

Viewpoint Your Students Are Your Legacy

This Viewpoint boils down into a few magazine pages what I've learned in my 32 years of mentoring Ph.D. students.

ONE OF MY favorite activities is advising, so I was happy to accept the invitation to give advice about giving advice. Some faculty members give new students a list of their expectations and student rights. One student did so well that I asked him if he knew why. He said I gave him helpful guidance upon entering graduate school, when he was eager to hear it. He then told me what I said, which I've been telling to new students ever since:

► *Show initiative, for fortune favors the bold.* Don't wait for professors to tell you what to do; if we were good managers, we probably wouldn't be faculty. Explore, challenge assumptions, and don't let lots of prior art discourage you.

► *Sink or swim.* We'll offer you what we think are great projects with plenty of potential, and we'll support you the best we can, but it's what you do with the opportunity that makes or breaks your graduate student career.

► *Educate your professor.* We're in a fast-moving field, so for us to give you good advice we need to know what you're working on. Teach us!

It Takes a Village to Raise a Child

Advising is simpler if you foster an environment that helps students learn how to become successful researchers. The general goals of the environment should be:

► *Acquiring research taste.* Provide ways for students to acquire research

taste; in particular, how to identify problems that if solved are more likely to scale and have impact.

► *Frequent feedback.* Offer opportunities for students to practice communication skills by presenting to outsiders, to improve their research via honest feedback, to inspire them with earned praise, and to set milestones for their research.

► *Foster camaraderie and enthusiasm.* Create a community that provides camaraderie, group learning, mentoring from senior students, and learning from peers to make the whole Ph.D. process more enjoyable.

Meeting these goals is not always easy. I'll describe three techniques

that have worked well for me and many Berkeley systems students: team-oriented, multidisciplinary projects; research retreats; and open, collaborative research labs.

Exciting multidisciplinary projects. I try to work with colleagues to create exciting, five-year projects that I would die to work on if I were a graduate student again. We self-assemble into teams of typically two to four faculty members with the right areas of expertise to tackle a challenging and important problem, then recruit 10 to 20 graduate students to work toward building a prototype that demonstrates our proposed solution. The accompanying table shows



Network of Workstations (NOW) group reunion in 2008.

the 10 Berkeley projects on which I participated.

The multidisciplinary nature of the project means students gain hands-on knowledge about other areas by working closely with students and faculty in other fields. The experience they gain building the common prototype helps them develop taste in research topics, which in turn helps them pick interesting research topics for their dissertations and later in the rest of their careers.

Group projects create communities where students have others with whom to interact. In particular, the more senior students can mentor the junior ones. Being a Ph.D. student can be a very lonely experience, especially when it comes time to write a dissertation; being part of a larger group can allay those feelings of isolation.

We recently started celebrating the 10-year anniversary of the end of projects. The high participation level at these reunions indicates that these personal ties in such communities remain 10 years later. The accompanying photo shows the Network of Workstations (NOW) group reunion held last year.^a

Research retreats. Key to the success of these projects, and to the development of Berkeley systems graduate students, has been twice-a-year, three-day retreats where students on the project present their results to one- or two-dozen guests from industry or non-academic labs. These are intensive events, lasting from early breakfast to late-night discussions, although we do take off one afternoon to have some fun. Retreats act as project milestones, with the specter of presenting to outside visitors motivating students to meet the milestones. We close the retreats with an outsider feedback session that offers advice on any aspect of the research. It's surprisingly rare in academia to get frank feedback about research, but who can't benefit from constructive criticism?

Retreats give graduate students two chances per year to give a serious talk

^a Additional photos are included with the version of this Viewpoint available at the *Communications* Web site, cacm.acm.org. The online version has names and group photos for RAID and SPUR reunions and for the most recent Par Lab and RAD Lab retreats.

Patterson's research projects.

Years	Title	Professors	Students
1977–1981	X-Tree: A Tree-Structured Multiprocessor	3	12
1980–1984	RISC: Reduced Instruction Set Computer	3	17
1983–1986	SOAR: Smalltalk On A RISC	2	12
1985–1989	SPUR: Symbolic Processing Using RISCs	6	21
1988–1992	RAID: Redundant Array of Inexpensive Disks	3	16
1993–1998	NOW: Network of Workstations	4	25
1997–2002	IRAM: Intelligent RAM	3	12
2001–2005	ROC: Recovery Oriented Computing	2	11
2005–2010	RAD Lab: Reliable Adaptive Distributed Computing Lab	7	30
2007–2012	Par Lab: Parallel Computing Lab	8	40

and receive advice from experienced researchers outside academia with different experience and perspectives from the faculty on the project. Students are energized when external people care about their work and find it important. When we advisers say something is good, many students will assume we are just acting as cheerleaders or just trying to get them to work harder. I believe interaction with thoughtful colleagues from industry and non-academic labs is vital to acquiring research taste in computer systems by learning to identify critical problems and impactful solutions. Retreats also introduce students to a network of colleagues that may prove useful later in their careers.

Such projects and retreats might be difficult at some places. Building collaborations with local universities and industry can produce many of the same benefits. The key is to get everyone to stay the full time and have people outside your group provide candid feedback. For example, there is an annual Boston Area Architecture workshop involving Brown, Harvard, UMass, Northeast, RPI, and local industry so that their students can cut their teeth in front of a friendly audience and get feedback from outsiders.

We have been doing retreats for 25 years. To my surprise, three years ago we discovered another technique that is becoming just as important to the success of projects and graduate

students.

Open collaborative laboratory. We were increasingly seeing people optimize their schedules to avoid disruptions by working from home when they didn't have classes or meetings, since computers and networks were just as fast at home as in the office. The negative global impact of such a local optimization can be thought of as corollary of Metcalf's Law: if the value of a network is proportional to the square of the number of connected users, even a small group leaving a network can significantly decrease its value. This drop in value can in turn cause others to leave, with the negative feedback loop continuing until the network nearly collapses.

In 2006, we experimented by creating a physical office area with contiguous open space for everyone in the project, including the faculty. We hoped that easy access to faculty would draw students to campus and that the open space would inspire innovation by increasing the chances of spontaneous discussions.¹

The open space makes it very convenient to quickly grab a group of interested people on a moment's notice for a discussion rather than trying to wander around the building or exchange a volley of email messages to schedule a meeting. We have also been surprised to see new students in this space quickly act like senior graduate students. Apparently, easy access to faculty plus

watching how senior graduate students operate helps new students move up the learning curve quickly.

The research retreats and open space also build esprit de corps, as we play together one afternoon at retreats—for example, skiing, paint ball, and river rafting—and in the lab we collectively watch presidential debates, movies, and big sports events.

The challenge of our open space is then to preserve concentration while enhancing communication,¹ for otherwise people will still stay home. Distractions are reduced with large displays, headphones, and relying on cellphones instead of landline phones; the custom is to make and take calls outside the open space. We also included many small meeting rooms in which to hold vigorous conversations. The result is an open space about as quiet as a library or coffee shop, which is good enough for most to concentrate while encouraging spontaneous communication.

Actual Advising

Clearly, the students who always do well are a joy to meet. I do wonder how much advising you are really doing for them. For those students who need more help, the only thing I can say with confidence after 32 years is that every student is different, and its unlikely there is a single path that works for all. Moreover, there are limits to how much you can change, since students have had at least 20 years of people shaping their personalities before they even meet you. You can tell new students that being a successful researcher is different from being a successful undergraduate student, as they generally have no opinions on the topic when they arrive. For example, it's often a surprise that grades are less important than research, and that they need to learn how to work on their own rather than just follow orders. They also need to find the right balance between learning the literature and starting to build. Clearly, advice changes over time. New students may need a "starter" project, and you give them larger tasks as students mature: reviewing, mentoring, and even helping write proposals.

Here are a half-dozen other topics for advisors, including bolstering confidence, helping with speaking, spend-

ing time together, giving quick feedback, counseling them, and acting like a role model.

Bolster confidence. Self-confidence can be a problem for students, especially early in their careers and for some belonging to underrepresented groups, so look for chances for them to succeed. Perhaps it's suggesting a paper they can be lead author on, taking a summer internship at a company that is a good match for their talents, or even having success as a teaching assistant. I have seen even very senior students blossom late in their careers when they have some wins under their belts that everyone recognizes.

Make sure that you praise such students when they do have real success; all of us love praise for a job well done, but some of us need it more than others do. Students learn from criticism as well as praise, just be careful it doesn't deflate potentially fragile egos. I try to remember to phrase critiques as questions—"What do you think about...?"—both orally and in my written comments on papers. I try to include something to praise in all the red ink that I put on a student's paper, but keep in mind that false praise for a mediocre job may hurt more than help.³

Practice public speaking. Good work is often lost due to poor presentation, yet giving good talks is a problem for many students. Our culture is that practice talks are good for everyone, so we all do them, including me. We practice answering difficult questions as well as delivering smooth talks to avoid a "deer-in-headlights" incident during

the actual talk.

Spend the time. Weekly meetings gives students a chance to talk about what they're working on and forces them to think in advance about how to utilize their time with you. I tell Ph.D. students in their last six months that they have highest priority on my schedule and can meet as often as they want, which helps reduce their anxiety.

Give feedback, quickly and often. I try to review a student paper within a day or two and give my comments for them to read before we meet, which means I am not the bottleneck. Making students write the paper and the guiding them through the revision process teaches them how to write.

Be a trusted counselor. Students may ask for personal advice, perhaps even for serious problems. As they are often far from family and friends, you must be there for them.

You're a role model; act like one. I am struck from parenting two now-grown sons that it's not what you say but what you do that has lasting impact. I bet this lesson applies as well to your academic progeny. Hence, I am conscious that students are always watching what I do, and try to act in ways that I'd like them to emulate later.

For example, my joy of being a professor is obvious to everyone I interact with, whereas I hear that some colleagues at competing universities often complain to their students about how hectic their lives are. Perhaps differing advisor behavior explains why many Berkeley systems students try academia?

Tricks of the Trade

Surely the most traumatic matter for the students is picking the thesis topic, as they believe it determines their careers. Gerald Estrin, who had worked with John von Neumann, was one of my advisors in graduate school. I still remember him telling me: "Every CS Ph.D. student I have seen, including myself, had a least one period when they are convinced that their dissertation topic is utterly worthless." Just retelling this story can help students cope, but look for opportunities to get others to praise their work. Projects and retreats help: there are others to talk to and they get regular feedback on their chosen topic from the outsiders,

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which can energize those on the lonely trail to a Ph.D. My view now is that it's not the dissertation topic so much as what students do with it.

Here are four pieces of advice for advisors: help if they stumble, aid non-native speakers, try co-advising, and offer lifelong mentoring.

Help if they stumble. Students may underperform not because they lack ability but because they come to think that "good enough" is OK. Have a heart-to-heart discussion where you point this out and ask if they agree, and from now on they're expected to perform to the best of their ability. The book *The One Minute Manager*² offers advice on handling such touchy situations successfully for all involved.

One colleague asks students that seem stuck to send him a daily report about their research and progress. Some days it could just summarize a paper or talk, or even "I didn't do anything." He finds that three to four weeks of this often gets them back on track.

When students really stumble in the program and stop making progress, I have had luck with sending them to industry for a six-month leave, as three months may not be enough to do something significant. Twice students have come back fired up knowing what they want to do for their dissertation and, perhaps more importantly, why they want to do it. A third student decided to stay in industry. That was likely a good decision, as I didn't look forward to trying to drag him across the Ph.D. finish line if he didn't return with a greater sense of purpose, and I'm not sure he would have graduated if he wasn't reinvigorated.

Berkeley CS faculty members hold two meetings a year to review the progress and give feedback to all Ph.D. students. Students meet with advisors beforehand to set mutually agreed upon milestones. Hearing others both praise and criticize your students provides a valuable perspective, and collectively we develop ideas on how to help students in need. Reviews also ensure that no student falls through the cracks. Occasionally, after several warnings, we tell students that their progress is so slow that they should drop out. In more than one instance, these letters lit fires under lethargic students and they filed their disserta-

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tions soon thereafter.

Aid non-native speakers. Non-native English speakers can offer another set of challenges. As far as I can tell, they just need practice speaking and writing English. (I wish this need were limited to non-native English speakers!) Strunk and White's *The Elements of Style*⁴ is my writing bible, which I share with all my students. Some colleagues have had luck hiring graduate students from other parts of campus to work with CS graduate students to improve their writing. One colleague suggests making sure that if they share an apartment that their roommates don't speak the same language so that they are forced to speak English. I am trying an experiment to improve the diction of an international student by having him take a course outside the university called "Learn to Speak like an American."

Try co-advising. As part of our new open labs, we are also trying joint advising. I hear my co-advisors offer great advice that I wish I'd said, and I hope vice versa. Co-advising also has the benefit that when one advisor is traveling there is someone else to meet with the student. It also makes advising more fun for everyone involved. I believe it works well if the advisors meet with the student simultaneously, so that they give consistent advice. (From my long years of experience in academia, I've learned you get just as much credit whether you are the sole advisor or if you co-advise a student.)

Mentorship doesn't end at graduation. After investing five or six years training an apprentice, it must be worthwhile to spend a little more time after graduation to help him or her succeed. I offer to give a talk at their new institution to give them one last shove in the right direction. Danny Cohen recently asked

for advice from Ivan Sutherland—who supervised his 1968 thesis—adding that Danny views advisor is a lifetime job. I agree. I still offer advice to, and receive it from, my former students. (In fact, my former student Mark Hill suggested I write this Viewpoint.)

Advising in Retrospect

When I was finishing my Ph.D., I read a book based on interviews of people talking about their jobs to help decide what I would do next.⁵ What I learned from the book was that people were happy with their careers if they designed or built objects that lasted, such as the Empire State Building or the Golden Gate Bridge, or if they shaped people's lives, such as patients or parishioners. Thus, I went into the job of assistant professor with the hypothesis that my long-lasting impact was not the papers but the people.

Thirty-two years later, I can confirm that hypothesis: your main academic legacy is the dozens of students you mentor, not the hundreds of papers you publish. My advice to advisors is to get your students off to a good start, create stimulating research environments, help them acquire research taste, be a good role model, bolster student confidence, teach them to speak well publicly, and help them up if they stumble, for students are the real coins of the academic realm. C

References

1. Allen, T.J. and Henn, G. *The Organization and Architecture of Innovation: Managing the Flow of Technology*. Butterworth-Heinemann, 2006.
2. Blanchard, K.H. and Johnson, S. *The One Minute Manager*. William Morrow, 1982.
3. Carnegie, D. *How to Win Friends and Influence People*. Pocket, 1998.
4. Strunk, W. and White, E.B. *The Elements of Style*, 4th ed. Longman, 1999.
5. Terkel, S. *Working: People Talk About What They Do All Day and How They Feel About What They Do*. Pantheon Books, Random House, New York, 1974.

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