<u>Preparing Physics Graduate Students for Careers in Industry</u>

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Consider the tale of 2 physics PhD students recently hired into industry. Bob has experienced the traditional graduate student program and is highly skilled and knowledgeable in a narrow branch of physics. Alice has a similar background but has also developed a broader base of experience relevant to the needs of industry. Both are told they will be leading critical development programs. Bob is panicked because he is thrown into a new situation with no sense of how to succeed, Alice has essentially led all aspects of her graduate program and has a broad base of relevant experiences and is confident she will be successful. For one new hire, it was the best of times, for the other, the worst of times.

Most physics graduate students will not have academic careers. Yet, it may be difficult for physics professors to prepare their students for careers in industry since most professors have not experienced professional life outside of academia. While most professors would no doubt like to better prepare their students for industrial careers, the lack of knowledge about this career path as well as lack of time and resources to prepare and teach a class in this area are significant barriers to providing a solution to this problem. In this note, I will describe the basic attributes and skills that are useful for industrial careers from my perspective, and will propose ways in which this education can be accomplished with minimal cost in time or resources. I base this on my 30 years of experience in industry in many roles including physicist, materials scientist, engineer, technical project leader, program manager, and engineering manager.

A new PhD physicist entering industry will be expected to at least be a technical leader, and will also likely be asked to manage some or all aspects of a small R&D program, or some significant part of a larger development program. So they will be responsible for the success of a program. They may also be asked to manage the schedule, budget, technical progress, and the work of others, including scientist, engineer, or technician co-workers, and outside collaborators and vendors. This means the new hire will need to do whatever is necessary to ensure success. In a broader context, a PhD will be asked to successfully negotiate transitions from basic research to early stage development, or early stage development to initial production, areas fraught with challenges. The latter transition is known as the competitive "Valley of Death" (Ref. 1) to those with a business or entrepreneurial orientation, while those in large Department of Defense or NASA programs may refer to these issues in terms of Technology Readiness Levels (Ref. 2), or TRLs.

So how can PhD level graduate students learn the necessary skills to be successful in this environment at minimal cost to physics departments? I propose two solutions, one relevant to course work and the other to the research effort, both based on my own experience as a graduate student of more than 30 years ago, where courses were almost exclusively devoted to derivations, mathematical manipulations, and standard end of chapter problems. Students should be also able to apply their knowledge to new situations, a key requirement for industrial physicists. Courses should include real world examples of the applications of the basic physics principles; for example, problems from a related engineering course would be useful to show real world uses. They should be asked to construct conceptual models of the physics, should be able to discuss the physics and applications, and should be able to draw/pictorialize the basic physics. When there are physical parameters (e.g. refractive index, extinction coefficient, permeability, permittivity), students should learn values for typical materials and the typical ranges as well as have a conceptual understanding of them. Preferably, students should also be introduced to computational methods/software packages used in industry. I know that almost none of these occurred in my graduate education. These changes to the graduate curriculum will allow students to more easily navigate the transition between basic physics and the engineering applications of their physics, as well as communicate the basic conceptual physics with fellow scientists, engineers, technicians, program managers, upper management, and customers. It would also, I think, make courses more relevant and interesting for many students.

The second solution involves small but important changes to the later years of a graduate research program. These changes should also improve the training of graduate students if they choose the academic route, so are applicable to all graduate research students. In many ways, professors, who are research program leaders, are much like program managers in industry: they write proposals, interact with their sponsors, give presentations, lead the research effort, and are generally responsible for the success of their programs. The major differences are that the efforts are mostly aimed at basic research in academia, whereas they are focused on solving a well defined technical problem or developing a product in industry with specific cost and schedule constraints. Nevertheless, the process by which a successful project is managed is fundamentally similar.

First, later stage graduate students should be involved in all aspects of proposal writing, preferably leading the effort with guidance from the professor. The student should take the lead in finding and understanding the request for proposals as well as writing the technical proposal, including background information and the rationale and expectations for the research effort. They should note the expertise and research done by other groups in their research area and should consider the rationale of why a funding agency should fund them instead of other competing groups; in other words, they should do a "competitive analysis." They should also help develop the budget and also provide a schedule for the work to be done. While academic work is often open ended, with schedules not a standard part of proposals, a schedule should still be generated using the best available knowledge. For example, if an experiment can't be done until some equipment is purchased, the schedule would show some time to investigate and determine the best piece of equipment, and include the expected delivery time, time to set up and debug the equipment, and the time to get some results. More generally, students can use commercial software, such as the industry standard Microsoft Project, to develop a Gantt chart (Ref. 3). At the same time, students can determine how rapidly the funds will be spent, and can develop a chart that shows the expected cumulative spending vs. time.

Second, when a proposal has been funded and the work started, the student should be given a high level of responsibility for all aspects of their specific research program, including working with others and procuring needed materials, equipment, and expertise, again with guidance, as needed, from the professor, post-docs, senior staff, or more advanced graduate students. The student should be given monthly updates of costs incurred for their part of the grant, so the student can track the actual spending vs. the amount planned in the proposal, and discuss the impact of any difference with the professor. The student should also track the progress of the work in a monthly basis and show progress on an updated home-made chart or on a more official Gantt chart. In this way, the student is acting as a program manager for the part of the effort that is their own, and is gaining valuable program management experience in a low stress, relatively simple environment. In addition, they are learning the critically important work attributes of being proactive and taking responsibility for all aspects of their program. An added benefit in using a schedule is that it can also be used as the basis for discussions between student and professor about progress towards the PhD degree in a quantitative manner

Near the end of the research effort, students should be asked to consider the technological applications of their research. It is likely that some aspect of what they have done has either short term or long term technological applications. They should consider these applications and determine challenges that need to be overcome before they can be transformed into useful technologies, preferably providing some ideas as to how to overcome these challenges. They should also consider other commercial products or patents already existing in this area, describe their characteristics and note the companies that make these products. Further, students could evaluate potential regulatory, environmental, safety, political, and social impacts of possible applications of their research. By doing this students will be learning about the challenges of crossing the “Valley of Death” or equivalently, greatly increasing the TRL. Note that this also could help meet the broader impacts aspects of NSF proposals in that a standard part of each research program will be to have the lead graduate student evaluate the broader impacts of their research and preferably include these analyses in their thesis.

In most industrial careers, the scientist has significant interaction with others: technicians, fellow scientists, engineers, managers, directors, and customers. It is important to develop interpersonal skills that allow good oral communication, including listening, and the ability to work well with others, to motivate them, and work as a team. Writing skills are equally important as scientists will asked to write proposals, technical reports, and project related reports as well as generate presentation materials for themselves and others. The teaching and education outreach skills that many graduate students develop to communicate complex scientific ideas to students and the public are truly transferable to industry, since they will be communicating complex scientific ideas to their managers and directors to try to get funding, as well as educating their technicians and engineers so that they understand the reasons for the work being done so they can better support the technology development.

Other skills or habits are also needed to succeed in industry. Some years ago, I generated a 15 point guide for success in industry, based on my experience. All can be practiced throughout graduate school. They are listed below:

1. Be responsive – return phone calls and emails promptly. When asked to do something, do it on time – be sure to ask when it should be done. Document requests and responses in writing.
2. Become the world expert in your particular area.
3. Continually expand the depth and breadth of your knowledge and skills.
4. Utilize all information resources available - books, science magazines, web sites, search engines, search services, colleagues, patents, trade magazines, catalogs, sales reps, conferences.
5. Get involved with or develop projects that have a high probability of contributing to the company's success
6. Understand and be aware of project constraints such as your personnel and company capabilities, competitor's strengths, and customer needs.
7. Innovate continuously. Always push your envelope as well as the science and technology envelope. Stay uncomfortable with what your skills and knowledge are.
8. Document your work in manner that can be easily understood by a co-worker a year from now. Use spreadsheets, tables and charts to convey your results in a concise, visual, and easy-to-understand manner.
9. Make sure that you learn something useful from any tests or experiments that you perform. These results should form the basis for future tests.
10. Learn from your mistakes. Don't repeat them.
11. Don't believe everything you are told, even if it is company lore or told to you by an expert. Be skeptical.
12. Enjoy your work.
13. Treat everyone you work with (above and below you) with respect. Thank them for their work. Acknowledge their contributions whenever possible. Keep them informed as to what you are doing and why you are doing it.
14. Have a sense of humor.
15. Develop a unique and necessary skill and knowledge set that complements those of your co-workers and greatly increases the value of your project/team. Be indispensible.

The graduate student that has these experiences will be adept at applying their knowledge to new applied problems, can generate proposals, lead and manage programs, provide strategic planning to their employers by evaluating competitive strengths as well as evaluating challenges. They will also have the skills and habits to work well and responsibly with others and become valuable contributors to their company's success.

This is a quick overview of how relatively small changes can be made to the graduate physics curriculum so that for all graduate students beginning industrial careers, it can be the best of times.

References:

1. http://www.nsf.gov/eng/iip/innovation.pdf

2. http://en.wikipedia.org/wiki/Technology_readiness_level

3. http://asq.org/learn-about-quality/project-planning-tools/overview/gantt-chart.html