

Zeitschrift:	Bulletin / Vereinigung der Schweizerischen Hochschuldozierenden = Association Suisse des Enseignant-e-s d'Université
Herausgeber:	Vereinigung der Schweizerischen Hochschuldozierenden
Band:	44 (2018)
Heft:	3-4
Artikel:	Selecting and coaching doctoral students : a view from a US engineering department
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DOI:	https://doi.org/10.5169/seals-893767

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Selecting and coaching doctoral students – a view from a US engineering department

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This article gathers thoughts based on the author's personal experience as faculty member in two top-five departments of Materials Science and Engineering in the USA. It is a "composite portrait" based on his 27 years as a faculty member in two private universities, first as Assistant and then Associate Professor at the Massachusetts Institute of Technology (MIT, Cambridge, Massachusetts) from 1991 to 1997, and second as Associate and then full Professor at Northwestern University (NU, Evanston, Illinois) from 1997 to 2018 (present time).

1. Materials Science and Engineering departments: a research-centric experience for graduate students

Materials Science and Engineering (MSE) departments, in all but a few US universities, are housed in Engineering Schools, where they are among the smallest departments, in terms of *undergraduate* student count, as compared to the much larger Electrical, Mechanical and Computer Engineering departments. However, MSE departments typically have high *graduate* student populations, in absolute terms and especially when normalizing by their faculty count, as counted as "full time equivalent" positions, which is in the low 30s for MIT (one of the largest MSE department in the US) and the low 20s for NU. In the top-tier American MSE departments, professors typically teach one class per quarter or semester, with 3–4 hours per week of class time. Teaching represents about 10–20% of their time, when averaged over the full year (there is no teaching in the summer), with another ~10–20% devoted to leadership and service activities (both in- and outside the university), and 0–10% to consulting. The bulk of their time (50–70%) is thus devoted to research, which includes: (i) raising funds, via proposal writing, (ii) executing research and (iii) communicating research, via presentation and articles. In all three areas, but especially the latter two, graduate students are deeply involved, with a rising share of postdoctoral fellows and visitors. A small part of the research effort is carried out by undergraduate students, usually mentored by graduate students.

Graduate students are thus central to the success of a MSE research group, and there is strong incentive for both the professor (the adviser) and the student (the advisee) to carry out and publish the best pos-

sible research. Incentives are generally well aligned, but for somewhat different reasons. For the graduate students, the main goal is to perform research and write a thesis to receive the PhD degree which is the gateway to employment; jobs for doctoral students are mostly in MSE-centric industry (spanning research, development, production and sales), from very large companies (e.g., Airbus, General Electric, Samsung, Toyota) to mid-size, and small companies and even start-up companies. Other MSE-related employment are also open to students with MS or PhD degrees, including: consulting, government (especially National Laboratories or Defense Laboratories), universities (as postdocs and very rarely directly as faculty members), law (e.g. patent law), medicine (implants, biomaterials), journalism (science journalism), and business. The graduate students must receive their PhD degree to access the job market, and they also depend on letters of recommendation from their advisers when seeking employment.

2. Graduate students funding

During their PhD studies, the graduate students are financially supported by their advisers through Research Assistantships (RA), paying both a living stipend and all university tuitions; these student

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David C. Dunand, Ph.D., was born and raised in Geneva, Switzerland. He received his BS/MS degree in materials science (Werkstoffingenieur) at the Swiss Federal Institute of Technology (ETH Zurich) in 1986, and his Ph.D. in materials science and engineering from the Massachusetts Institute of Technology (MIT). After serving on the MIT faculty from 1991 to 1997, he joined Northwestern University (NU) where he is Full professor. His research focuses on the processing, structure and mechanical properties of metallic alloys, composites and foams. He is co-founder of NanoAl, LLC, a start-up company active in aluminum alloys, which was acquired in 2018 by Braidy Industries. He is a fellow of TMS (The Materials Society) and of ASM International, the recipient of the 2009 Distinguished Scientist/Engineering Award (Structural Materials Division of TMS), the 2012 winner of the *Materials Science & Engineering A Journal Prize*, and twice a departmental Teacher of the Year at NU. He is particularly proud that 22 of his students and postdocs have joined academia, of whom 9 are female.

expenses are the main lines of spending on the grants professors receive from governmental and industrial sources. Graduate students can also receive internal fellowships (usually for part or all of their first year) from their host MSE department. If they are American, they can apply for external fellowships – usually from the US government, e.g., from the National Science Foundation (NSF), the Department of Defense (DoD), the Department of Energy (DoE) or from US private foundation, e.g., the Hertz Foundation, the Sloan Foundation, the Xerox foundation. International graduate students also sometimes bring partial or full funding in the form of scholarships from their home countries. Another source of funding comes from Teaching Assistantships, lasting one or more semesters and consuming ~50% of the student time with teaching duties, with the rest of the time available for their PhD research. It is exceedingly rare that PhD students use their own personal funds, unlike undergraduate students who are using both loans and personal funds to pay for tuition and living expenses.

The exception to this no-self-funding rule are “terminal MS students”, who are not pursuing a PhD upon achieving a final MS degree which is designed to be short (1 year) and mostly focused on classroom experience, with optional laboratory-based research. After graduation, most such students enter the workforce, occasionally returning to earn their PhD at a later date. Sometimes, undergraduate students, both domestic and international, pursue a BS-MS joint degree, for which the funding comes from the student *via* a mixture of their own funds, debt and outside or university fellowships, the latter being often need-based and covering a substantial portion of the total cost.

3. Selecting and coaching graduate students: the first few months in the graduate program

At NU and in most US universities, the entering graduate students must, within a few weeks of joining a MSE department, select an adviser and join their research group. This is done in an *ad-hoc* manner in many smaller MSE departments, but at NU, a well-defined mechanism is in place which gives the student the most choice and freedom, while taking into account the needs and preferences of the faculty. At first, the entering class of PhD students (typically 30–50 in size) listens to oral presentations by each of the faculty members who highlight their research opening(s) and describe their groups. The students are then encouraged to visit professors in their office and discuss one on one the project(s) of interest, while also gathering information on the individual advisers (e.g., their publication record,

the jobs held by the group alumni), attending group research meetings, and discussing with older graduate students the adviser’s mentoring style, expectations, strengths and weaknesses.

A few weeks into the first quarter, the entering graduate students rank their top three adviser/project choices. The faculty members then meet to decide on the allocation of students to their various research groups: with the full matrix of student preferences, each student name is considered in alphabetical order; for example, Student A has listed as their first choice Professor X, who is asked whether or not he/she will take them for their project. If so, student A is placed and the next student B is considered. Otherwise, Student A’s second choice (Professor Y) is asked followed by, if needed, their third choice (Professor Z). Rarely are students not placed within their first three choices. This approach guarantees an active adviser choice to the student, while also giving a right of refusal to the professor, in case they feel that a specific student is not best suited for the project, and/or if more than one student has listed their particular project as their first choice. Almost every year, there are fewer students than projects, so the students are in a “buyer’s market” situation, with advisers putting their best foot forward to try to convince the students to list their project(s) as their first, second or third choices.

Placement concludes when the few students who were not placed via the above three-choice mechanism are asked to select projects from the pool of unclaimed projects. Two waypoints are now in front of the student: the Preliminary Evaluation and the Qualifying Examination, as described in the next section.

4. The graduate student cursus

At the end of their third quarter (i.e. before their first summer quarter) and upon completion of nine course credits including the required core courses, students undergo a **Preliminary Evaluation** by the entire faculty; this evaluation is based on class performance, as assessed from their Grade Point Average (GPA), on research performance, as assessed from written adviser comments and on a one-page summary of research progress provided by the student. The vast majority of students receive a notice of satisfactory progress and proceed with graduate coursework and research, leading to the Qualifying Examination about a year later. A few students received a notice of questionable progress, requiring a later re-evaluation (typically after 2 additional quarters) where the outcome is usually satisfactory or, very rarely, unsatisfactory, at which point they must leave the graduate program.

The **Qualifying Examination** is the second waypoint, occurring after about two years. The student delivers a document of about 20 pages summarizing their research to date and proposing additional research for the rest of their PhD project. They present their past and future research orally to a committee made up of the adviser, two other MSE professors, and an expert from outside the university. A passing assessment means that the student is recognized as a candidate for the Ph.D. degree. A non-passing assessment means that the student cannot continue towards the PhD, but is usually given the opportunity to earn a MS degree, upon writing of a thesis. Also, before reaching the point of defending a research proposal, a few students decide to conclude their research and receive a MS degree (e.g., if their interests and plans have changed). A journal article manuscript submitted for publication is accepted in lieu of a MS dissertation document, an option often taken by MS students.

At the end of their PhD research, the students must successfully pass a **Final Examination** based on work presented in their written dissertation. The same committee who met for the Qualifying Examination conducts the Final Examination which involves an open and publicized oral presentation during a first hour, followed by an examination closed to the public lasting about two hours. In many cases, the PhD thesis consists of chapters, each of which is a published or submitted journal (or conference) article, with additional material in the thesis residing in draft article form.

About 6–12 months before defending their PhD theses, the students start looking for employment, often helped by the adviser via their contacts and letters of recommendation.

Thus, a PhD cursus consists of two main blocks of time, before and after the Qualifying Examination. Before qualification, in their first two years, the student spend about a third of their time taking graduate-level classes and passing the end-of-term exams. The rest of their time is devoted to research, to achieve sufficient preliminary results to take the Qualifying Examination. The vast majority of the students pass this exam, and with coursework concluded, they devote all of their time to experimental, computational or theoretical research, while also writing articles and sponsor reports, helping the adviser writing proposals, presenting their work at conferences and workshops, and mentoring younger graduate and undergraduate students.

5. Co-reliance between graduate students and advisers

Based on the above system, the students are *reliant* on the adviser over a number of area during their PhD career, for which there are also strong opportunities for *coaching*, when the adviser:

- identifies a research project, usually based on a funded proposal or continuing an existing line of inquiry;
- provides research opportunities outside the adviser lab when beneficial to the student's project (e.g., National Laboratories, companies, laboratories of colleagues);
- identifies conferences where the student can present their research, listen to talks and network, and provides help for preparing oral presentations and posters;
- provides scientific mentorship for the first two years, including reviewing the thesis proposal, so that they pass their qualifying exams;
- offers mentorship for the execution of the research in the later years;
- gives guidance in writing articles and the PhD thesis, from first draft to final manuscript;
- provides opportunities to present preliminary results during group meetings;
- assigns undergraduate students doing research under the mentorship of the graduate students;
- involves the student in proposal writing, both to fund their later years in the research group and for future students, and to access equipment and facilities in National Laboratories;
- writes, jointly with the student, patent disclosures based on the PhD research;
- gives the opportunity to review articles or proposals, received from journals and funding agencies;
- helps the student identify employment opportunities (in their last year);
- writes recommendation letters and provides recommendations by phone when the student applies for a job;

Other coaching opportunities are related to group dynamics and human interactions, where the adviser:

- provides a culture of lab safety, respect and fairness for all individuals during interactions between students, postdocs and adviser;
- helps conflict resolution when they arise, while also providing other resolution avenues if needed (e.g., through departmental and university channels, as described below);
- discusses and solves research ethics quandaries (e.g., how to assign authorship and author order, how to review an article or proposal which overlaps with one's unpublished research);

- insures that students are sufficiently connected to the rest of the research group so they can benefit from scientific interactions with their peers, while also avoiding redundant or competitive situations, such as students feeling pitted against other students or postdocs in a zero-sum research situation.

Finally, the student is *financially dependent* on the adviser for funding of:

- their stipend and tuition;
- their research expenses;
- their travel expenses to conferences or outside research facilities;
- their publication fees.

Conversely, the adviser is reliant on the student on many of the same points. In particular, the adviser's research productivity, as measured via publication quality and quantity, is crucial for the renewal of research proposals, which benefit the next generation of students and the overall career of the adviser. A non-performing graduate student can lead to loss of funding and damage to the adviser's reputation, making fundraising for future projects more difficult.

This co-reliance between student and adviser creates, in most cases, a strong team spirit between them, as their goals are fully aligned, i.e., to produce the best research possible, to publish it in the best possible journals, and to push science and engineering into new territories. However, the motivations and rewards, while mostly aligned, can be somewhat different: (i) for the students, their main goal is receiving a PhD degree and secure their first employment, where the means are publishing articles; (ii) for the advisers, their main goal is to publish articles (as it leads to further funding as well as recognition in the field by colleagues) while also mentoring and forming the next generation of scientists and engineers.

There is also a strong human component associated with adviser and student walking on the same research path for 4–5 years: the student learns from their adviser many "soft skills", usually by observation and "osmosis", including:

- fostering creativity while remaining able to build upon prior achievements from others;
- independence of thought while remaining able to learn from others;
- communication, both speaking and listening productively;
- perseverance against adversity but ability to determine when to cut one's losses;
- finding a balance between collaboration and independent research and thinking.

The advisers also learn and benefit from their interactions with their students, via:

- the enthusiasm and energy of somebody new to scientific research;
- the creativity and productivity of students able to focus with more time and intensity on their particular projects;
- the novel and unexpected discoveries made in the lab (or at the computer or desk) by students fully immersed in their research;
- the reward of seeing a young person grow from green undergraduate student to experienced researcher, and following their professional trajectories years or even decades after they graduate.

6. Conflict prevention and resolution

While the vast majority of students/adviser interactions are constructive and mutually beneficial, there are cases where differences, disagreements and conflict may arise, and for which a robust network for fair and rapid resolution exists beyond the adviser, as described below for NU.

In terms of prevention, at the departmental level, all PhD students and postdocs undergo training related to Responsible Conduct of Research, consisting of an online course with nine common core modules and a five-week live course on the topic (GEN ENG 519 – Responsible Conduct of Research for Engineers). Also, there is a policy in place addressing the situation when an adviser proposes to involve students or postdocs in activities associated with their start-up company: a review takes place to ensure that the students are engaged voluntarily, that their involvement is beneficial to their development, and that their activity is not interfering with their academic progress. Finally, beginning in the 2018–19 academic year, NU is implementing a new sexual misconduct training which is required annually for all students.

Further preventive measures are also in place concerning romantic or sexual relationships between faculty and graduate students. The NU policy reads: "No faculty member shall enter into a romantic, dating, or sexual relationship with a Northwestern graduate/professional student under his/her supervision. Should such a relationship begin, the department chair must be notified promptly so that arrangements for alternative supervision and removal of evaluative authority can be made."

For students who have any concerns, the MSE department has five representatives to interact in a confidential manner: three members of the research faculty (the Department Chair, the Associate Department Chair, the Director of Graduate

Studies), the Assistant Department Chair (who is a non-research faculty member), and the Department Business Administrator. Students are encouraged to try to resolve personal conflict first by speaking directly with the other party. If they are not comfortable doing so, they are encouraged to reach out to the points of contact. If a problematic situation is identified, the Department Chair is then informed of the situation and of the plan to address the conflict, with the express approval of the student. At any time, the student may contact the Department Chair directly.

At the university level, the Office of Student Conduct (OSC) has for mission "to provide support and education to students involved in campus conduct matters, to facilitate the resolution of student conflicts, and to play a key role in educating and training students, faculty, and staff about community expectations, values and standards". Students can come to OSC to report or discuss concerns related to:

- the wellbeing of a student or the behavior of a student who may have violated a NU policy;
- sexual misconduct, stalking, dating violence, or domestic violence, with two different procedures if the person accused is another student or a faculty/staff member/third party.
- a hate or bias incident.

NU prohibits discrimination and harassment on the basis of 16 protected classes: race, color, religion, national origin, sex, pregnancy, sexual orientation, gender identity, gender expression, parental status,

marital status, age, disability, citizenship status, veteran status, and genetic information. In particular, sexual misconduct is a form of prohibited harassment which is explicitly defined as any of sexual assault, sexual exploitation, stalking, dating/domestic violence, and sexual harassment. All NU employees (including staff and faculty) and graduate students with teaching or supervisory roles must promptly report to the Office of Equity all sexual misconduct allegations of which they become aware during their work for the University. Furthermore, all personnel in teaching or supervisory positions (including Teaching Assistant students) must report allegations of discrimination or harassment to the Office of Equity. Further support services are provided by the Women's Center, the Center for Awareness, Response & Prevention (CARE), and the Office of Institutional Diversity and Inclusion

7. Conclusions

Professors and their PhD students, as research advisers and advisees, are scientifically and financially reliant on each other, and have aligned incentives and goals: doing the best possible research and publish it in the best possible journals. This alignment results in a smooth journey through the PhD program for most students. Because conflicts are unavoidable in any human enterprise, the university is offering a variety of prevention and resolution avenues, acknowledging that students have less power than advisers and must therefore be offered respect, support and protection. ■