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Life on Both Sides of the Fence: Mentoring Versus Being Mentored

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My mentoring style is an outgrowth of both my rigorous undergraduate career at Caltech and my interdisciplinary scientific training. Caltech undergraduates are expected to drink from the firehose of knowledge, and I try to give the same opportunities to my students. Additionally, to convey an appreciation for science, it is extremely important to impart not only knowledge that is directly germane to a project and how to attack it but also to illustrate just how much wonderful stuff there is to study and some of the places where a student's particular research problem fits into the big picture.

In this article, I will indicate how undergraduate research is organized at Caltech and review my own experiences there. I will subsequently discuss my mentoring history and summarize with a few pithy pieces of advice. I examine several of these points in further detail in an expanded version of this essay [**1**].

1. Undergraduate Research at Caltech

Caltech's primary research program for undergraduate students is the Summer Undergraduate Research Fellowship (SURF) program, which has been around since 1979 and currently offers research opportunities—both on campus and at the Jet Propulsion Laboratory (JPL), which is run by Caltech—for about 250 Caltech students and 150 students from other institutions each year. The SURF program, a campus-wide research initiative, permeates Caltech's culture. It encompasses all academic fields and is a fundamental part of Caltech's undergraduate education, as roughly three quarters of all Caltech undergraduates students participate in SURF at least once before they leave.

As described at *http://www.surf.caltech.edu/*, the SURF program is modeled on the grant-seeking process. Each student starts by collaborating with a potential mentor to develop a project. Applicants then write research proposals, which are reviewed by a faculty committee that recommends awards. Students work during a 10-week period from the middle of June until late August, earning a salary of $500 per week. During this time, they submit two progress reports that detail unexpected challenges, how their goals have changed from those in their initial proposal, and other similar items. At the conclusion of the program, students submit a technical paper and give an oral presentation at SURF Seminar Day, a symposium modeled

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on a professional technical meeting.[1] A draft of the final report is due right before Caltech's fall quarter starts at the end of September and a final version approved by the mentor is due on November 1st.

Every December, the entire Caltech faculty is solicited to advertise SURF projects that they are offering the following summer. As they are received, research opportunities are compiled on a website, which is organized according to Caltech "Divisions" such as "Physics, Math, and Astronomy"). Each opportunity includes a terse description of the problem(s) available and other germane information such as allowed majors; coursework requirements; whether the work is theoretical, computational, or experimental; whether non-Caltech students will be considered, and so on. Students then contact the appropriate professor (or faculty who have not actually advertised projects, which is also often successful) and arrange a meeting. Potential mentors typically have informal interviews with several students for a given project before they decide which one(s) they want to advise.

Caltech's SURF program also includes a variety of extracurricular activities—including weekly seminars by Caltech faculty and JPL technical staff; a participatory discussion series on developing a research career, graduate school admissions, and other topics of interest to future researchers; and social and cultural endeavors. This facilitates interactions between students from other universities and those who attend Caltech, which tends to have a fairly insular student body.

2. My Undergraduate Research Experiences

As a Caltech undergraduate, I undertook three research projects. My work did not yield any publications, but my experiences played strong roles in shaping my mentoring style. I also learned a lot of technical material, how to use LaTeX, how to write scientific reports, and developed strong opinions about what to do (and not to do) as an advisor. Here I will briefly describe my two SURF projects, which both resulted from unsolicited e-mails I sent to professors.

Seeking a career in dynamical systems, I worked in summer 1996 with Jerry Marsden on a project entailing the writing of an expository article on the Hopf fibration and its applications in mechanics. I learned a lot not only about geometric mechanics but also about mathematical exposition and LaTeX. Some of my other lessons were more surprising. For example, I attempted unsuccessfully to get my expository article published on my own. This was a mistake, as I should have instead asked Marsden to be a coauthor, worked with him further to revise the paper, and sought more extensive advice about appropriate journals for the paper. While such misadventures are probably rare for undergraduates, this experience has compelled me to always discuss the publication and dissemination of work with all my research students. I have published papers with several of them, but I let them know very early that this is something we do together.

My summer 1997 SURF project helped me refine my research interests and learn some things one should *not* do as a mentor. I decided to undertake a pure mathematics project in which I was to prove a result motivated by a physical process known as diffusion limited aggregation. Unfortunately, I spent the summer in a constant state of frustration. I did learn a lot and had the chance to read some seminal physics papers, but my advisor was absent from campus virtually

[1]There is a seminar day predominantly for non-Caltech students in the middle of August and one for Caltech students in the middle of October.

the entire time and I was horribly stuck with nobody to ask for help. I did not know how to find journal articles on my own, which journal articles I should get, what techniques I should try to learn, etc. However, the physics papers I read were extremely interesting, and I did learn that pure mathematics was not for me. I also learned, by counterexample, additional ways advisors can help. Because of this experience, I always teach my students how to use the research literature.

3. The Transition from Mentee to Mentor

3.1. The Mathematical and Theoretical Biology Institute (MTBI). My first significant mentoring experience came during the summers of 2000 to 2002 as part of Carlos Castillo-Chavez's Mathematical and Theoretical Biological Institute (MTBI). My role included assisting students with homework problems and acting as an advisor and critic for research projects.

I strongly encouraged the MTBI students to attend research conferences. In 2002, the Society for Industrial and Applied Mathematics's annual summer meeting was held in Philadelphia. We thus arranged a road trip so that the current MTBI students could attend the meeting, where Stephen Wirkus and I co-organized two sessions on mathematical biology whose speakers were all MTBI alums [**3**]. This "minisymposium" allowed the students to see what people who used to be in their shoes had accomplished, meet with them and discuss both academic and social issues, and experience the usual benefits of attending conferences.

At MTBI, I was known for my tendencies to ask tough questions during presentations and return manuscript drafts containing numerous suggestions written lovingly in red. I know from my own education that academic rigor should be stressed even at the birth of a scientific career. It's also important to ask tough questions in a relatively friendly environment to prepare students for future situations, such as doctoral thesis defenses and conference talks, in which the stakes are higher. On occasion, students would try to finagle answers to my questions, which compelled me to ask even tougher follow-up questions to teach them that that is simply not permissible. I find that many students don't appreciate that it is acceptable, and in fact preferable, for them to give an honest answer of 'I don't know.' and (ideally) to ask the questioner to discuss the matter further offline.

My first experience as the primary advisor on an MTBI research project was a bit rough around the edges. My regular meetings with my students were reasonably productive, but I had a personality conflict with one of them. My initial expectations for her were too high, and she did not appreciate my attempts to push her. Thus, while my belief that one should have high expectations for every student was untempered, I realized that what actually constitutes this varies greatly from student to student. Accordingly, I revised my advising goal as one of making sure that students left my charge in a more advanced state than when they entered it. For some students, this means a peer-reviewed publication, but for others it may be as simple as understanding (and duplicating) some calculations, proofs, or numerical computations from a book or article. I also learned that it is essential that I show my frustration only when I think a kick in the butt will help the student. I still experience considerable frustration when advising many of my students, but I am purposely better at showing it only when I have judged that it's what the student needs to see. Finally, I learned that for me to be a good mentor, it is imperative not only that the students be interested in the project but that I am as well.

3.2. Georgia Tech's VIGRE Program. I began advising projects at Georgia Tech in summer 2003 through the math department's REU, which was funded through the department's National Science Foundation VIGRE grant. When a student first contacts me about research, we meet in person so I can ascertain his/her background and interests. Many students are ready to undertake research without extensive coursework, and I like to be able to accommodate that. (Some of my best students initially approached me during their freshman years.) Alternatively, one can adjust the scope of projects to accommodate students who haven't had as many courses. Progress might be slower, but the first term of a project typically entails more time learning background material than producing original results anyway and student projects that lead to publications almost always last longer than one term. During our first conversation, I also encourage my prospective advisees to contact my past students. Most students seem to be ready to sign up on the spot, but I want them to get into the habit of seeking advice.

My ideas for student projects come from several sources. One of the first I advised, on modeling bipolar disorder, was an extension of an MTBI project. Another, entailing the construction of a graphical user interface to simulate billiard systems, was motivated by a question that arose during a seminar at the Mathematical Sciences Research Institute. Other projects have developed through traditional means such as exploration of the research literature. Many of these have been in network theory, a subject that is particularly suited for undergraduate research.

To facilitate group meetings, establish collaborations, and delve into new research areas, I occasionally co-advised student projects with Georgia Tech faculty. Starting in summer 2003, for example, I co-advised a pair of students who were studying two different networks but needed to learn similar concepts. I found that students typically advance much faster when they are working on similar projects and can bounce ideas off each other. Assigning two students to the same project can be beneficial as well, but I think it's much better if their projects overlap rather than duplicate each other. Additionally, the presence of two advisors with complementary skills is wonderful for both students and mentors. In terms of my own research program, I had learned some network theory in graduate school but had never conducted research in it and was very keen to do so. These student projects were my first forays into network theory (in which I have remained active). My subsequent research groups have included students from multiple majors and faculty from other departments, allowing my students to be introduced not only to research but also to interdisciplinary collaboration. For example, one group included a biology professor, a math professor, an electrical engineering major, a math major, and me.

Motivated by Caltech's framework, I insisted that my students write final reports that we would then polish together by working through several drafts. (I also insisted that they use LaTeXto write these reports and provided them with a tutorial for first-time users that I had written while at MTBI [**2**].) This not only improved my students' communication skills but also allowed us to better appreciate the gaps that still needed to be filled when it came to possible publication. I also arranged for my students to give short talks in group meetings of Georgia Tech's Center for Nonlinear Science (with which I was affiliated) and to present posters and talks at conferences.

3.3. On the Other Side at Caltech. I have continued my student mentoring as a Caltech postdoc. The 2006 version of my research-opportunity announcement included the following information:

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Projects in Nonlinear Dynamics and Complex Systems

Michael Cross, Professor, Department of Physics

Mason Porter, Postdoctoral Scholar, Department of Physics
and Center for the Physics of Information

Majors: Any major is good, but students in applied math, physics,
and math are likely to be especially interested in these projects.

Prerequisites: It depends on the specific project. Some require more
than others. I will work with the student's background to design something
appropriate. This should not be considered any sort of obstacle.

Type: Theoretical and/or Computational

Note: This is an on-campus SURF. Caltech students only.

Nonlinearity and complexity abound throughout science, nature, and
technology, as their understanding helps to provide explanations of
myriad phenomena---including synchronization of flashing fireflies and
lasers, chaotic motion in double pendula, the formation of patterns in
chemical reactions, species co-existence in plankton populations,
correlations between political ideology and congressional committee
structure, and chaotic dynamics in both classical and quantum systems.
In this project, the student(s) who work with me will work on some
mathematical modeling of some phenomenon (to be discussed in private
communication) using computational and/or analytical techniques. To get
an idea of the types of things I like to study, please see
www.its.caltech.edu/~mason/research or drop me a line. Possible projects
include ones involving Bose-Einstein condensates, complex networks (such
as congressional networks), quantum chaos, billiard systems, pattern
formation, synchronization, and others.
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Several of these items require some explanation. First, a member of the Caltech faculty (in this case, my postdoctoral supervisor Michael Cross) must be listed as the official mentor. Caltech asks mentors to list "allowed" majors, although I instead indicated who was more likely to enjoy my projects. I purposely included several project ideas with the intention that the particular projects students chose would be functions of not only my interests but also theirs.[2]

One change I have made in my advising since returning to Caltech has been to establish group meetings along the lines of what is perhaps more familiar in physics departments than in math departments. Hence, in addition to meeting

[2]One of my past students was sufficiently advanced that I asked him to come up with his own project, which proved to be very successful.

individually with each student twice a week (for roughly 30 minutes each time) and communicating over e-mail and instant messaging, my students and I meet collectively for about an hour every week. In a typical meeting, two of my students will present material in front of the whole group, the others are expected to ask questions, and I will occasionally speak up when I want to highlight a particular point (which may be related to science, exposition, or both). In some meetings, students practice more formal oral presentations or read and discuss each others' written reports. I specifically instruct my students to ask tough questions and make critical comments, and I expect my them to be similarly critical when reading their peers' papers. While my purpose with these exercises is to improve their oral and written presentation skills, I think the students also might learn a bit about peer review as a byproduct. Once my students have given comments, I add a few of my own, and I accentuate the previously-raised points with which I particularly agree.

The final SURF reports are supposed to be written in the format of an appropriate scientific journal. Caltech's SURF office recommends *Nature* as a default but leaves the final decision to the research mentors. I discuss publishing issues with all my students (even the weaker ones) and select a journal style that is appropriate for their particular project and situation. My past journal models have included both broadly-oriented venues such as *Nature* and the *Proceedings of the National Academy of Sciences* and archival journals such as *Physical Review E* and *Chaos*. As with the initial proposal, I go through four–five drafts of the final report with each student.

4. Conclusions

As I have discussed at length, my undergraduate research experiences at Caltech and my interdisciplinary training have fundamentally shaped my mentoring style. Students obtain an optimal research experience when expectations are high (but not too high). It is extremely valuable for students and faculty from multiple backgrounds to interact regularly, and weekly group meetings provide an excellent supplement to one-on-one meetings by reinforcing this and other boons. From a selfish perspective, I have found advising student projects to be an ideal means to enter new research areas. Although it can be very frustrating at times, my close involvement with talented students is perhaps my favorite academic pursuit.

Acknowledgements

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References

[1] M. A. Porter, *Life on Both Sides of the Fence: Mentoring Versus Being Mentored (Extended Version)*. physics/0611046, 2006.

[2] M. A. Porter, *A Hitchhiker's Guide to LaTeX (or how I learned to stop worrying and love writing my dissertation). http://www.math.gatech.edu/∼mason/papers/draft/lala.pdf*, 2002.

[3] S. Wirkus and M. A. Porter, *SIAM hears from next-generation mathematical biologists at Philadelphia meeting*, SIAM News, 35 (2002).

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