degree students.) In their applications, students are asked to describe their interest in coming to University of Chicago, and we can evaluate their desire to pursue careers in teaching and research. It is our policy to admit only those students who have these career objectives. To meet the purposes of the GAANN program, we evaluate domestic applicants separately and make special efforts to give opportunities to Americans with outstanding potential, understanding the variety of ways in which this potential can be manifested. Our procedures and objectives allow us to award grants to students of outstanding quality, drawn from both traditionally represented and traditionally under-represented groups. We will be careful to ensure that grants only go to those who satisfy the eligibility requirements of GAANN fellows.

## Extent of the Need for the Project

There is an overwhelming consensus in educational, governmental, and industrial circles that mathematics education in this country needs to be vigorously enhanced, and that mathematics research needs to be sustained and expanded in scope. There are numerous studies from these communities clearly demonstrating the national need for these activities, beginning with the half century old report [1], and there are recent calls for action such as [2]. However, a diligent search found few graduate level studies of substance in recent years. Annual data collected by the American Mathematical Society [5] is illuminating. Focusing only on data from the 48 group I Departments of Mathematics, there were 414 new PhD's in 2000 and 538 in 2010. While that is an increase of 30%, it is still a small total. There were 78 women in 2000, or 19%, and 125 in 2010, or 23%. Of the 125, only 66 were US citizens or permanent residents.

The numbers for under-represented minorities show negligible improvement. During the 1990s, NSF statistics [4] show that 71 PhDs in mathematics went to Black US citizens, an

average of just over 7 per year. According to [3], 10 African Americans received PhDs in mathematics at US universities in 2004. According to [5], the numbers for the years 2005-2009 were lower. There were only 6 African Americans and 6 Hispanics among the 538 cited above from 2010. In contrast, 136 of the 538, fully 25%, were Asian citizens on temporary visas. It is admirable that the US is open to talent from all over the world, but the demand for well-trained mathematicians is increasing elsewhere and there is no guarantee that foreign students will choose to remain in this country. Clearly we must recruit more US citizens, especially women and members of under-represented minority groups.

This is the general need that the proposed project seeks to address. This training is expensive, and it is difficult for us to continue our program with its current number of students without support of the type that the proposed project would provide, let alone increase the number as we propose to.

When we admit students for graduate study, we make an unconditional pledge of support for five years of work on completing their doctorate, assuming they are making satisfactory progress. In addition, we offer each student support for the summer, so that their research and education is not interrupted regularly by having to find other means of self-support. Learning to teach and to communicate effectively is an integral and required aspect of this program. Each student beyond the first year is expected to be in either the teacher training program (to be discussed in detail below) or to be teaching, unless a student receives support from a source which does not allow teaching responsibilities and requires research only. However, we feel it is important that each student teach only one course at any given time. This allows students to have time to concentrate on research and their own mathematical education, to concentrate effectively on the course that they are teaching, and to have time to be involved in outreach

programs. The bulk of the projected sources of departmental income to meet these financial commitments are funds from the University of Chicago, research assistant support from principal investigator NSF research grants held by individual members of the department, and until recently the department's now expired NSF VIGRE grant. The University is now committing approximately $2,500,000 per year of its own funds in support of our graduate program. This amount will be difficult to sustain in a period of economic retrenchment for all universities. Furthermore, the amounts available for research assistantship funds from NSF grants have also been under pressure. In the absence of other sources of funds, the necessary result would be a decrease rather than an increase in the numbers of students. The combination of GAANN and VIGRE grants have allowed us to avoid significant contraction. The fellowships that this project will allow us to give will enable us to train the number of graduate students that our educational, mathematical, and physical resources are capable of handling.

## The Quality of the Graduate Academic Program

For many decades, the graduate program in Mathematics at the University of Chicago has been ranked among the top six in the country. Most relevant to this proposal is that applicants admitted to Chicago or to one of the other five top ranked schools generally choose to attend one of the six unless there are special circumstances, such as two body problems, that lead to an alternative choice. The program at Chicago is quite different from those of the other five since it is tailored explicitly to work effectively not just for excellent students coming from exceptionally strong undergraduate programs but also for exceptional students coming from less strong undergraduate programs. It therefore has appeal to a broader segment of the population.

The first year program

In the first year we offer a carefully structured program of intense mathematical activity.

The goals of the program are to give students a working knowledge of a large body of mathematical ideas from a number of different mathematical disciplines. At the same time, the importance of communication, both with faculty and with other students, is stressed. The basic program consists of three 3-quarter sequences, one in algebra, one in geometry-topology, and one in analysis. There is a good deal of year-to-year variation since there is such a wealth of material that every educated mathematician should know. The algebra sequence usually contains material in group theory, representation theory, Lie theory, commutative algebra, homological algebra, and number theory. The geometry-topology sequence covers manifolds and differential topology, an introduction to connections and Riemannian geometry, Lie groups, and a course in algebraic topology covering basic homotopy and homology. The analysis sequence covers integration and basic functional analysis, more advanced topics in functional analysis and an introduction to partial differential equations, and complex analysis together with an introduction to Riemann surfaces and, in recent years, some probability theory.

These courses are challenging and intense, and although they begin with similar prerequisites, they cover significantly more than many other first year programs at other institutions. An important feature of these courses is that large numbers of problems, of varying difficulty, are given, offering the students a much greater working knowledge than "book knowledge" would provide. Students are encouraged to discuss the problems among themselves, which is the beginning of their learning the importance for their education of communicating outside the classroom and of collaborative research. All students are required to take these courses or to place out of them by demonstrating comparable knowledge and facility. For students with a particularly well developed interest, there is flexibility in the structure. For example, students intending to work in applied mathematics are required to take the analysis

sequence, and two other 3-quarter sequences, usually a sequence in dynamical systems and a sequence in analytical and numerical approaches to partial differential equations. Similarly, a student with a clearly developed interest in logic may take a sequence in that subject during the first year, postponing one of the standard sequences until the second.

Throughout the program, the importance of the interplay of ideas is stressed. Thus, the courses are not presented as isolated streams, but rather with an emphasis on the importance of the interaction of a variety of ideas and techniques in understanding basic mathematical phenomena. In addition to the courses, we also offer a series of special seminars throughout the year expressly for first year students, held in the evening. These are more informal presentations, designed to expose the students to a variety of more advanced themes in mathematics.

The nine courses the students take are each taught by a different senior faculty member. The evening seminars are given by senior faculty members who are not teaching one of the first year courses. In this way, in their first year, students typically have explicit interactions with most of the senior faculty members. The first year students all have desks in a common very large office space, with blackboards and couches as well, and this encourages collaboration in working on the problems in the first year courses and frequent spontaneous gatherings of small groups in which various mathematical issues are examined together. This combination of intense interaction with each other and extensive contact with the senior faculty helps to create an esprit de corps among our students that contributes to their sense of full membership in the department.

The first year program is a challenge even to those with very strong backgrounds. It is sometimes the case that students of excellent ability who come from less strong backgrounds have difficulty keeping up with the pace of the courses when combined with the additional work of having to fill in background that they may not have had. In this case, we sometimes remove

the student from one of the sequences, allowing concentration on the other two. Such students take a summer reading course to fill in background to prepare them to take the remaining course in the second year. If they complete the two sequences and reading course successfully, they are viewed as making satisfactory progress through the first year. This has been an extremely successful approach for many students and accounts in part for our success in training talented students from undergraduate programs that are not among the traditionally stronger ones.

The students' progress during the first year is carefully monitored. Interestingly, in our frequent solicitations of student input, the first year students have uniformly preferred not to have a formal assigned first year advisor. Rather, the co-chairs of the committee on graduate study, Benson Farb and Greg Lawler, and J. Peter May (the PI) talk frequently with all first year students and all teachers in the first year program to monitor progress. Students know that they can go to any of these people for guidance and help with any difficulties that may arise. Farb and May are also co-chairs of graduate admission and have generally met most of the incoming first year students before their arrival. There is an introductory orientation meeting for the entering students at the beginning of the year at which the program and resources for guidance are discussed, the PI holds an open house during the orientation period at which he discusses the program with all of the entering students individually, and there is a meeting late in the year to help students make the transition to the next stage in the program.

The Topic program

After completing the first year program, students begin working towards a deeper knowledge of a particular area or areas, aiming towards beginning their own research. There are two types of formal vehicles that we use. First, there is an extensive program of advanced courses and seminars, which we discuss below. Second is the main formal requirement of the

second year of graduate study, which is the completion of a required Topic Presentation. In cooperation with a faculty member, a student works out a program of study in an area of mathematics. This consists of reading books, articles, surveys, and discussion in a direction agreed upon by the student and a faculty member. This learning period generally lasts approximately 6-8 months, and it culminates with a lecture on the material by the student, followed by a period of extensive questioning by at least two faculty members.

During the middle of the period of preparation, the student must submit a formal written proposal, which describes the mathematical ideas and results to be presented. This is in the form of a several page written summary in which the student is expected to give an overview of the subject and to give an idea of how he or she is integrating and synthesizing the material. The proposal is read by members of the committee on graduate studies. After consultation with the faculty advisor, changes may be suggested, comments offered, and when deemed satisfactory, approval is given. The proposal is then distributed to the entire senior faculty for their approval. Thus the student's progress in this work is monitored at various levels of intensity by the advisor, the committee on graduate studies, and the senior faculty as a whole. We have found the Topic to be an extremely valuable approach to help with the difficult transitional period between being a student and becoming a researcher. The goal of the Topic is to move the students forward in this transition by encouraging them to integrate and articulate subjects for themselves. While working on a Topic, a student has regular contact with the faculty advisor.

Advanced courses and seminars

The Department offers an extensive list of advanced courses, seminars and lecture series. All our advanced students are expected to participate in these activities, and virtually all do so with enthusiasm. Each quarter, there are typically 10 to 15 advanced courses aimed at graduate

students beyond the first year (see Appendix A), and there are also regular student run seminars. These cover the entire expanse of the department's mathematical interests. In addition, there are weekly seminars throughout the year in a variety of areas: number theory, algebraic geometry, algebraic topology and category theory, geometric topology and differential geometry, dynamics and ergodic theory, representation theory, analysis, probability, applied mathematics, and group theory, as well as occasional seminars in logic and other areas of strength in the department.

The attendance in the courses and seminars includes graduate students, junior and senior faculty, visitors, and occasionally advanced undergraduates. The seminars are lively and offer the graduate students an excellent opportunity for exposure to mathematical ideas as well as informal interaction with faculty and visitors. The department's extensive visitors program brings in large numbers of excellent mathematicians from around the world whom the students can meet and with whom they can interact. All of this creates a very dynamic mathematical atmosphere in which the graduate students are active participants. There is also a special seminar held weekly by and for graduate students, called the "pizza seminar". This is a highly successful tradition. Faculty are not invited (but the Department pays for the pizzas), and the students discuss mathematical topics among themselves. Almost all students attend each week. There are in addition, four special lecture series held annually: The Albert Lectures in Algebra, the Zygmund-Calderon Lectures in Analysis, the Namboodiri Lectures in Geometry and Topology, and the Amick Lectures in Applied Mathematics. These are series of 3 lectures each, given by some of the world's leading mathematicians.

Special seminars and courses for graduate students

In addition to the large variety of outstanding advanced research seminars, which are part of a great tradition in the Department's education of graduate students, various new types of

seminars and courses have been developed in recent years. The first is a result of the appointments of A. Beilinson and V. Drinfeld. These two remarkable mathematicians are among the greatest algebraists in the world; for example, Drinfeld is a Field Medalist. They direct a seminar for graduate students and faculty on the Geometric Langlands Program. They have recently been joined by the 2010 Field Medalist Bao Chau Ngo. This seminar contrasts to the more traditional ones, in which a faculty member or visitor presents his or her own research. In the Geometric Langlands Seminar, faculty, visitors, and occasionally graduate students lecture to each other in an attempt to learn together one or another major topic. Other distinguished senior faculty participate in this popular and successful seminar.

A second new type of course that is now offered regularly is a year long seminar in which faculty in a given field teach material from some large mathematical area as a team, with the goal of giving students a deep and broad background in the area in which they intend to specialize. The first effort in this direction was a course in "geometric literacy," designed for all graduate students interested in specializing in geometry. This course is divided into modules that are typically 2-4 weeks in length. Each module is intended to give students an introduction to an important area of current interest. This course has turned out to be an important complement to the topic program as an effective way for students to make the transition between elementary and advanced material, and between formal book learning and conducting research.

A third type of new course is the topology proseminar, in which students and faculty introduce central material in topology and category theory for students working in those areas. It is to be distinguished from the topology preseminar, in which invited speakers in the algebraic topology seminar present background material helpful or necessary to understand the actual seminar. As with the other courses and seminars described in this section, the topology

proseminar and preseminar also give students the opportunity to interact with faculty and visitors to discuss subjects of current research interest.

Together, these new courses represent a very special opportunity for graduate students to learn from some of the greatest mathematicians in their chosen area of specialization, and are some of the most exciting developments in graduate education in the Department in some time.

Dissertation

In addition to the course requirements and Topic presentation described above, the requirements for completing of the doctorate degree are the completion of a dissertation and passing a language exam (in French, German, or Russian). Of course, the dissertation is the central requirement, and students work closely with their dissertation advisor towards the completion of this project. The seminars and courses are designed to encourage the development of the perspective of a researcher. Students are encouraged to speak in seminars to report on their work as it progresses, and thus to obtain input from others. The final requirement is presentation of the dissertation results at a dissertation defense.

Faculty and research

The University of Chicago Department of Mathematics is one of the country's most distinguished in terms of research achievement. It consistently ranks among the leaders in national surveys. There are 32 tenured faculty members, (see Appendix B), 6 of whom have joint appointments (4 with Computer Science, 1 with Statistics, and 1 with Neurology). The 32 do not include the President of the University of Chicago, Robert Zimmer, and the Dean of its Physical Sciences Division, Robert Fefferman, both of whom are mathematicians; Fefferman has written a letter of support included in this proposal. There are also several active Emeritus faculty, several people with permanent associate appointments, and several regular annual

visitors. All of these are an active presence in the Department.

Remarkably, 8 of the 32, a quarter of the faculty, have been hired or promoted to tenure within the past three years: In addition to Bao Chau Ngo (Langlands program), they are Marianna Csornyei (analysis), Matthew Emerton (number theory), Kazuyo Kato (arithmetic algebraic geometry), Leonid Polterovich (symplectic topology), Amie Wilkinson (dynamics), Roger Lee (financial mathematics), and Antonio Montalban (logic). Wilkinson is the winner of the 2011 Ruth Lyttle Satter Prize. A professorship offer is also out to our current visitor Katherina Stroppel. We emphasize that three of these people are women. That is no accident. The department formed a special committee focusing on the identification of top women mathematicians who might possibly be attracted to Chicago. This entailed exploration beyond the fields in which we already had expertise. These appointments not only begin to rectify the lamentable absence of women professors in the department, they also markedly broaden the range of mathematical areas of study available to graduate students. Even more remarkably, every one of these new professors is a mathematician who loves to teach and wants to do so. Csornyei, Emerton, Kato, Ngo, Poterovich, and Wilkinson are all teaching in the first year graduate program in 2011-12.

This distinguished faculty, most of whom have spoken at the International Congress of Mathematicians, in turn attracts an outstanding junior faculty, which now numbers 26, of whom 7 are women. It is taken for granted that women postdocs will be hired each and every year. We have a very diversified, active, dynamic, and distinguished faculty with an outstanding record of published research. It is also a faculty with a great commitment to teaching. Three of its members (Robert Fefferman, Diane Herrmann and Paul Sally) have won the University of Chicago Quantrell Award for Excellence in Undergraduate Teaching and three others (Victor

Ginzburg, J. Peter May, and Benson Farb) have won the university award for excellence in graduate teaching. Paul Sally won the 2000 Award for Distinguished Public Service of the American Mathematical Society and the 2002 Deborah and Franklin Tepper Haimo Award for Distinguished College or University Teaching of Mathematics.

The record of the Department in producing PhD students speaks to its commitment to graduate education. The entire graduate program is designed from the premise that faculty are available and accessible to students, starting from the initial interaction with faculty members in courses and evening lectures in the first year, and continuing with regular contact and interaction in advanced courses and seminars. The physical structure of our buildings and the neighborhood also contribute to this accessibility and feeling of community. All students have offices in the main mathematics building, Eckhart Hall, or in a nearby building. Newly renovated space for graduate students has just been made available this year. The majority of the faculty live in Hyde Park, in close proximity to the University, and the amount of time they typically spend in the department is very high.

The faculty of the Department of Mathematics is chosen on an equal opportunity basis.

Recent production of doctorates

The Department has had a record of producing excellent PhD's ever since the University was founded in the 1890's. The faculties of most leading departments of mathematics in the U.S. include alumni of our department. Just over the past five years, 76 students have received PhDs from our department, 48 of them American and 19 of them women. Many of them are now at leading research universities around the US.

Retention rate

Our goal is to guide every student who enters to completion of the doctoral program.

Students are generally asked to leave the program only if they are not making satisfactory progress, and only after we have made every effort to help them eliminate any obstacles standing in their way. Even then, we help them gain admission to less demanding programs than ours. It is important that those few people who do leave the program do so early, and our attrition beyond the second year is negligible. Of the 168 people who matriculated in the ten years between 2002—2011, 66 completed the PhD, 83 are current students in good standing, 5 are in graduate school elsewhere, and 2 are not enrolled but are expected to complete the PhD.

An NSF VIGRE grant and its benefits

In 2000, the Mathematics Department was awarded a five-year VIGRE grant, which was renewed for an additional five years in 2005 and extended through the summer of 2011. This grant substantially enhanced the quality of our graduate program, but it had an even more marked effect on the undergraduate level. The synergy between the levels is central to what the department has accomplished in the past decade. We will devote our Supplement to telling our remarkable success story on the undergraduate level and showing how it relates to our GAANN proposal and to the goals of the GAANN Program as a whole.

## Supervised Teaching Experience

The Department of Mathematics of the University of Chicago has a long history of careful supervised training of our graduate students as teachers. The care with which this program has been built and the success it has achieved can be seen by the University's own policies. The University traditionally was very restrictive in the use it allowed of graduate students as teachers. The most significant exception was in the Department of Mathematics, where we developed a program that the University views so highly that it was for years the only major graduate student teaching program in the University. Now the University has moved to allow greater activity for

graduate teaching in other subjects, and other departments are using the model of the Department of Mathematics for training their graduate student teachers. The success of our program is reflected in the report of an External Review Committee for Computer Science, Mathematics, and Statistics at the University of Chicago, chaired by Prof. G.D. Mostow of Yale University, former President of the American Mathematical Society. This Committee reported:

> "The undergraduate mathematics program is an extraordinary success story. No less than 5% of the undergraduate student body select mathematics as their major. Even the most elementary calculus course at Chicago demands a level of rigor that has been abandoned everywhere else we know of. Rather than drive students away from mathematics, which would be the standard wisdom elsewhere, at Chicago mathematical rigor seems to fuel the intellectual appetite of the Chicago Freshmen.
>
> "This success is rooted in labor intensive instruction. The organizing skill and hard work of Paul Sally and Diane Herrmann are basic ingredients. Another is the faculty supervision and mentoring of the graduate student teaching assistants. The impressive results justify the cost of the undergraduate program. The list of prestigious graduate mathematics departments into which Chicago math majors are admitted is much longer than that of larger excellent universities."

As we will point out in the Supplement, the undergraduate mathematics program has become even more successful in the period since that report was written, with over 8% of Chicago undergraduates currently majoring in mathematics. Much of this is due to the effective participation of graduate students in the undergraduate teaching program, which in turn, through VIGRE, led to their role in the new REU and DRP programs discussed in the Supplement.

Graduate students in Mathematics at the University of Chicago receive extensive training before being assigned to their own classrooms to teach undergraduate classes, and they receive considerable support and supervision once there. In their first year of graduate study, mathematics graduate students have no teaching obligations and are expected to focus on their required courses. The students' formal training as educators begins in their second year of graduate study, with our College Fellow program, which has been in operation since 1972. This is a one-year program. It must be completed by every student, regardless of source of support or

field of interest. In the second year of graduate study, after completion of the Master's degree, graduate students become College Fellows and are assigned to senior members of the department, who serve as mentors to the College Fellows. The students attend a course taught by their faculty mentor and serve in the course as apprentices.

In this capacity, the student spends the year watching and working with an expert teacher, learning how to give lectures, how to assign and grade homework and exams, how to design exams, how to interact with students, and how to assign final grades. He or she attends the course the mentor is teaching and, under the careful supervision of the mentor, prepares a number of homework and test problems and runs review sessions. Techniques concerning these tasks, lecturing, and other pedagogical issues are discussed in individual meetings. The College Fellow gives one or more supervised lectures, usually one in the Autumn Quarter and then a sequence of several consecutive lectures on a given topic in the Winter and Spring Quarters. There is immediate feedback. The lectures are discussed and analyzed in detail with the faculty mentor. The College Fellow holds office hours, grades homework, and learns by observing a classroom in which he or she already knows the material. At times this means watching what to do and at times this means watching what not to do. The College Fellow is expected to provide feedback from the undergraduate students to the faculty member teaching the course. In effect, the undergraduates benefit from having two teachers.

The College Fellow Program is supervised by Paul Sally, Diane Herrmann, and John Boller who are the Director, Associate Director, and Assistant Director of Undergraduate Studies. In the week before the Autumn Quarter begins, they hold orientation meetings with the College Fellows and with all teachers in the undergraduate classes. At these meetings all manner of details of organization, procedure, classroom technique, activity outside the classroom, expectations, and grading are discussed, and both College Fellows and teachers are given

guidance on the overall structure of Chicago's undergraduate program and the role in it of the class to which they have been assigned.

After satisfactory completion of the College Fellow year, a third year student is deemed ready to give stand-alone lectures and is appointed a Lecturer in the College. Students in their third, fourth, and fifth year teach their own classes, with undergraduate tutors and graders serving as assistants to them. These are regular undergraduate classes and range from pre-calculus through calculus and linear algebra. Their syllabi and texts are set by the department, but the Lecturer writes his or her own lectures, homework assignments, and exams, and he or she assigns final grades. Expectations of the material to be covered are explained in detail during the September orientation meetings.

The students' progress as teachers is monitored very carefully. Their classes are visited by a senior faculty member, who makes a written report to the Director of Undergraduate Studies. This report is discussed with the student. If there are areas that need improvement, these are noted and discussed, and the student is revisited shortly thereafter. The Associate Director of Undergraduate Studies makes a written report to the Master of the Collegiate Division of Physical Sciences, who must approve any reappointment of the student as a Lecturer. The Associate and Assistant Directors of Undergraduate Studies are also in very close contact with the undergraduates, who know to whom they should bring grievances, and any difficulties with teaching by graduate students are spotted informally in this way. Students who have particular difficulty with becoming good teachers are given extra attention and receive extensive individual help from Sally, Herrmann, and Boller.

In addition to this very careful and attentive formal structure, an important factor is the cultural emphasis in the Department and the University on the importance of teaching and

communication. Not only are the graduate students given instruction and training in teaching, but the junior faculty are as well. It is made very clear to new junior faculty members that teaching is taken very seriously and is a very important part of their responsibilities. Advanced undergraduates also play a role in this culture of teaching. They serve as tutors and graders, and they also have the opportunity to serve as University Tutors, in which role they hold extra work sessions for freshman in a variety of courses. The culture of teaching pervades the program.

## Recruitment Plan

Graduate student selection and recruitment is a major activity of the Department of Mathematics and one it approaches with great care and attention. The selection process is carried out by the Graduate Admissions Committee. Applications are invited in notices that appear in national mathematical publications, and in flyers sent to large numbers of individual colleges and universities, including small colleges and traditionally predominantly African-American institutions. In addition, we contact faculty at colleges and universities, particularly our alumni, who are in a position to encourage students who would be good candidates for our program. Our applicant pool has traditionally been large and has recently increased sharply, mainly due to increased numbers of foreign applicants. We had 170 applicants in 1989, 250 in 1999, 343 in 2009, and 426 in 2012, including 200 US citizens and nearly 100 Chinese citizens; the remaining applicants were a veritable UN. The current co-Chairs of the Admissions Committee are Benson Farb and J. Peter May. The committee as a whole consists of 9 tenured faculty members. This year each application was read first by Farb and May and at least one other committee member. They selected all plausible candidates for admission and posted the names on an on-line spreadsheet accessible to all committee members. They all ranked these applicants and, after intense discussion, they chose which students to admit.

In 2010, two African Americans matriculated, and one Hispanic matriculated in 2011. All three are doing well. We have accepted two African Americans, one of whom is female, and one Hispanic for 2012, and we are actively working to recruit them. These are admittedly small numbers, but in view of the tiny annual number of new PhDs graduating from Group I universities from these under-represented groups, they are at least a step in the right direction. In a continuing and disappointing recent trend, the number of women applicants we felt sure would benefit from the program and would have an excellent chance of completing the program was disappointingly small. We will vigorously recruit the dozen we admitted. We note that 24% of Chicago's current mathematics graduate students are women. While we would like to do better, a check on the web shows that only between 10% and 16% of the graduate students at the other five of the top six graduate departments in mathematics are women.

We actively seek applications of women through extensive networking, both in terms of explicit requests to our alumnae, who are in a position to be mentors to talented young women undergraduates, and direct efforts at outreach, such as contacting women who have won, been runners-up or received honorable mention in the competition for the Alice T. Schafer Prize, administered by the Association for Women in Mathematics. The co-Chairs of Graduate Admission, Benson Farb and J. Peter May, have between them been advisors to 21 women PhDs since 1998, and between them they have 6 current women students. They take special responsibility for the effort to recruit women and minority students.

We seek students with outstanding natural ability. Many of our students come with outstanding records and backgrounds from the leading universities in the country. However, in view of our commitment to provide opportunities to traditionally under-represented groups, we regularly and deliberately admit talented students from small colleges and less renowned

universities. They sometimes have weaker mathematical background than those admitted from top research universities, but the design of our program allows them to thrive. There are often circumstances, such as a late decision in college to major in mathematics, that can superficially mask an applicant's potential. While we do not admit people we think are unlikely complete the program successfully, we do try to ensure that our evaluation takes all issues into consideration and focuses on the potential for mathematical growth that the applicant shows.

All students whom we admit are guaranteed five years of full financial support for the nine-month academic year, assuming satisfactory progress; in practice, we give six years of support to students who need an extra year to complete the PhD. This includes a full stipend (which for 2012-2013 is $21,350 for the 9 month academic year), full tuition and health coverage. We also offer summer support of $4,000 for each of the first four summers. We offer selected students the departmental Amick Fellowship or the divisional McCormick Fellowship, either of which gives a $4500 yearly supplement to our standard stipend for a period of two years. These are assigned on a competitive basis.

All admitted students are invited to visit the Department at the University's expense (up to a cap of $750). During this time, they meet with faculty, attend courses, talk to graduate students, and attend social functions. Their visits are coordinated by a committee of second year graduate students. Many of the visitors stay in the homes of graduate students. We have found this to be an extremely effective recruitment practice. One reason that this is so successful is the very positive, engaging, and dynamic atmosphere in the department. Another is the contribution of current graduate students. They are eager and effective recruiters of prospective students. Our candidates are among the top in the country and indeed the world, and in recent years we have had an acceptance rate for our offers of around 30% despite fierce competition. We

regularly have a number of students who have won NSF, NDSEG or other similar fellowships in a national competition. Their excellence is also seen in the end result, which is the quality of their work and the nature of the positions they obtain after completing their degree.

The information we receive from applicants makes it clear which students are eligible for a GAANN fellowship. We only accept students into the Department who have the intent of working towards a PhD (with the exception of our Master's program in Financial Mathematics, which has a separate admissions process). We evaluate all students in terms of their academic excellence and ability. In addition, an essay is required discussing their long term objectives, so we are able to identify those who plan a career in teaching and research. Information on nationality and residency status is required of all successful applicants. Before a student is appointed as a GAANN Fellow, financial need is ascertained. The Department requires each student to provide a Statement of Projected Income, which is forwarded to the Graduate Financial Aid Office of the University. Need is determined in a uniform way throughout the University by this office. The University of Chicago determines GAANN Fellows' eligibility for stipends by using the Federal Needs Analysis Methodology, the formula used to determine students' eligibility for Title IV programs. The methodology takes into consideration the student's cost of attendance, income, assets, and family size. In this way, all requirements for carefully and properly ascertaining that a potential fellow is indeed eligible for a GAANN Fellowship will be fulfilled.

One of the most important features for recruitment and retention of traditionally under-represented groups is individual attention, and an environment in which it is clear that they are important and integral members of the community. As explained above, this is a strong feature of our program and one in which we make a particular effort. The esprit de corps and close

connections of graduate students also provide a supportive environment. In addition, the Department's efforts at community outreach and the importance we attach to it is a further message of the Department's commitment to help individuals on their own terms. These are features of our departmental program that are particularly well suited to creating an atmosphere in which women and traditionally under-represented groups can flourish. In addition, there are special directed efforts towards these groups on the part of the University as a whole and the Physical Sciences Division (PSD), which will be discussed under Institutional Commitment.

Our success in attracting and training talented women as graduate students is excellent. In the past eight years we had 31 female students who completed doctoral degrees. Most of them took academic positions at American universities or colleges, including 3 at Michigan, 2 each at Harvard, Yale, Cornell, and Notre Dame, 1 each at MIT, Stanford, UC Davis, UC Riverside, Northwestern, UIC, UIUC, Indiana, Purdue, Ohio State, Arizona, Colorado State, and Oklahoma. A number of female students who have graduated within the past fifteen years have attained remarkable success in the academic world; they include tenured professors at MIT, Columbia, CalTech, and Johns Hopkins. Currently 8 of our Dickson Instructors are women. At a younger level, over the past decade 3 or 4 women per year have gone on to graduate study in mathematics after obtaining a BA at Chicago. With the combination of these outstanding female undergraduate mathematics majors, graduate students, and junior faculty, and with our two and possibly three new women full professors, we feel that Chicago is now a leader in creating a positive environment for the development of the abilities of young women in mathematics.

There are very few representatives from minority groups who are entering mathematics at the graduate level. We do not believe that there is a simple and quick solution to this problem. However, our Department has taken the lead in attempting to make a significant contribution to

the long-term solution of this problem, while at the same time continuing our efforts to identify current potential candidates. The Department runs three major outreach programs that are designed to foster the education of talented students from traditionally under-represented groups and to encourage their interest and abilities in mathematics. Over the long term, these programs, and others like them, can have the effect of changing the atmosphere for these students and encouraging some of them to go on to careers in mathematics teaching and research.

One of the programs, the Young Scholars Program run by Paul Sally, is for gifted Chicago area students in grades 7-12. It has an intensive work period during the summer and meets regularly on weekends during the academic year. This is an exciting enrichment program for these students, and our own graduate students are enthusiastic participants in this educational experience. The program has a very high representation of women and African-Americans. It is partially supported by funds from the University of Chicago. We cannot claim large numbers, but an illustrative success story shows how our programs can ideally recruit minority students. One African American from the south side of Chicago participated in the YSP as a high school student, attended the University of Chicago and participated in its REU, became a Churchill Scholar, obtained a PhD in mathematics from MIT, and has since been a Dickson Instructor.

The other programs are enrichment programs for Chicago Public School teachers of mathematics, run by Robert Fefferman and Paul Sally, respectively. These are designed to further stimulate the mathematical efforts of these teachers and, for many of them, to bring them back into the larger community of mathematics and mathematics education. They have been very successful programs, and the help these teachers are given in communicating the excitement of mathematical ideas will in turn help stimulate the mathematical and educational interest of students enrolled in the Chicago public schools. These are of course projects with long term

goals. But we believe them to be among the most important things we can do now to ultimately bring the number of many traditionally under-represented groups in mathematics research and education up to levels that all of us would like to see. In the interim, we try to identify current potential candidates through the significant personal contact that many of us have with people working at traditionally African-American institutions and at other colleges and universities throughout the country.

At the University level, another program relevant to these goals is the Collegiate Scholars Program, specifically its component in mathematics. This is a three-year enrichment program offered by the University of Chicago specifically for Chicago Public Schools students. Ninth-graders who have distinguished themselves through their academic achievements and contributions to school and community are invited to apply. The program is offered free of charge to approximately 50 selected scholars per year. Several faculty members of the Department teach in the program.

## Project Administration

The proposed project will be administered by J. Peter May (the GAANN project director), Shmuel Weinberger (the Chair of the Department of Mathematics) and Benson Farb and Gregory Lawler, (the co-Chairs of the Committee on Graduate Studies). As already noted, Farb and May are also co-Chairs of the Graduate Admissions Committee. Fellows will be selected by the project director and the Committee on Graduate Studies. We shall award these fellowships to the best of the students in their respective classes who meet the GAANN requirements of need and do not hold other fellowships that would render them ineligible. This will be determined for entering students by information from the Graduate Admissions Committee on the members of the entering class, and by performance to date for more advanced students. The Department will

make all decisions concerning those otherwise eligible without regard to race, color, national origin, religion, gender, age, or disabling condition.

The structure of our program has inherent within it an ongoing monitoring of the students' progress toward the PhD, and the attention of the Committee on Graduate Studies provides further information. During the first year, students are asked in all three courses to submit a significant amount of written work on average about once a week. This work is read and graded by (paid) advanced graduate student graders. There are also mid-term and final exams in most of the courses. Any student doing unsatisfactory work is spoken to by the instructor and either Farb, Lawler, or May. In practice, things are less formal. Students know when they are having difficulty, and they know that they should seek advice from a faculty member right away. The orientation sessions before classes begin are very clear about this.

At the end of each course, if a student has not done completely satisfactory work, he or she will either be asked to complete additional written work and possibly take an extra examination on the course material at the end of the academic year; in very rare cases the student will have to retake the course. In the latter case the student is no longer deemed to be making satisfactory progress. At the end of the first year, the entire faculty meets to discuss each first year student's progress. During the second year, the student submits the Topic Presentation proposal as discussed above. This is read by the entire Committee on Graduate Studies and then, perhaps after some suggested changes, by the entire faculty. In addition, the student has regular contact with the advisor for the Topic Presentation. A written record is made of the student's performance on the Topic Presentation. Beyond the second year, a student works with an advisor on a dissertation. Each year the Committee on Graduate Studies interviews each advisor for each student to determine the progress that is being made, and each advisor submits a written

report on his or her advisees. If at any time a problem is revealed, the advisor and/or a representative of the Committee on Graduate Studies will speak to the student. This monitoring continues through to the completion of the degree.

A basic feature of our program is communication and the integration of the student as a full member of the Departmental community. Students are encouraged at all times to bring any issues or concerns they might have to the attention of May, Farb, Lawler, Weinberger, or any other faculty member. In addition, regular meetings are held with all students at various stages to discuss issues they will be confronting. For instance, at the first year orientation meeting students are encouraged to consider any variation in the first year program that may better satisfy their own academic needs (such as taking a logic sequence and postponing one of the standard sequences until the following year.) First year students meet with representatives of the Committee on Graduate Studies later in the first year, which gives them an opportunity to bring up any problems or special needs that may have arisen. There are also meetings regarding their entry into the College Fellow program and into teaching. There are meetings that discuss the nature of appropriate Topics, what they should consist of, and how to get help with them. Advanced graduate students also hold meetings with first year students to talk about the Topics and about faculty advisors. We try to anticipate what types of concerns and needs may arise. But a very important aspect of the program is the atmosphere that encourages any student to come to any of us at any time to bring forward special needs or concerns.

For students coming from traditionally weaker programs, our policy of making special arrangements for them in terms of the first year program can play an important role in their potential for success. The esprit de corps and close connections of graduate students also provide a supportive environment. The department's efforts at community outreach and the

importance we attach to it is a further message of the department's commitment to helping individuals on their own terms. In addition to efforts at the departmental level, there are valuable University and Divisional activities that actively provide support to under-represented minorities and women and help ensure their retention. For example, the University's Office of Minority Student Affairs has recently been reorganized to provide more comprehensive services for graduate and undergraduate students across the University. In addition, there are over fifty recognized student organizations for under-represented students, which host many social and networking events throughout the year to build community among under-represented graduate students across campus.

The Department has extensive experience in the administration of federal grants. The current Committee on Graduate Studies has considerable experience in administering the graduate program, and functions very effectively in dealing with the variety of tasks it faces. Paul Sally, Diane Herrmann, and John Boller have a truly outstanding record in administering the undergraduate teaching program, which includes training and advising graduate student College Fellows and Lecturers. In addition, there are two key staff members who would devote considerable time to aiding the project director in administering the project. The Department has an Assistant for Graduate Studies whose sole responsibility is to do the staff work related to administering the graduate program. She works directly with Farb, Lawler, and May in their roles as co-Chairs of the Committee on Graduate Studies and the Graduate Admissions Committee. She will be involved as staff support for the administration of the project. In addition, we have a knowledgeable Financial Services Representative, who has long experience in administering federal grants and managing budgets and who will be involved in the administration of the financial aspects of the project.

## Institutional Commitment

The Department of Mathematics at the University of Chicago unconditionally guarantees all admitted students full support including stipend, tuition, and summer support for 5 academic years, assuming the student is making satisfactory progress towards the completion of the PhD. The Department guarantees that all students supported under the proposed project will have the benefit of this guarantee, independent of funds available on the proposed grant or termination of the proposed grant. In fact, students in good standing who require more time are given six rather than five full years of support. Furthermore, during the tenure of this grant, the University of Chicago will supply matching funds of over $700,000, well in excess of 25%, by virtue of the Department's paying the remaining tuition due in excess of the tuition funds available from the institutional allowance of the program. At just over $77,000 per student, the total cost of the current 32 first and second year students, who have no teaching duties or are College Fellows, is approximately $2,500,000, most of which comes from University funds. In addition, the Department purchases a good deal of computer equipment and has invested a significant amount in an extensive computer network, including a computer lab and computers in many graduate student offices, and it continues to invest in hardware, software, and support. Fellows have unlimited free access to this network. The University also spent a considerable sum during the summer of 2011 renovating space for graduate student offices.

The commitment of the University of Chicago to the goals of the GAANN Program is made manifest by the resources that it made available to the Department of Mathematics to allow it to make simultaneous full professorship offers to three superb women mathematicians.

There are a number of recent university-wide initiatives that also illustrate this commitment. William McDade was appointed Deputy Provost for Research and Minority Issues

in 2011. He had previously provided leadership in recruiting young minority scholars for academic medicine careers. Chinonye Nnakwe was hired as the University's Director of Graduate Diversity Recruitment in 2011. She travels to undergraduate research conferences to meet prospective recruits, connects with diversity officers at undergraduate institutions, and is currently planning a first-ever campus-wide Visit Weekend for minority students admitted to graduate study at the University of Chicago. The University also launched a new website, devoted to news, events, affinity groups, and support services, among other things (http://diversity.uchicago.edu/).

Mary Harvey, Associate Provost for Program Development, heads the Women's Leadership Council, which advises the Provost on policies and programs for attracting and retaining the finest women scholars university-wide. The Women in Science Project organizes events that bring women faculty in the sciences together to share their work, make connections centered around shared research interests, and build community to counter-balance the isolation that some might experience in their departments. The University entered into a three-year partnership with Northwestern University to advance women faculty in science, technology, engineering, and mathematics (STEM) disciplines at our institutions. Through joint programs and research projects, the partnership aims to identify obstacles our women faculty see to success in the sciences, encourage women to be deliberate and purposeful in planning their careers, open women's eyes to leadership possibilities, and create and expand women's networks.

At the Divisional level, as described in the Dean's letter of support, the PSD has organized two standing committees to identify policies and actions that will help the PSD increase the number of women and minorities in its programs. Both have members from the Department of Mathematics. Farb is Chair and Kevin Corlette is a member of the PSD Diversity Committee,

and Farb, May, and Diane Herrmann are members of the Women in Science Committee.

The Diversity Committee in the PSD collaborates with the Diversity Committee in the Biological Sciences Division to organize regular social events for minority graduate students across the two Divisions. These social events help students meet a broader community of scientific colleagues with diverse backgrounds. The two Divisions offer a Scientific Diversity Weekend for minority students who have been admitted to Ph.D. programs. Admitted students visit the campus to meet current students, attend a career panel discussion, listen to research talks by current faculty and students, and get to know each other at evening receptions. Among other things, the Women in Science Committee helps departmental search committees become more aware of unconscious bias when recruiting new faculty and hosts speakers who bring remaining obstacles to light. For example, Nancy Hopkins, Professor of Biology from the Massachusetts Institute of Technology gave a talk in 2011 about how she and her colleagues at MIT worked to change the status of women at MIT, and the Yale Astrophysicist C. Megan Urry will give an analogous talk in 2012.

These university wide and divisional initiatives are complemented by less formal practices at the departmental level which contribute to the support of women in the Department. These include traditions such as a quarterly tea for women in mathematics in the Chicago area, which brings together female graduate students and faculty, and the recent organization of a student chapter of the Association for Women in Mathematics. Both the organizing first president and the current president of the Department's AWM chapter are students of May. The AWM and all its events are open to everyone. The AWM chapter seeks to create a sense of community for women at all levels who are interested in mathematics. It hosts game nights which allow interested undergraduates to get to know women graduate students; it hosts coffee-breaks to

welcome new women post-docs and faculty and to allow the graduate students to get to know them better in an informal setting; each spring it organizes a panel on applying to graduate school; and it invites women from Chicago and elsewhere to give colloquium talks and to have an informal lunch with the graduate students to discuss issues faced by women in mathematics, job applications, job concerns, career/family balance, and other relevant matters. As already noted, the Department has had marked recent success in recruiting women faculty members. The increasing visibility of women on the faculty should serve as an encouragement to female students, both undergraduate and graduate, who aspire to a career in research and teaching.

## Key Personnel

The project director is J. Peter May, Professor of Mathematics, who is co-Chair of the Committee on Graduate Studies and of the Graduate Admissions Committee. He is a well-known researcher who has himself trained 50 PhD's and has 8 current PhD students. He was also the director of the VIGRE program and the organizer of its REU, about which more will be said in the Supplement. He is a past chair of both the Department of Mathematics and the University of Chicago's Council on Teaching, and he is a past member of the Joint Committee on Women in the Mathematical Sciences (a joint committee of seven national mathematics teaching and research organizations.) He has been deeply involved in the development and running of the graduate program for forty-five years (and he has no intention of retiring.)

Benson Farb and Gregory Lawler, as co-Chairs of the Committee on Graduate Studies and Farb as co-Chair with May of graduate admissions will share in the management of the project. Farb is a geometer who has trained 20 PhDs and has 8 current PhD students. Remarkably, 13 of these 28 are women. Farb and May are winners of the Faculty Award for Excellence in Graduate Teaching at the University of Chicago. Lawler is a probabilist who has trained 13

PhDs and has 5 current PhD students. Shmuel Weinberger is Chair of the Department of Mathematics as of January, 2012. He is a topologist who has trained 13 PhDs and has 5 current PhD students. All four will work together. They have long experience of doing so. Their CVs are collated and included in this proposal.

The current members of the Committee on Graduate Studies are Kevin Corlette, Marianna Csornyei, Alex Eskin, Benson Farb, Victor Ginzburg, Denis Hirschfeldt, Carlos Kenig, Gregory Lawler, J. Peter May, Leonid Polterovich, Paul Sally, Wilhelm Schlag, and Takis Souganidis. The current members of the Graduate Admissions Committee are Eskin, Farb, Ginzburg, Hirschfeldt, May, Schlag, Souganidis, Sidney Webster, and Amie Wilkinson. All of these are tenured members of the Department of Mathematics, and all are well-known researchers. Farb, Ginzburg, May, and Sally have all won university wide teaching awards; Sally is one of the country's leading mathematics educators, and his CV is also included. The members of these two committees collectively have a great deal of experience in graduate education, have taught numerous graduate courses including the first year sequences, and all have advised students working on doctoral dissertations. In addition to the members of the Committee on Graduate Studies, Sally, Diane Herrmann, and John Boller are important participans in the project since as Directors of the Undergraduate Program they play a central role in overseeing the training of our graduate students as teachers.

The time commitment of each of these key figures to the graduate program is very significant. It is of course difficult to separate out much of the time for administration of the proposed project from the administration of the graduate program in general. The same is true for the commitment of time for the educational responsibilities of these persons. May spends roughly 10% of his working time on the administration of the graduate program, doing a lot of

work informally in the background and, more important, spending a great deal of time talking with graduate students. The same can be said of Farb and Lawler, who are among the most popular and gregarious of the faculty members. The remaining members of the Committee on Graduate Studies spend perhaps 5% of their time, 20 hours/quarter on the administration of the graduate program. The work of the Admissions Committee is concentrated in the first weeks of the winter quarter, when each member of the committee spends at least 25 hours in the evaluation and selection process. They later spend considerable time in the recruitment process. All members of both committees, and the Department Chair, spend many hours each week in the multifaceted aspects of the educational process itself. However, under any circumstances, the project director and other key personnel are committed to investing all the time necessary in order make the project function efficiently and effectively and to achieve the aims of the project. All employees of the University of Chicago, and all personnel to be involved in this project, are selected without regard to race, color, national origin, religion, gender, age, or disabling condition, except pursuant to a lawful affirmative action plan. All searches for new employees at every level are done in such a manner as to ensure the opportunity for all interested and qualified candidates to be considered fairly.

## Budget

Program funds will be used to pay stipends to students who are eligible to become fellows under the program. The institutional allowance will be used to pay for a part of the students' tuition. (For all students in the first three years of graduate study, the tuition charge at the University exceeds the institutional allowance.) Precisely, for the first year, the total of stipend, tuition, and fees is $77,653 per student, of which $43,975 will be chared to the GAANNs grant and $33,678 is matching funding from the University.

The costs of the project are based on an award of 5 fellowships. The scale of the proposed award is commensurate with the size of our doctoral program, and will enable us to achieve the goals set forth in this proposal.

## Evaluation Plan

The ultimate measure of success of the project will be the training of excellent researchers and educators in mathematics, and the degree to which it brings about a broadening of the representation in these areas of traditionally under-represented groups. A minor aspect of evaluation and reporting is budgetary, verifying the amount of funds spent for a given purpose and verifying that all funds are spent appropriately. Our evaluation relating to the specific goals of the project will be of two types, one for the progress of each individual fellow, and one of aggregate data. This information will be collected by the Assistant for Graduate Studies from evaluations made by the Committee on Graduate Study, the instructors in courses, and faculty advisors to students both in the Topic Presentation stage and the dissertation stage. This data will be assembled, evaluated by the Committee on Graduate Studies, and reported at the end of each academic year by the project director. In the first year, each student will be evaluated for successful completion of the first year program of courses. In the second year each student will be evaluated on the satisfactory completion of the College Fellow program and the Topic Presentation. In the third year and beyond, students will be evaluated on progress towards their dissertation, possible completion of the dissertation, and their performance in teaching.

Questions involving aggregate data that we will assemble, evaluate, and report on will be:

a) numbers and rate of satisfactory completion of each evaluation question at each stage;

b) rate of attrition of fellows compared to the rate of attrition of those not receiving the award;

c) years to degree, and comparison to the years to degree of those not receiving the award;

d) numbers and degree of success of women and other traditionally under-represented groups.

In truth, these are soft measures. We expect all first year students, whether or not supported on GANNS fellowships, to successfully complete the first year program. We expect no attrition and will regard it as a distinct negative if there is any. Of the 168 students who matriculated in the past decade, 5 students transferred in good standing to other graduate programs (MIT, Stanford, CalTech, Oxford, and Toronto), all for personal reasons or reasons of field, 1 died in a tragic accident, and 4 dropped out in favor of more remunerative jobs. Of the ten people who transferred, died, or dropped out, not a single one was a woman or minority student. Without exception, all students who matriculated over the past four years are still here and are in good standing. With very few exceptions, all students complete the PhD in five or six years, and there is no onus on taking six. Of the 40 new PhD's in the past three years, one student took seven years and one (a woman who is now an NSF postdoc and Benjamin Pierce Assistant Professor at Harvard) took only four. Therefore the numbers we report are unlikely to be very informative. The number of new matriculations will be more significant; depending on our success at recruiting those who meet our standards, we aim for at least 16 and at most 18 new students each year. We aim to have a quarter of our graduate students be women and to matriculate at least 1 to 3 minority students each year. We will report on whether or not these goals are met.

The nature of the evaluations of the progress of individuals and their methods of collection were discussed above, and we briefly review them here. First year students are evaluated by instructors in their courses. Grading is on a pass/fail basis, and written evaluations are sometimes added. These are evaluated by the Committee on Graduate Studies and then by the entire Department. Students are judged to be making satisfactory progress or not. In the second year, performance as a College Fellow is given a written evaluation by the faculty mentor. This

information is examined by the Department's Director of Undergraduate Studies and then by the Master of the Collegiate Division of Physical Sciences. A judgment is made as to whether satisfactory performance has been achieved. Also in the second year students are evaluated on the Topic proposal by their advisor, the Committee on Graduate Studies, and the entire department, and then on the Topic Presentation itself by the advisor and at least one other faculty member. Again, a judgment is made as to whether or not the performance is satisfactory. In the third year and beyond, the teaching performance as a Lecturer is given a written evaluation by faculty members who attend some of the students' classes. Again, the evaluations are examined by the Department's Director of Undergraduate Affairs, and then by the Master of the Collegiate Division of Physical Sciences. A judgment is made as to whether satisfactory performance has been achieved. In the third year and beyond, the faculty advisor reports whether there has been satisfactory progress towards a dissertation. The data is considered by the Committee on Graduate Studies, which determines what specific help or adjustments any given student may need. Each year, a formal report will be written reporting on and evaluating these issues. We summarize these evaluation procedures in the following time chart.

| Year of Study | Activity | Evaluation Question |
|---|---|---|
| 1 | first year courses | satisfactory completion |
| 2 | Topic proposal | satisfactory completion |
| | Topic presentation | satisfactory completion |
| | College Fellow training | satisfactory completion |
| 3 | Lecturer | satisfactory performance |
| | Dissertation work | satisfactory progress |
| 4 | Lecturer | satisfactory performance |
| | Dissertation work | satisfactory progress or completion |
| 5 | Lecturer | satisfactory performance |
| | Dissertation work | satisfactory progress or completion |
| 6 | Latest date to complete the PhD | Aggregate data on PhD student cohort |

Aggregate evaluation of the performance of each entering cohort of students and annual

comparisons with past performance are essential to the overall evaluation process. We have substantial data on past history from which to make an informed determination as to whether or not improvements are being made as a result of the GAANN program. We will continue to track carefully the positions of all PhDs from our graduate program, both GAANN Fellows and others.

In 2001, we conducted a thorough evaluation of our graduate program. A committee of nine graduate students at different levels collected and collated issues and concerns of the graduate students. Their concerns were studied by the Committee on Graduate Studies, and the graduate student input was instrumental in the design of our VIGRE program. As part of our GAANN evaluation, we shall institute a formal annual evaluation of our graduate program from the graduate students themselves. Use of a graduate student committee will ensure anonymity, and the committee will determine which concerns are those of a few individuals and which are more generally shared. A remarkable feature of the graduate student concerns in 2001 was a focus on the undergraduate program. The students felt that there was insufficient senior faculty input and commitment to the teaching of undergraduates. Much has changed since then, as we will explain in the allowed Supplement. They were loud in their concern about the lack of women faculty members, and we have worked hard to address that. They were concerned with the unevenness of the mentoring and advising of graduate students, with some feeling that some of the senior faculty themselves need mentoring about how to mentor. With our influx of new senior faculty, that issue can now be addressed more effectively. The nature of their concerns, in particular their emphasis on teaching in the undergraduate program, illustrates their seriousness of purpose. We are committed to a partnership between faculty and students, and we believe that serious evaluation from the graduate students will both help us improve our program and provide the GAANNs Program with a far more valuable evaluation than mere numbers can provide.

## Adequacy of Resources

The Department of Mathematics has outstanding physical and educational resources for its graduate students. The Department has two main interconnected buildings, namely the second, third, and fourth floors of Eckhart Hall and the third floor of Ryerson Hall. These buildings house the faculty, department offices, classrooms and seminar rooms, central computer facilities, a common room, a kitchen from which tea is served to the Department members every day, and the library of the Departments of Mathematics, Computer Science, and Statistics. In addition, it has offices for some of our graduate students, including all of the first year students. There is a computer lab located near the graduate student offices with a large array of computers available for the use of our graduate students at any time, and some graduate student offices are also supplied with computers. This is a part of our extensive and up-to-date network.

Other graduate students currently have offices in Jones or Kent, which are the buildings just west of Reyerson on the main campus, or in the building directly across the street east of Eckhardt. Every graduate student in the department is assigned an office throughout the student's enrollment in the program. The physical area of the department is excellent for all purposes: teaching, office space, informal discussion and seminar space, computational facilities and computation. Eckhart houses an excellent mathematical sciences library of which students make extensive use, and it is supplemented by the nearby Crerar Science Library of the University, which houses an outstanding collection related to all aspects of science. Convenient online access to the libraries has been implemented. At present, there are 32 tenured and 26 non-tenured faculty members. Even ignoring the non-tenured faculty, the graduate student/faculty ratio is 2.6:1. In all respects, the University has outstanding physical, educational, and personnel resources for graduate students with which to successfully implement the proposed project.