Adventures in Academic Year Undergraduate Research

Kathryn Leonard

This article is the fourth in an occasional series intended for graduate students. The series is coordinated by Associate Editor Lisa Traynor.

When I accepted a position at a university without a Ph.D. program, I knew a first order of business would be to involve undergraduates in my research. For one, original research has become increasingly standard as an expectation for graduate school admittance. For another, I have too many problems to work on and not enough time: I needed to share my wealth. At the time, I had no knowledge of undergraduate research. I was never involved in research as an undergraduate, and, until a few years ago, I was completely unaware that undergraduates performed original research. (I'm not sure what I thought went on in the undergraduate poster session at the Joint Meetings, but certainly not original work.) This article describes my inaugural year of mentoring an undergraduate research group, with pitfalls and advice given their due, and with the hope that the uninitiated and the terrified will be tempted to try it.

Midway through my first year in the new job, a colleague told me of a mini-grant to support an undergraduate research group, funded through the Center for Undergraduate Research in Mathematics (CURM) at Brigham Young University (BYU). A brainchild of CURM director Michael Dorff, the grant provides funding for a course release, a workshop for faculty to build mentoring skills, stipends for student researchers, and travel funds for students and faculty. For me, the faculty workshop was almost more appealing than the course release, as I felt entirely unequipped for mentoring undergraduates. The NSF-supported[1] CURM is designed to replicate BYU's successful undergraduate research program in departments across the country. A few things make the BYU model different: research groups meet during the academic year instead of the more common summer REUs (Research Experiences for Undergraduates), research groups are organized much like lab science groups with more advanced students (including graduate students) mentoring newcomers, students are involved in these groups as early as sophomore year and continue through graduation, and students are paid stipends for their work.

My research group consisted of three juniors and one master's student. We tackled a problem arising from image modeling: modeling deformations of periodic textures. Throughout the year, the group met once per week with me and twice with each other. During the first semester, I also met individually with each student once each week. The group was exhausting but rewarding. As one student put it:

> *The CURM experience for me has been like a rollercoaster. Sometimes I'm frustrated and sometimes I feel like I'm on top of the world. The research is difficult and challenging especially with school going on at the same time. But this challenging experience is addicting! It is great to be given a problem where the answer is not in the back of the book.*

From the professorial point of view, I completely agree. My hope is that, though the answer to being an undergraduate research mentor is not in the back of the book, this article will at least give step-by-step hints for how to begin the problem. Many

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[1] *DMS-0636648.*

suggestions below originated from colleagues at the CURM workshop, whose wisdom has earned my fervent gratitude.

Identify Your Goals

The first step toward building a successful undergraduate research group is to take an honest look at what your goals for the group are. I found out the hard way that goals not explicitly stated will affect your ability to mentor. Mid-year, I became increasingly frustrated that the students were not progressing as quickly as I thought they should. Once I realized the frustration originated in an unstated goal—I wanted the end-of-year product to be publishable—I was able to set the goal aside and focus on helping the students progress at their own speed. I still want a paper to come out of the project, but I've altered my timeline to fit the students' needs and abilities.

Differentiate between goals that benefit the students and goals that benefit you. My personal goals were to involve students in my research in a sustainable way, to raise the on-campus profile of mathematics, and to prioritize research above the noise of the academic year. Of course, some of your goals will be unrealistic. For example, I thought my students would work on small problems while I worked on larger, related problems. It turns out that I could have solved the smaller problems in much less time than it took to mentor the students, and the mentoring took time away from working on the larger problems. But the group did offer a weekly motivation to prevent research from getting lost in the pressures of teaching, and it also spread word of my research to other parts of campus.

My goals for the students were more realistic. I wanted them to experience the beauty of mathematical research, to see that math is alive and relevant, to build confidence in their mathematical abilities, and to learn to communicate effectively. I also wanted to pique their interest enough to apply to graduate school and to consider research mathematics as a possible career.

Find a Problem

I often hear the objection that a colleague's research requires too much machinery to involve undergraduates. Such an objection should not discourage you from supervising undergraduate research. Many participants in the CURM workshop work in esoteric areas, but nonetheless mentor successful undergraduate research projects year after year.

The challenge is to find an interesting yet realistic original research project for the particular students in your group. What is "realistic"? That depends on the students. One CURM participant argued that a good project has enough flexibility to accommodate three levels of research: guided discovery, where the professor expects to take a greater role in offering steps toward a solution; independent investigation, where the student works independently on a simpler problem; and scholarly activity, where the student works independently on a harder problem.

Below are several suggestions from the CURM workshop for where to find good undergraduate projects. I have organized them into broad categories based on relatedness to the professor's research program.

General Resources

- MAA columns with problems for research
- undergraduate journals
- talks in other disciplines
- Pi Mu Epsilon problems
- linear algebra

Resources from Your Research Area

- mistakes in others' proofs
- constructive proofs of others' theorems
- Ph.D. theses
- (re-)interpretation of results for industry applications

Resources from Your Research

- small examples of a larger theorem you're trying to prove
- testing "thresholds" in your own work
- specific examples of a general solution
- spinning research out from a course you teach
- any side calculations

Ideally, the project should have a "hook" problem that the students can understand and start to work on within the first month of the project. If not, the problem probably requires more background than the students can handle. Other pitfalls include choosing a problem you lack the required background in, not sufficiently understanding your students' backgrounds, and not modifying the problem when it proves to be ill-suited to the students' levels of preparation.

The problem I chose was too hard. Toward the end of the fall semester, I performed triage, reformulating the project into something more manageable. We found a partial solution to the new problem this year, and I expect the students will complete the solution shortly after returning in the fall.

Find Students

I found my research students by asking for recommendations from professors who taught sophomore level math courses the year before, then inviting those students to a meeting where we discussed the research project. A few students did not have the time or interest to participate, and a few other students were so flaky that the initial meeting never took place, so the group ended up being self-selecting. Other CURM participants recruit students directly from courses they regularly teach whose content gives relevant background information for the research project. This seems ideal when feasible because then you have direct knowledge of what a student has learned.

My school is still very small, so I did not have the luxury of selecting the best from among a crowd of interested students. If I am ever so lucky, I will try to pick students who are well-matched in personality and ability. In particular, I will look for pairs of students at a similar level but with complementary coursework who seem to have the potential to work well together (though I am unsure how to measure said potential). For me, four students is the ideal number to maintain group momentum without overwhelming my schedule with requests for one-on-one meetings, but the number ranged from two to six among the other CURM participants.

Get Started on Research

At the first group meeting, be prepared to explicitly state what you expect of the students, what the students can expect of you, and what the mechanisms will be for ensuring those expectations are met. Facing the uncertainty inherent in original research will be easier for your students if you clearly state all aspects of the project that can be made concrete. To better prepare my students for the research process, I gave them an article about how solving research problems is different from solving homework. At the very least, it is probably wise to let your students know that feeling stupidly incapable is one of the many delights of research.

I mentioned finding a "hook" problem above, which was arguably the best piece of advice I received during my CURM experience. The hook problem is one that the students can understand almost immediately and that the professor could solve in a lazy afternoon. The point of such a problem is to get the students involved in solving something at the outset, before or at the same time as they learn the necessary background. Ideally, it will be a problem that, once solved, will lead to the meat of the project. Or it might be that the students require the entire year to solve the hook problem. Either way, it gets the students actively working from the start and it helps the professor avoid the problem selection pitfalls mentioned in the previous section.

Another suggestion from the CURM workshop is to start the students on a "fake" problem, a problem possibly unrelated to the project that has a known solution but requires research-like thinking to solve (e.g., using the geometry of rectangles to prove the Pythagorean Theorem). I tried a fake problem with my students but quickly abandoned it because it distracted them from their primary task. Next year, I might try again with a fake problem that relates in some way to the work we are trying to accomplish.

Maintain Momentum

According to CURM director Michael Dorff, the key to a successful research group is maintaining student enthusiasm. Sounds simple, right? Until you remember that students will be experiencing the research cycle for the very first time: the thrill of a new challenge, the satisfaction of growing understanding, the excitement of the first attack, the disappointment when the attack fails, the dullness of days spent staring at equations awaiting new insight, the paralysis of stupidity, the glimmer of hope at a second attack, the disappointment…and so on. Meanwhile, other courses offering the comfort of well-defined tasks and deadlines can lure the students away from the research project. Research will not be a party every day, but here are some ideas for maintaining student focus during the Slough of Despond.

- Intersperse more concrete tasks, such as writing a portion of the final paper or designing a poster, with the open-ended research tasks.
- Schedule a seminar talk for the students to present their research problem so they can see how interesting the project is to other mathematicians.
- Ask students for results from a concrete experiment or computation.
- Require students to maintain records of their work through time sheets or progress logs. Not only will it keep them focused on work, it will allow them to see their progress.
- Do fun things occasionally, like going to lunch or playing a math game or talking about the history of relevant mathematicians.
- End every meeting with a concrete plan for the next few days.
- Rescue students who have struggled in the dark for too long.
- Emphasize that the process of mathematics is the process of making progressively less incorrect mistakes rather than a process of correct answers[2].

Midterms and papers for other courses will still distract some of the students some of the time, but ideally, momentum of the group will carry individual students through.

Manage Group Dynamics

For me, negotiating group dynamics was the most difficult aspect of mentoring. My group of four students consisted of three undergraduates and one master's student, two men (one married), two women, two Hispanic, one Filipina, three who are the first in their family to attend college, one who is the child of academics. These students brought different assumptions, skill levels, and outside responsibilities to the group, as did I, which resulted in some misunderstandings of the behavior

[2] *This suggestion is courtesy of Michael Starbird.*

of other group members. Consequently, the group faced a few difficult moments that could have been avoided if I had anticipated the types of behaviors that would be most damaging.

Need for control. Power struggles will undoubtedly surface in any group, many of which will resolve themselves sensibly. Occasionally, however, a student's unwillingness to cede decision-making to the group will paralyze an otherwise productive group. Not only does the student's controlling behavior disrespect the other students' opinions, it also undermines the independent thought and creativity a research project is meant to foster. The other students will eventually surrender their voices to avoid disdain and argument from the controlling student. Controlling behavior usually indicates deep anxiety or insecurity, so the professor must somehow reduce the student's death grip on control without further damaging his or her self-esteem.

Lack of communication with other group members. Occasionally, a subset of the group may come to an agreement concerning a group decision during a conversation outside regular group meetings. When the subset informs the group of the decision as *fait accompli*, the remainder will likely be upset by their exclusion from the decision making process. Even worse is when the subset acts on the decision without discussion with the other group members, who are perhaps acting on the assumption of a different decision. These miscommunications generate resentment and mistrust among the excluded group members. The research mentor should establish a standard method (email, wiki, blog) for students to maintain open lines of regular communication.

Closure to constructive criticism. Research is challenging and often requires several wrong approaches to find the correct approach. Unfortunately, many students have been conditioned to focus on finding the answer rather than engaging in the *process* of finding the answer. These students will likely struggle with learning from mistakes, particularly when someone else points them out. The transition from homework to research mindset requires the shift of emphasis from answers to understanding. The challenge is to ease the student into viewing mistakes as new information about the problem rather than as an evaluation of student worth.

Sporadic involvement. Some of my students faced substantial responsibilities outside of school, resulting in periods of intense group involvement alternated with periods of absence. Overall, the students worked the same amount, but the students with more consistent involvement lost faith in the others because of their apparent unreliability. I struggled to prevent the absent students from being excluded from important decisions, encouraging the consistent students to empathize with the heavy responsibilities of the sporadic students. At the same time, I urged the sporadic students to hold to a minimum weekly involvement with the group.

I believe the key to addressing these behaviors is to preempt them by making the group process explicit at the outset. Before the group begins the mathematical work for the year, ask students to think about their past group experiences: what characteristics have worked for them? what characteristics have not? how would they like to make group decisions? how would they like to share work? what is the best way for them to hear/give constructive criticism? what if a student misses a meeting? Write a list of these mutually agreed upon norms for group interaction, and return to the list whenever you feel the group dynamic is breaking down. Encourage the students to refer to the list periodically to evaluate whether the group is abiding by its norms. My group could have avoided most of the above scenarios if we had developed methods for addressing them before they arose. Additionally, my interventions would have felt less like scolding if I could have pointed to norms generated by the students themselves.

Enjoy Success

At the end of the year, you may have achieved all—or none—of the goals set out in Step One. Regardless, your students have changed, you have changed, your understanding of the project or the students or both has changed. Change represents success: relish it.

Here at the end of my inaugural year, my students have presented two posters, given five talks, and written a decent draft of a research paper. They can summarize their work efficiently and field questions like pros. All four students plan to apply to Ph.D. programs next year. Already, their understanding of research far outstrips mine upon entering graduate school, so I expect them to excel at the next level. Two of the undergraduates are continuing to work with my group, joining two new students in the fall who will be funded by CURM, and so my dream of a continuous research group has hope of materializing. As a result of the undergraduate grapevine, two students and a colleague in computer science have approached me about my research, resulting in potential research students for the following year and a fledgling faculty research group with the computer scientist and another colleague in physics.

On a larger scale, the dean of faculty at CSUCI has initiated a program to encourage student research groups in all disciplines, thereby institutionalizing undergraduate research on our campus. If our young campus, beset by a state budget crisis, can carve out a small program to support student research, so can yours. Ask your dean for funding, talk to your office of sponsored research, apply for grants, talk to industry partners. Taking the first step may lead you to an elevator.

Things to Try Next Year:

Looking to the coming year of research, I plan to try some assorted techniques that didn't find a home in the above sections:

1. Meet outside my office, preferably in the room where the students meet without me, to free me from distractions and to provide some continuity to the group meetings.
2. Require weekly time cards to be turned in. This year I asked students to keep progress logs but did not collect them, so they dwindled away.
3. Pop in on student meetings from time to time to answer questions and keep the conversation on track.
4. Invite a colleague in the communication department to talk to students about developing productive working groups.
5. Moderate the number of talks and posters so students have longer stretches to focus solely on research.

One final thought: some of the CURM faculty last year were concerned that academic year research programs were not as effective as research programs offered in summer when students and faculty have no other distractions. I believe each is valuable for different reasons. In fact, two of my students will participate this summer in REUs. For me, the pros of academic year research are that it more closely mimics the life of a mathematics researcher, it creates a community of research within the student body, and it allows for the continuity of a research group over the years. In addition, as a pre-tenure faculty member, I want to reserve my summers for my own research. I encourage those who disagree to involve themselves in one of the many wonderful summer REU programs. For now, I am sold on the academic year model.

Other Resources:

- `http://curm.byu.edu/curmresources.htm`
- `http://math.la.asu.edu/~crook/undergrad.html`
- `http://www.maa.org/columns/resources/resources_2_08.html`

Undergraduate Research Journals:

- *Involve*
  `http://pjm.math.berkeley.edu/inv/about/journal/about.html`
- *Rose-Hulman Undergraduate Math Journal*
  `http://www.rose-hulman.edu/mathjournal/who.php`
- *Pi Mu Epsilon*
  `http://www.pme-math.org/journal/overview.html`
- *The Pentagon: The Official Journal of Kappa Mu Epsilon*
  `http://www.kappamuepsilon.org/pages/Pentagon.php`
- *Journal of Undergraduate Sciences*
  `http://www.hcs.harvard.edu/~jus/about.html`
- *Journal of Young Investigators*
  `http://www.jyi.org`
- *Furman University Electronic Journal of Undergraduate Mathematics*
  `http://math.furman.edu/~mwoodard/fuejum/welcome.html`
- *Morehead Electronic Journal of Applicable Mathematics*
  `http://www.morehead-st.edu/mejam/`