CUR Focus

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Transforming Practice Through Undergraduate Researchers

Introduction

"It has inspired me to push the limits, to keep asking questions and keep believing we can solve any problem. I have been exposed to many applications that I did not know existed before. I used to think doing research in math was purely proof based. Now I see that research in math has endless possibilities." This feedback is from one student who participated in a Research Experiences for Undergraduates (REU) program funded by the National Science Foundation (NSF) at George Mason University (GMU) in 2010.

"I am most interested in how mathematics can be used to help people in the real world. With the passing of my uncle, the idea that my (undergraduate) research could some day be used by doctors to help them understand and prevent aneurysms is a very rewarding feeling." This comment came from another George Mason undergraduate who was funded in part by the NSF Computational Science Training for Undergraduates in the Mathematical Sciences (CSUMS) Program and the Undergraduate Apprenticeship Program in the George Mason Honors College in 2010-2011.

Both comments are great illustrations of the impact of exposing undergraduates to research in advanced topics in mathematical sciences that have applications in the real world. Such undergraduate research (UR) programs not only help develop innovative research methods to explain fundamental mechanisms needed to understand quantitative and qualitative behavior underlying scientific and engineering applications; they also can help student researchers become change agents for transforming practice in teaching, research, and education.

According to the Council on Undergraduate Research, "Undergraduate research is an inquiry or investigation conducted by an undergraduate student that makes an original intellectual or creative contribution to the discipline" (CUR 2011). Several leading institutions have initiated interdisciplinary programs in UR intended to train individuals in such inquiry-based aspects of problem solving. Students in many institutions across the country are able to use new knowledge acquired through UR to produce new results that have made a difference in the disciplines.

However, a great need still exists for these students to also learn to use their UR experience to become change agents, helping to transform an institution. In other words, to make the research they participated in more meaningful, students must also learn to wear the hat of a change agent, promoting and communicating their UR to a broader community of learners. Such a student transformation will require a systematic approach that involves a lot of mentoring, guidance, and support. This investment can help student researchers become competent enough to create, to facilitate, and to sustain an institutional culture in which peers, graduate students, faculty, and administrators continue to learn and evolve with them.

This article describes the role of undergraduate researchers as change agents who not only help to enhance ongoing interaction among communities of people, including students, educators, and academicians, but who also serve as catalysts to help reinforce and drive reform across an institution. UR in computational mathematics is used as an example because of the author's expertise in guiding several UR projects in this discipline over the years. However, the concept and approach described can be easily extended to other disciplines and, indeed, to transform teaching and research practices for students and faculty from the high school to the graduate levels. The role of institution and faculty in helping transform students into change agents is described, and specific examples of programs and opportunities at George Mason University are discussed, including one model program that has had cascading effects on student learning.

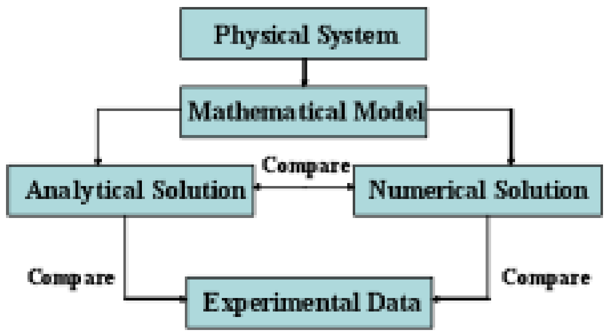
UR in Computational Mathematics

Undergraduate research in computational mathematics, a field that comprises modeling, analysis, simulation, and computing, is quickly becoming the foundation for solving most complex problems in science and engineering. These real-world problems often involve complicated, dynamic interactions among multiple physical processes, thus presenting significant challenges in representing the physics involved and in handling the resulting behavior. Hence, to capture the complete nature of the solution to the problem, a "coupled multi-physics" approach is essential.

Performing research and teaching in computational mathematics therefore, require an in-depth understanding of the underlying mathematics and the fundamental principles that govern a physical phenomenon. It is understood that such physical systems can be described by complex partial differential equations that cannot be solved by textbook solutions. Thus, understanding the behavior of the numerical solution to such equations is of paramount importance for elucidating the actual physical problem. Researchers in this field have come to appreciate that analyzing a numerical technique requires a combined theoretical and computational approach. Theory is needed to guide the performance and interpretation of the numerical technique, while computation is necessary to synthesize the results.

The methodology for a solution therefore involves formulating a mathematical model from a physical system and then being able to solve this model using an analytical (exact) approach or a numerical (approximate) approach. The mathematical models developed as a part of the UR are then validated using real experimental data. This problem-solving methodology is illustrated in Figure 1.

Figure 1: A Solution Methodology for UR in Computational Mathematics



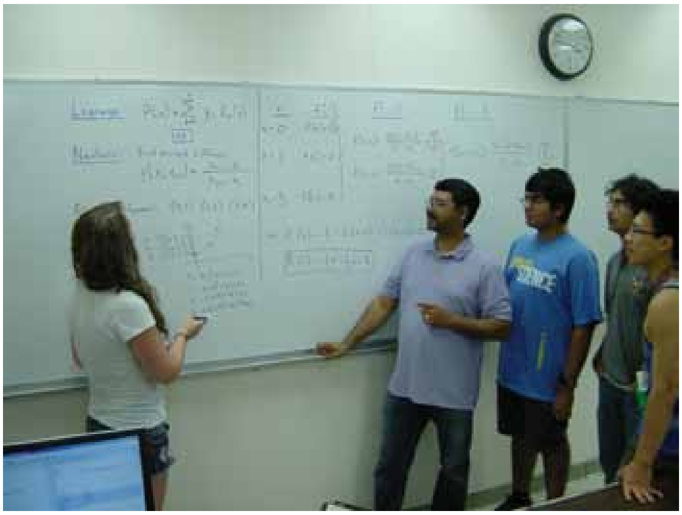
The focus of most undergraduate researchers' projects in computational mathematics is to systematically combine sophisticated mathematical techniques with high-performance computing to develop problem-solving methodologies that are then applied to several computationally challenging problems. These new methodologies not only benefit various scientific and engineering fields, but also aid in the process of designing better products and processes.

Students As Institutional Change Agents

Breakthrough research, education, and teaching in UR programs often involve multidisciplinary efforts spanning scientific and engineering disciplines. George Mason University is committed to excellence in this realm by engaging students in UR through a variety of research programs. Some examples of these include the Undergraduate Apprenticeship Program/Undergraduate Research Scholars Program (open to all students); the School of Dance's Senior Synthesis Presentations (College of Visual and Performing Arts); the Diversity Research Group's Ethnography of Diversity project (an interdisciplinary project in the Office of University Life); Undergraduate Research in Computational Mathematics (mathematical sciences); the Aspiring Scientists Summer Internship Program (College of Science); and Students as Scholars Program (Center for Teaching Excellence).

While most universities provide such opportunities both within and outside the institution, one of the key problems that many institutions have faced is the lack of communication and coordination of these independent research programs, often making it difficult for students and faculty to know how they can get involved or even know that such programs exist. "If anything is clear from the debate about education, it is that the various levels of formal learning cannot operate in isolation, and that the quality of scholarship surely begins in school, and especially in college—a time when the student's breadth of knowledge and intellectual habits will be either strengthened or diminished" (Boyer 1990).

One way to improve this is by encouraging students to become change agents and promote students' awareness that their education means engaging with scholarship and that it is not just about making good grades in their courses. Along with exposure to undergraduate research with a faculty men-



Students and faculty working in a group research session.

tor, students must be given opportunities by their institutions to engage in collaboration, interdisciplinary work, and creative activities. The skills gained in such activities will help them to become effective change agents—to reach out to other students and to people outside the university community to share the value of their undergraduate research.

This experience will not only help the students gain a deeper understanding of their own research and place it in context, but also will help them acquire important skills in leadership, building group dynamics, and communicating their discipline to both technical and non-technical audiences. As change agents, students will also help faculty transform their practices in undergraduate teaching, research, and education through multidisciplinary efforts—which in turn often have led to new collaborations and open-ended explorations.

Being a change agent is now becoming an integral part of the work of many students and faculty members at George Mason, and this has helped stimulate improved methods for organizing, tracking, and publicizing ongoing activities and projects. GMU also supports the dissemination of the results of UR projects at the institution through several local opportunities, such as the Celebration of Achievements (hosted by the Office of the Provost and the Office of Research & Economic Development); the Undergraduate Research Symposiums and Conferences (separate conferences hosted by the College of Science, the College of Humanities and Social Sciences, and the School of Conflict Analysis and Resolution); Juried Undergraduate Exhibitions (the College of Visual and Performing Arts); Aspiring Scientists Summer Internship Program Poster Presentation (the College of Science); and the STEM Accelerator Program (the College of Science).

These local dissemination opportunities have not only helped in the professional development of the students but also have helped them prepare to be better change agents as they disseminate their work beyond campus. Some of the external opportunities have included the CUR Posters on the Hill, the Colonial Academic Alliance's Undergraduate Research Conference, the undergraduate research conference of the Virginia Collegiate Honor's Council, the Joint Mathematics Meetings Undergraduate Research and Poster Presentations, and the National Conference on Undergraduate Research (NCUR).

UR also is promoted through university-wide publications that include the *George Mason Review*, a cross-disciplinary undergraduate journal that publishes exemplary scholarly works from Mason undergraduates; *Volition*, a magazine that serves as the creative voice of GMU undergraduates; *the Hispanic Culture Review*, a journal that contributes to GMU's multiculturalism; and *Diversity at Mason*, an annual publication of the Diversity Research Group. These publishing venues have helped to disseminate innovative approaches to undergraduate scholarship and created a community of learners who actively acquire additional knowledge.

Mentors, both faculty members and graduate students, are central to the process of UR students' becoming change agents. Mentors help students master the content necessary to perform research and also help them to transform their understanding of the disciplinary habits of mind. Students can then help promote the faculty's research and the discipline as a whole to other potential students who may be thinking of careers in the particular field. Graduate students gain the valuable experience of mentoring, and faculty may gain different insights into their work from exposure to undergraduate researchers' perspectives, since the students begin the work they are assigned without any bias or opinions about what is or is not expected from the research. Such fresh student insights may often open up new research questions or questions overlooked by the current research. Through this scholarly interaction with faculty and graduate students, the undergraduates become change agents who help in furthering the faculty and graduate students' research programs, their professional development as mentors and educators, and their teaching and pedagogical practices.

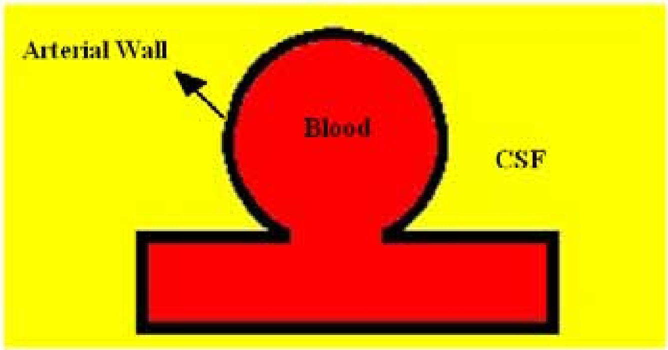
The following describes one UR project that has had a cascading effect on student learning, created change agents at various levels of education, and helped to transform the teaching practices of the high-school teachers and faculty involved.

Multi-Level Change Agents

A recent undergraduate research project involved mathematical and computational modeling of intracranial saccular aneurysms—thin, membranous balloon-like widening of arterial walls—the rupture of which are the most common causes of bleeding onto the surface of the brain, which results in strokes. Despite advances in neurosurgery, these aneurysms continue to result in significant numbers of deaths. Therefore, predicting the potential of aneurysms to rupture is fundamental to clinical diagnosis and treatment. The UR project helped to develop a very simple mathematical model of a thin-walled, spherical intracranial aneurysm surrounded by cerebral spinal fluid or CSF (See Figure 2). This model involved solving coupled partial differential equations for fluids (modeling blood and cerebral spinal fluid) interacting with elastic structures modeling aneurysms using novel approaches (Venuti and Seshaiyer 2010).

The UR project that gave opportunities to two undergraduate students in their junior year during 2009-2010, was able to validate this model using analytical techniques and computational tools. The mathematical tools developed as a part of this transformative UR project have since been extended to provide better understanding of the mechanics of the rupture of aneurysms. The original findings also were extended to study the dynamic behavior of the aneurysm wall in response to periodic (blood) forces. The project ultimately led to some open-ended questions that evolved into separate summer research projects for two other undergraduates. Not only did the overall UR project lead to new discoveries, but it also went on to receive three national awards for outstanding UR, one at the second annual undergraduate poster session of the Society for Industrial and Applied Mathematics

Figure 2: An illustration of an aneurysm-arterial wall-CSF interaction

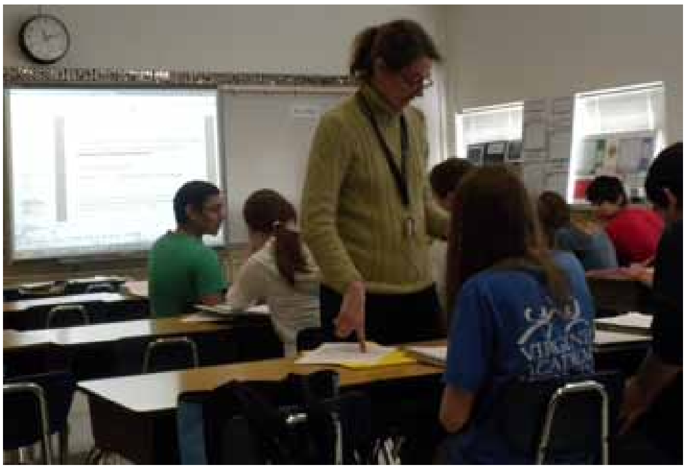


and two at the Mathematics Association of America's undergraduate poster session at the Joint Mathematics Meetings (2009 and 2010). One of the research questions from the UR projects also led to a doctoral thesis, completed recently (Samuelson and Seshaiyer 2011).

Change Agents In K-12 Outreach

The computational project involving aneurysms also became a perfect platform for K-12 outreach. In particular, the UR student who worked with the author ended up co-mentoring a high-school teacher during the summer research program. The teacher was able to work on a related aspect of the project and take it back to her school and district to discuss how important, innovative, and useful the UR project was to teaching the high-school curriculum. Not only was the teacher able to use the UR project in her intensive pre-calculus classroom; she also was able to teach a "lesson study" that helped high-school students understand the importance of pursuing mathematics and science.

"Lesson study" originated in Japan and has become widely accepted as an effective form of professional development for teachers (Lewis 2002, 1998). It is based on a research process that includes observation of live classroom lessons taught by a group of teachers/researchers; collection of data on teaching; learning and collaborative analysis; and revision. Although lesson study is becoming popular at the elementary and middle-school levels, there are very few examples of successful lesson studies at the high-school level. In her lesson, the teacher was able to effectively con-



Kris Kappmeyer implements "lesson study" in her high school classroom.

Posters on the Hill Students meeting with Senator Mark Warner.

nect with her students to communicate the importance of a traditional mathematics formula by providing an important experimental context in which it has been used. The students would not have gained this type of understanding if the teacher had not made this extra attempt to engage them.

Said the teacher, Kris Kappmeyer: "As a high-school teacher, my reasons for participating in the UR Program were to improve my credentials as a professional in the teaching field and to broaden my knowledge base in order to give more current answers to the question, 'When am I ever going to use this?' The UR program really gave me a broad survey of the available fields in math and has most definitely enhanced my understanding." Not only did Kappmeyer enhance her teaching practice by going beyond traditional classroom teaching, but the UR project also helped to enhance students' learning by incorporating the research component in her presentation.

In fact, Alicia Hamar, one of the students in Kappmeyer's classroom, was inspired to continue on to work with the author on another aspect of the project. This high-school project won the grand prize in the Northern Virginia Science and Engineering Fair in 2009 and the student was invited to the Intel Science Fair Competitions. This domino effect led to the original UR project, "Mathematical and Computational Modeling of an Intracranial Saccular Aneurysm," being showcased at the 2010 CUR Posters on the Hill in the mathematics/computer science category. This event gave the original George Mason UR student an opportunity to meet and discuss the importance of UR with several Congressmen and Virginia Senator Mark Warner (see photo).

The same picture with Senator Mark Warner also appeared on page 18 of CUR's Triennial Report. The highlight of all the ramifications of this project was a letter from the Governor of Virginia's office commending the contributions that this UR project made to the study of the STEM (science, technology, engineering, and mathematics) fields.

Change Agents In Faculty Growth

As a faculty mentor, my involvement in this UR project and several others I have directed has helped me to recognize the importance of integrating teaching and research to improve the effectiveness of teaching and student learning. My goal in directing such UR programs has always been to demonstrate the value of coordinated multidisciplinary research activities and also to provide a realistic setting for the teaching and enhancement of research skills. I have also learned to build sustainability into the UR projects I direct in order to help provide opportunities for students to become change agents by extending their work beyond the classroom.

The report, "Why So Few? Women in Science, Technology, Engineering and Mathematics," published by the American Association of University Women (AAUW) and funded by a grant from the National Science Foundation, involves a review of literature about gender and science published over the past 15 years. The contributors examined some of the findings about why women and girls remain underrepresented in the fields of science, technology, engineering and mathematics (STEM). One of the contributors, Andresse St. Rose, a research associate at AAUW, wrote "In schools and in homes the environment that is created serves to subtly and perhaps in some cases not so subtly discourage girls or encourage them to focus on other areas, even if they might have a brimming interest and ability in science."

The UR project described in this article gave research opportunities to five women and two men. They included four undergraduates (three women—one an African-American—and one African-American male); a female high-school student and a female high-school teacher; and a male graduate student. UR is a great way to encourage women and underrepresented minorities to pursue multidisciplinary mathematical careers that bridge the scientific and engineering communities. The author strongly believes that UR is essential for the development of a diverse and well-prepared workforce of scientists, engineers, and educators that is needed to build the infrastructure and knowledge for enhancing STEM learning.

Acknowledgement

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National Conference on Undergraduate Research (NCUR) is an opportunity for more than 3,000 undergraduate students to present their research, scholarly or creative projects.

NCUR 2013 will be held April 11-13, 2013, at the University of Wisconsin LaCrosse.

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