Undergraduate Research in Mathematics

Report to the CUPM from the Undergraduate Research Working Group:
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The *Overview of Majors in the Mathematical Sciences* recommends that every major student should "work, independently or in a small group, on a substantial mathematical project that involves techniques and concepts beyond the typical content of a single course. Students should present their results in written and oral forms." A student can have such an experience by participating in undergraduate research, either by working one-on-one with a faculty mentor or by being a member of a research group, perhaps with both faculty and student mentors.

Members of the MAA Subcommittee on Research by Undergraduates have written "Mathematics Research by Undergraduates: Costs and Benefits to Faculty and the Institution" (http://www.maa.org/cupm/CUPM-UG-research.pdf). This brief report to CUPM and its accompanying Appendix summarize some of the major points in the subcommittee's report.

The subcommittee's report uses the definition of undergraduate research as having the following components:

- The student is engaged in original work in pure or applied mathematics.
- The student understands and works on a problem of current research interest.
- The activity simulates publishable mathematical work even if the outcome is not publishable.
- The topic addressed is outside of the standard undergraduate curriculum.

This definition does not include situations in which undergraduate students are working on difficult problems whose solution is not known to the students but have been solved by someone in the mathematical community. While such activities can be very beneficial to students (and meet the CUPM recommendation in the *Overview*), they are called by other names, such as independent study, a capstone experience, inquiry-based project, etc.

The benefits to students from doing undergraduate research are many[1]. Students who participate in undergraduate research in a STEM discipline gain knowledge and

[1] M. Osborn, K. K. Karukstis, ``The benefits of undergraduate research, scholarship, and creative activity,'' *Broadening Participation in Undergraduate Research: Fostering Excellence and Enhancing the Impact*, Council on Undergraduate Research, Washington, DC, pp. 41-53, 2009. This article lists many references. Also, see the appendix to this report for references.

skills, show increases in academic achievement and educational attainment, and grow and advance professionally and personally. For students from underrepresented groups, a research experience with an experienced faculty mentor is positively correlated with improvements in grades, retention rates, and motivation to pursue and succeed in graduate school. Specifically, research projects for undergraduates can help them prepare for graduate school in mathematics by preparing students to make the transition from structured course work to open-ended research that requires a longer period of work on a single problem without many inherent clues on how to prove results. Students who do not plan on attending graduate school also can benefit from doing undergraduate research. Such students typically are employed in business and industry or teach mathematics in high schools. These professions often require employees to analyze data, work on unsolved problems, and present mathematical ideas orally or in writing – all of which are skills learned while doing undergraduate research.

Undergraduate research can occur in an intense summer program or spread out through the academic year. There are advantages and difficulties each approach. (See the Appendix for more details.) While undergraduate research is often done with advanced students, there is a growing trend to work with students earlier. Engaging students in undergraduate research early in their academic careers helps to retain students in the major and provides them a chance to work on research over several semesters or summers.

Faculty who are interested in beginning to mentor undergraduate research should examine successful programs; some are listed in the Appendix. MAA *Focus*, the AMS *Notices*, and the MAA online column *Resources for Undergraduate Research* are places to look for relevant articles. The Joint Mathematics Meetings and MathFest often have panels, sessions, and mini-courses related to successfully doing undergraduate research. Also, there are training programs available at the Center for Undergraduate Research in Mathematics (CURM), the Council on Undergraduate Research (CUR), the Park City Mathematics Institute (PCMI), and American Institute of Mathematics (AIM).

Here are some aspects of successful programs:

- Finding students – Often it is necessary to seek out students to do undergraduate research. Faculty can recruit students by talking to students about their research, recruiting students in the classes they teach, and soliciting recommendations from faculty colleagues.
- Choosing good research problems – Characteristics that are common to most good research problems are that the problems require a limited amount of background for the students to begin, are specific, lend themselves to computational aspects, are composed of several layers, and are problems for which the faculty mentor has an idea for a solution.

- Mentoring students – Undergraduate research should begin with the faculty mentor presenting introductory material as needed, getting students involved in solving basic problems, exploring, and making conjectures. As the research continues, harder aspects of the exploration can be attacked. Mentors should be aware that they may need to address social and emotional needs of the students.
- Helping students communicate their work – Being able to communicate mathematics is an important skill, and undergraduate research provides students with opportunities to improve writing and oral presentation skills. Faculty mentors should help students improve these skills by assisting students to develop oral and written presentations of their research.

(More details about these aspects are given in the Appendix.)

If no undergraduate research program exists at a school or in a department, a great way for a faculty member to start doing undergraduate research is to work with students as an undergraduate thesis advisor – this may be as part of an honors program or a capstone experience. If neither of these options are available and a faculty member has a problem or two that could be worked on by students, they should advertise this – for example, talk about undergraduate research in their courses and have interested students contact them, or let their colleagues know and ask them to advertise.

Before seeking funds for undergraduate research, faculty should build a track record of working with students outside the classroom by working with students on projects and having those students present their work, judging student talks, and learning more about how to be successful at undergraduate research. These efforts should be documented. Next look for local funding – possible sources of funding include a summer undergraduate research program from the chair or dean, start-up funds, work-study monies, alumni, or the development office. Finally, consider external funding. Three organizations that offer funds are the MAA, NSF, and CURM, the Center for Undergraduate Research in Mathematics (See the Appendix for more information.)

Over the past decade there has been a dramatic increase in undergraduate research activities at colleges and universities nationwide. This has brought about the discussion of some important questions for the future.

- Should undergraduate research in mathematics move away from the traditional model of a faculty member working with students individually to a model similar to the laboratory sciences in which a faculty member works with groups of students on a single project?
- What are appropriate models for rewarding faculty for doing undergraduate research?
- How can undergraduate research be integrated into collegiate-level mathematics courses and the mathematics curriculum?
- How can the effectiveness of undergraduate research be assessed?

- Should undergraduate mathematics majors be required to have a significant research experience as part of their major?

Each individual or institution will have to provide their own answers to these questions – the authors of this report to CUPM take no stand on them.

Appendix to Report to CUPM on Undergraduate Research

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1. What is undergraduate research in mathematics?

CUR, the Council on Undergraduate Research, is the largest organization for undergraduate research and serves all disciplines. Their definition of undergraduate research is: "An inquiry or investigation conducted by an undergraduate student that makes an original intellectual or creative contribution to the discipline."

Some people think that undergraduate research should include the situation in which undergraduate students are working on difficult problems whose solution is not known to the students but has been solved by someone in the mathematical community. While such activities can be very beneficial to students, we prefer to call them by other names, such as independent study, a capstone experience, inquiry-based project, etc. Some of these activities are addressed in another section of the CUPM Guide.

2. What are the benefits of doing undergraduate research?

The MAA CUPM Subcommittee on Research by Undergraduates produced a 2006 report titled ``Mathematics Research by Undergraduates: Costs and Benefits to Faculty and the Institution''. The report states

> "Students receive tremendous benefit from this activity. Students get to be involved in a significant mathematics project under close supervision by a professor. They gain experience with independent learning, a skill that will prepare them for research in graduate school as well as prepare them to be productive members of a company. They get control over their education in ways that are impossible to duplicate in the classroom environment. Students come out of this experience significantly enriched in their understanding of modern mathematics. Presentation of the results in written and oral formats improves the communication skills of the student."

Some specific studies about the benefits of undergraduate research are:

- B. Nagda, S. Gregerman, J. Jonides, W. von Hippel, J. Lerner, *Undergraduate student-faculty research partnerships affect student retentions*, 1998.

- J. T. Ishiyama, V. M. Hopkins, *Assessing the impact of a graduate-school preparation program on first-generation, low-income college students at a public liberal arts university*, 2002.
- E. Seymour, A.-B. Hunter, S. L. Laursen, T. DeAntoni, *Establishing the benefits of research experiences for undergraduates: First findings from a three-year study*, 2004.
- A. Barlow, M. Villarejo, *Making a difference for minorities: Evaluation of an educational enrichment program*, 2004.
- R. S. Hathaway, B. A. Nagda, S. R. Gregerman, *The relationship of undergraduate research participation to graduate and professional educational pursuit: An empirical study*, 2002.
- S. H. Russell, *Evaluation of NSF support for Undergraduate Research Opportunities (URO): Synthesis Report*, 2006.

Also, the Council on Undergraduate Research (CUR) is a good resource on the benefits of undergraduate research.

3. What are the differences between summer research programs and academic year research programs?

Originally, Research Experience for Undergraduates (REU), was the name given to NSF-funded undergraduate summer research programs, but now REU has come to mean any intensive, summer-long research program for undergraduate students. These programs are often collaborative, where students work in research groups with peers, supervised by or in collaboration with a faculty mentor. These programs are often residential, where students travel to another institution and live and work there for the duration of the program. REU programs are basically full-time research jobs for which students get paid a stipend. An REU can be a marvelous experience for a student, providing the opportunity to live and work in a new and different environment while engaged in a focused research problem. An advantage of a summer REU program is that the students are devoted exclusively to the research problems and, as a result, can make significant progress in a short period of time. Because of the condensed nature of a summer program, it is critical that the selected research problems provide opportunities for quick and meaningful progress. Also, group dynamics and interactions play a significant role, and group social activities are beneficial. Since summer research students often are visitors, identifying strategies for following up with students once they have left the program is essential, especially if the students are to be involved in submission and publication of their results.

Academic year programs are spread out over a semester or longer. The work is done at the same time that students are enrolled in classes and are participating in on- and off-campus activities; therefore, a successful academic year research program requires careful coordination

with student schedules. Scheduling regular times to meet with research students is an important component of this planning. Advantages of an on-going academic year research program are that it provides an opportunity for students to be involved in a project for an extended period of time and it allows experienced students to act as mentors for students who are new to research. Academic year programs face the challenges of finding students, deciding on mechanisms (if any) to provide academic credit or financial support for student researchers, balancing research against student and faculty obligations during the year, and maintaining momentum on the research throughout the year.

4. When should students begin undergraduate research?

Some of the NSF's programs promote the idea of getting students involved in undergraduate research immediately after their freshmen year. One advantage to this is that such programs might help retain students in the STEM fields. Another benefit is that students might be able to continue with the project over multiple semesters or summers. Working on a research project in a group of students has the potential of employing peer-to-peer mentoring.

5. What are some resources for faculty members who want to start doing undergraduate research?

Some articles to consider are:

- S. S. Adams, "Starting and Maintaining an Academic Year Undergraduate Research Program." A summary of the discussion by panelists S. S. Adams, R. Garcia, R. Gillman, D. Narayan, and D. Schaal at the January 2009 Joint Mathematics Meetings panel organized by MAA CUPM Subcommittee on Research by Undergraduates members M. Dorff and Z. Szaniszlo. MAA online column *Resources for Undergraduate Research*, no. 4, Apr. 2009. Available at http://www.maa.org/columns/resources/resources_4_09.html.
- B. Bailey, M. Budden, M. Dorff, U. Ghosh-Dastidar, ``Undergraduate Research: How Do We Begin?'' *MAA Focus*, **29,** no. 1, pp. 14-16, 2009.
- B. Bailey, M. Budden, U. Ghosh-Dastidar, ``Practical Tips For Managing Challenging Scenarios in Undergraduate Research,'' a summary of ideas discussed by a group of faculty participating in the 2008 Center for Undergraduate Research in Mathematics (CURM) Workshop. MAA online column *Resources for Undergraduate Research*, no. 3, Dec. 2008. Available at http://www.maa.org/columns/resources/resources_12_08.html.
- K. Leonard, ``Adventures in Academic Year Undergraduate Research,'' *Notices of the AMS*, **55,** no. 11, pp. 1422-1426, 2008.

The Center for Undergraduate Research in Mathematics (CURM) offers a 2-day summer training workshop on doing undergraduate research in mathematics for faculty members (http://curm.byu.edu/summerworkshop). Also, the Council on Undergraduate research (CUR)

offers training in undergraduate research in all disciplines through its Institutes program (http://www.cur.org/conferences_and_events/institutes/).

5. Choosing research problems

Choosing appropriate research problems for undergraduate students is a skill that faculty members can develop over time. Characteristics that are common to such problems are that such problems:

- Are of interest to the students and mentoring professor.
- Require a limited amount of background for the students to begin.
- Are specific.
- Lend themselves to computational aspects.
- Are composed of several layers.
- Are problems for which the faculty mentor has ideas on how to solve parts of the problem.

First, the problem should be of interest to the student and to the faculty mentor. Second, it is helpful if the student needs only a limited background to understand and begin working on the problem. This does not mean that the topic cannot be in an advanced area of mathematics, but if it is then the topic should have aspects that the student can grasp quickly. Students tend to be more successful in solving problems that are specific and concrete rather than theoretical and abstract. In addition, problems that lend themselves to explorations by computations or to the creation of specific examples or to doing computer explorations often are good choices. Such problems allow students to quickly explore examples, to get an intuitive feel for the problem, to make and explore conjectures. This gives students some ownership of the problem and permits them to direct some of the work. It is important that mentors not over-direct the research.

Projects are more likely to be successful if the problem is composed of several layers. By this we mean a problem that consists of multiple steps or sub-problems. Often the initial steps are easier to solve and provide background to solving the subsequent more difficult steps. This permits the student to solve some aspects of the initial layers of the problem and then proceed to more advanced layers.

Problems that are posed by researchers in industry or by faculty from other disciplines such as biology, physics, chemistry, or psychology can be good choices.

6. Mentoring students during the process

Mentoring students during the process of doing undergraduate research is an important component of helping students succeed in doing undergraduate research. This mentoring process includes:

- Quickly getting students to solve basic problems, explore, and make conjectures.
- Ramping up to harder problems.
- Addressing social and emotional needs.
- Helping students develop or improve communication skills.

It is beneficial to communicate work expectations with the students. But, faculty mentors should be realistic and not set goals too high. As the project proceeds, the faculty mentor and the student should modify the goals of the research depending on what seems reasonable for the student.

It is important to keep students motivated while doing undergraduate research. Most likely, at some point, the students will get stuck or frustrated. Students who are participating in research for the first time might feel that this is a result of their not being good enough mathematically. It is important for the faculty mentor to point out that getting stuck or frustrated is a common stage for everyone doing research. It is also beneficial for the faculty mentor to suggest some activities to help during this situation. Such activities could include:

- Taking a break.
- Explaining the difficulty to someone (mathematically trained or not).
- Reviewing background material.
- Seeing if the problem can be modified.
- Checking hypotheses or assumptions.
- Working out simple examples.
- Keeping going.

Mentors should not lose patience with their students. Undergraduate research is a learning experience for the student – not a part of the mentor's research program. Mentors should be willing to accept what the students can reasonably accomplish. Remember, research is a new activity for most undergraduate students and it is easy to expect them to make more progress on a research problem than they are capable of – be willing to accept what the students can reasonably accomplish.

7. Helping students communicate mathematics

Being able to communicate mathematics is a skill that is becoming more important in today's society, and undergraduate research provides two activities that help students improve in their communication skills. These two activities are oral presentations and written reports.

a. Student oral presentations.

Usually students are inexperienced in giving oral presentations about their research, and it is helpful for students to practice giving talks to students and faculty. Also, students should be informed about what will occur leading up to, during, and after their presentations. In addition, it is beneficial to give students guidance on how to make oral presentations. Here are some guidelines that can be shared with students:

- Know their audience; the talk should be prepared for the people who will be listening to it.
- Be able to summarize what was accomplished in one sentence, and repeat this idea several times during the talk (e.g., at the beginning of the presentation and at the end of the presentation).
- Give simple examples to help the audience understand definitions, theorems, etc.
- Explain why the problem and the results are interesting.
- Practice. Students should practice presentations. At least one of these practice presentations should be to people who are not familiar with the research area. Students should receive feedback on their presentation.

A good resource for giving a talk is

- J. Gallian, "How to Give a Good Talk," Math Horizons, April 1998.

b. Student written reports

It is important that students should be expected to write on a regular basis. For many students, a research journal works well. This helps them focus on what they have learned. Written drafts of the report should be handed in to the faculty mentor on a regular basis. This allows the faculty to provide feedback to the students and helps the students spot errors and understand how to write a mathematics research paper. Also, by turning in written drafts, students will be able to more easily produce a suitable final written report at the end of the project.

If appropriate, the written report could be submitted to a journal for publication. If the faculty mentor has worked with the students on the research, then it is common for s/he to be listed as a co-author. This has an advantage that it naturally allows the faculty

mentor to be involved in the revisions of the written report and the logistics of getting the paper published.

Besides the standard refereed research journals in mathematics, there are refereed journals that cater to undergraduate students as authors. These journals include Involve, SIAM Undergraduate Research Online, Furman University Electronic Journal of Undergraduate Mathematics, the Rose-Hulman Undergraduate Mathematics Journal, Morehead Electronic Journal of Applicable Mathematics, Mathematics Spectrum, Ball State Mathematics Exchange, and the Missouri Journal of Mathematical Sciences.

8. Finding sources for funding

The comments in this section come from the article "Obtaining funding and support for undergraduate research" by M. Dorff and D. Narayan which is to appear in *PRIMUS*.

Many faculty are unaware that federal work-study can be used to provide funds for students doing undergraduate research. A faculty member can hire a student through work-study for assisting with their research). Federal work-study funds are awarded to students who apply for financial aid and ask for this on their FAFSA with awards being based upon family financial situation. Typical awards are $2,000 for the academic year with the government covering 75% of this and the department covering the rest.

MAA programs that offer funds for certain aspects of undergraduate research include travel funds for students, Tensor grants, and National Research Experience for Undergraduates Program. The travel grants provide up to $750 for undergraduate students presenting their work at MathFest or the Joint Meetings (http://www.maa.org/students/undergrad/jmmtravelgrants.html). Pi Mu Epsilon, the National Mathematics Honor Society, also provides up to $600 in funding for students to present at MathFest (http://www.pme-math.org/conferences/national/2012/call2012.html). The MAA's Tensor Women and Mathematics grants can also be a resource for funding (http://www.maa.org/wam/tensor.html). These grants are designed to encourage women to study mathematics and are up to $6,000. The MAA's National Research Experience for Undergraduates Program (NREUP) awards grants of up to $27,500 to support one faculty member and at least four students from underrepresented groups to do summer undergraduate research at the faculty member's institution (http://www.maa.org/nreup/). NSF funds proposals to operate a summer REU. Mathematics REUs typically run for eight weeks during the summer with 8-12 undergraduate students working in groups on research problems under the direction of a faculty mentor. A list of current REU Sites in mathematics can be found at http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=5517&org=DMS&from=home. Faculty

who have an existing NSF research grant can apply for additional funding from NSF in the form of Research Experience for Undergraduates Supplements. These supplements provide funding to include undergraduate students in the faculty member's research.

Additionally, there are several NSF programs for increasing the number of students completing a STEM (science, technology, engineering, and mathematics) degree, and grants in these programs can be used to fund undergraduate research. These programs include Louis Stokes Alliances for Minority Participation (LSAMP), the Science, Technology, Engineering, and Mathematics Talent Expansion Program (STEP), and the Mentoring Through Critical Transition Points in the Mathematical Sciences (MCTP). Examples of undergraduate research programs funded by one of these NSF programs include the Pacific Undergraduate Research Experience in Mathematics (PURE Math). Long-term Undergraduate Research Experience (LURE), STEPping up Undergraduate Research at Middle Tennessee State University (STEPMT), and Positive Routes into Science and Mathematics (PRISM).

A third major resource for funding is the Center for Undergraduate Research in Mathematics (CURM) which is directed by Michael Dorff (http://curm.byu.edu). CURM awards mini-grants of up to $25,000 to support and fund faculty to do undergraduate research during the academic year with students from their own institutions. Activities include a three-day summer workshop to train faculty in doing successful undergraduate research and a spring research conference for students to present their work. The mini-grants provide a $3,000 stipend for each student, a $6,000 faculty stipend to reduce to faculty member's teaching load, and funds to travel to the summer workshop and spring conference.

9. Examples of successful undergraduate research programs:

A. Two-Year Community College

Fullerton College: Since 2008, math majors, non-majors, and basic skills students have been encouraged to participate in the College's weekly Math Colloquia which features a weekly talk on unsolved problems in mathematics by a student and then by a faculty speaker. Guest faculty lecture once per month. These talks have sprouted a vibrant and close-knit research community with approximately twenty to thirty students participating in research activities annually. Many of these students typeset their presentations in Beamer/LaTeX and give additional talks. Since 2009, over one hundred student math research presentations have been given by Fullerton College students at various local venues. In 2011, the student research program expanded into a formal 2-unit course and four informal learning seminars, attended by approximately 3-15 students each week. The topics currently are Clifford algebras, multiscale cancer modeling, probability, and the N-body problem. In Summer 2012, Fullerton College was able to financially support 11 STEM summer research interns. The first comprehensive

community college mathematics research/outreach program of its kind in the nation, Fullerton College's student research and outreach program has adopted pedagogy that can be effective for motivating lower-division and upper division students, majors, and non-majors to explore mathematical frontiers. Contact: Dana Clahane (dclahane@fullcoll.edu). Program Websites: http://staffwww.fullcoll.edu/dclahane/ma/meetings.htm & http://staffwww.fullcoll.edu/dclahane/ma/ma2012to2013.htm.

B. Liberal arts institutions

The College of St. Benedict and St. John's: The College of St. Benedict and St. John's University are paired small liberal arts colleges with a joint academic program. The entire Mathematics Department has supported undergraduate research for over twenty years and provides close faculty mentoring. Some students do extensive research and a thesis their senior year. For the past dozen years, the department has had dedicated stipends for two summer research students in mathematics and occasional additional funding in mathematical biology. Interdisciplinary research is encouraged and the faculty regularly co-mentor such projects. Some courses, notably Algebraic Structures II, Mathematical Modeling, and a Topics course, have incorporated student research into the class. Some students in Calculus and the sophomore level courses have chosen to participate in open investigations. All research students present their research both in writing and orally, for example at the annual regional Pi Mu Epsilon conference which is hosted by the department. Each year about one fourth of the approximately thirty graduating majors have participated in research. Contact: Tom Sibley (tsibley@csbsju.edu) http://www.csbsju.edu/mathematics.htm

Lafayette College: Lafayette's Excel Scholars program started in 1986 as a way to support student-faculty research in the natural sciences. It has expanded from its original 14 participants to between 100 and 120 students working during the academic year and approximately 150 working in the summer. All academic divisions are represented, including about a half-dozen working with members of the Mathematics Department each year. These programs take place during the academic year and also during the summer, when they run in parallel with an NSF-funded REU program. Students work closely with faculty and they engage in significant research projects; many of these projects have resulted in high-quality publications. Students present their research at undergraduate research conferences, national mathematics meetings and in other venues. Students are paid a stipend and their housing is included for summer and interim programs. Contact: Gary Gordon or Qin Lu (gordong@layayette.edu, luq@lafayette.edu).
Website: http://www.lafayette.edu/academics/special-opportunities-and-programs/student-research/excel-scholars/

St. Olaf College: Faculty-sponsored research experiences are common, and such projects are often carried out during the summer with funding for student stipends. On average, 3-5 students participate in summer research each year. Some students (mostly juniors and seniors) engage in research experiences for course credit at Level III (the highest at St. Olaf). Directed Undergraduate Research (DUR) provides a small group research experience in mathematics (6-9 students) for credit during the semester. Mathematics Practicum offers a small group research experience in applied mathematics and statistics (15 students), where students work on real industrial problems and present their results to scientists and executives from the company that posed the problem. Both DUR and Practicum give teaching credit to the faculty involved. St. Olaf also houses the Center for Interdisciplinary Research, which supports interdisciplinary teams of students using statistics, mathematics, and computer science to solve problems posed by faculty researchers from a variety of disciplines. Contact: Jill Dietz (dietz@stolaf.edu). http://www.stolaf.edu/depts/math/

University of Richmond: 1st and 2nd year students are encouraged to begin doing undergraduate research in the summer and to continue that research throughout the next two academic years. This program, known as LURE (Longterm Undergraduate Research Experience), began as an NSF-funded collaboration. The program builds upon the success of the apprentice model often used in the physical and life sciences, where students join a lab and are mentored by more experienced research students as well as the faculty member. All students can be paid for doing research with funds coming from a combination of internal and external funds. Many of these students have not declared mathematics as a major when they begin. Through closely supervised research and independent study activities spanning two summers and two academic years, students experience all steps in a research project, from background reading to the professional presentation of results. Contact: Jim Davis or Kathy Hoke (jdavis@richmond.edu, khoke@richmond.edu). http://math.richmond.edu/research/lure.html

University of St. Thomas: Primarily with support from the Center for Applied Mathematics (CAM), the department sponsors about 25 students working on about 15 research projects per year. Faculty mentors come primarily from the math department, but also from other departments in the sciences, economics, and business. Faculty receive stipends for their work. The CAM Summer Undergraduate Research Program has been very successful in getting mathematics students involved in research and has created a very strong undergraduate research culture in the math department. While not required for the major, very few math majors graduate from St. Thomas without working on a research project for at least one summer. Faculty advertise their projects on the CAM website, and students and faculty that are running summer projects are paired during the spring semester. Students get paid by the hour as they work on their projects, and log the hours that they work on the CAM

website. Contact: Patrick Van Fleet (PJVANFLEET@stthomas.edu)
http://cam.mathlab.stthomas.edu

C. Regional Universities

Valparaiso University: Almost every tenured or tenure-track person in the department chooses to work with students each year. Currently, there are approximately 20 students working in 7-8 groups. The groups are vertically integrated from freshmen to senior. Every incoming freshman is invited to become a member of a group, while the upper classmen either volunteer or are recruited by the faculty. Students are able to receive 1 credit per semester for participation. Each faculty adviser is assigned 1 teaching credit for directing a research group for a year. With three teaching credits a faculty member can get a course release. The main focus of the program is mentoring the participants and modeling the mathematical discovery process. Every project closes with a presentation and a written report; some projects result in professional publications although publishing is not the main goal of the program. The time commitment from the faculty is not too high, and many students are interested in working with faculty. For more information see
http://www.valpo.edu/mcs/undergradresearch/academicyearprogram.php
or e-mail Zsuzsanna Szaniszlo (Zsuzsanna.Szaniszlo@valpo.edu) or Lara Pudwell (Lara.Pudwell@valpo.edu).

Youngstown State University: All undergraduate mathematics and integrated mathematics education majors are required to write and present a capstone project. These projects are mentored by faculty members in the department and include a component of research in mathematics. The department conducts a variety of student activities to engage mathematics majors in mathematics beginning with first year students and continuing through their senior year. These include participation in a Problem of the Week, Mathematical Contest in Modeling (COMAP), problem solving seminars, Putnam competition, regional conferences where undergraduates present their research projects, working and publishing problems in the Mathematics Magazine and the Pi Mu Epsilon Journal, presenting results at the summer MathFest meetings, Ohio MAA meetings, Pi Mu Epsilon regional meeting, integration bee, game nights and many other cohort building and mathematics related events. Participation in these activities has become an expected part of being a mathematics major at YSU. Upper class students help beginning students to participate in mathematics. Contact: George T. Yates (gyates@ysu.edu) http://curmath.ysu.edu.

D. Polytechnic University

Worcester Polytechnic Institute (WPI): Every undergraduate student must complete a Major Qualifying Project (MQP) as part of her/his graduation requirement for a Bachelor's degree.

This project is usually done in the senior year and the work of the MQP is in the student's major and is advised by faculty in that department. In the Department of Mathematical Sciences, the student does original research in either pure or applied math. These qualifying projects take up one-quarter to one-third of a student's load for the year. The research work culminates in a project report and an oral presentation on Project Presentation Day. Abstracts of some past Mathematical Sciences MPQs can be found at http://www.wpi.edu/academics/math/recent-mqp.html. Advising undergraduate student research projects is part of faculty's teaching responsibilities. Mathematical Sciences students at WPI also have the opportunity to work on projects that come directly from business, industry, and government. The Center for Industrial Mathematics and Statistics (CIMS) was established to help develop contacts and research projects at both the undergraduate and graduate level. See http://www.wpi.edu/+CIMS. To date, research projects involving almost 70 different companies have been conducted. The current director of CIMS is Prof. Suzanne Weekes (sweekes@wpi.edu).

E. Historically Black College and University

Jackson State University: The focus of the undergraduate research experience is interdisciplinary and aims at collaborations with the Department of Biology to train students in the use of data to explain abstract mathematical theories and derivation of new theories. Students take part in collaborative research work at JSU during the academic year for a minimum of two years under the supervision of faculty teams from the biology and mathematics departments. The faculty teams work together to design a project and choose a team of undergraduate mathematics and biology majors to participate in the research. In 2011, JSU established a university wide Center for Undergraduate Research (CUR) that awards mini-grants of $7,500 to twenty faculty members drawn from the five academic colleges to conduct a yearlong research with five undergraduate students in their academic disciplines. Participating researchers are encouraged to design research projects that are interdisciplinary in nature. Contact: Tor. A. Kwembe (tor.a.kwembe@jsums.edu).
http://www.jsums.edu/~sst/cset/mathematics.htm.

F. Large universities

Brigham Young University: Beginning math majors are introduced to undergraduate research through a required freshmen seminar "Introduction to being a math major." The department web site has a section that describes available undergraduate research projects and allows students to apply online to work on a specific project. Students can do year-round undergraduate research often in groups of 2-5 with a faculty mentor. Groups are usually vertically integrated so they contain advanced, mid-level, and beginning research students. Experienced research students help mentor newer students. Undergraduate students can get paid for doing research with funds coming from the university, alumni, businesses and industry.

Research is done on unsolved problems in the area of the professors' research expertise. There is also an applied undergraduate research group, Interdisciplinary Mentoring Program in Analysis, Computation, & Theory (IMPACT), that works on problems obtained from business and industry. Students are expected to present their research at a spring college undergraduate research meeting. Some students also present at national and international mathematics conferences and publish their research in refereed research journals. Typically, about 75 mathematics students have being doing undergraduate research for at least one semester. Contact: Michael Dorff (mdorff@math.byu.edu), https://math.byu.edu/home/undergraduate/research.

East Tennessee State University (ETSU): Since 2002, all mathematics majors have been required to take MATH 4010, Supervised Undergraduate Research, which typically has 6-12 students. These students are matched with a research mentor according to their interest, and they conduct research for 15 weeks. The course is writing and oral intensive, and each student is required to give four presentations and write four drafts of a technical report using LaTeX. The students' work is often original, sometimes publishable, and in all cases new to the student. For some students, such as members of the honors program, MATH 4010 is head start of their honors thesis, while other students use this capstone experience as a bridge to summer programs outside of ETSU. Over the years, there have been at least one dozen mentors, and students have done work in epidemiology, probability, combinatorics, graph theory, statistics, mathematics education, knot theory, computational geometry, Euclidean geometry, numerical analysis, thermodynamics, and a variety of topics in applied mathematics. Interested persons may contact Ariel Cintron-Arias, (cintronarias@etsu.edu), for further information.

Texas A&M University: Students can do academic-year undergraduate research by starting with some preliminary project (e.g., in a readings course) followed by non-class research hours, and then write up their results in a class that gives them writing credit as well. The department also offers a math modeling course in which students do research projects. In addition, they have 2-5 week summer pre-REUs for students with a second semester calculus background -- students learn about signal and image processing and then do some projects in groups followed by doing some research on their own questions extending the projects. Contact: Sue Geller (sgeller@math.tamu.edu).

The University of Wisconsin-Eau Claire: Students in the mathematics department can participate in academic-year and summer research with faculty. Typically, about twenty students do research during the academic year, working either one-on-one with a faculty member, or in teams of two or three. Students receive stipends funded through the Blugold Commitment Differential Tuition program, a student-supported supplemental tuition initiative

approved by student government. Projects are drawn from pure and applied mathematics, statistics, math education, and actuarial science. Students present their work at the department's spring Math Retreat and the university-wide Celebration of Excellence in Research and Creative Activity, as well as regional and national conferences. Contact: Alex Smith (smithaj@uwec.edu). A list of recent projects may be found at http://www.uwec.edu/Math/news/Archived-Student-Facuty-Research-Projects.htm.