Council for Chemical Research
CTO Roundtable on Graduate Education
December 13, 2010
Crystal City, VA

Executive Summary

A gathering of leaders from industry, government labs, and academia met to discuss the current state of Ph.D. education in chemistry, chemical engineering, and allied fields. The focus was on whether the current model still meets the needs of the employers given that a majority of new Ph.D.s do not end up pursuing an academic career. Graduate education has, for the most part, evolved slowly in the last several decades. However, the way industrial and government labs operate has changed drastically – and incoming Ph.D. talent often has to spend significant time learning and adapting to a new culture and system before becoming a productive member of the organization. While technical training remains strong, the softer skills, such as communication, teamwork and an understanding of research in a global and rapidly changing environment, are too often lacking. The discussion focused around two questions:

1. What subject matter competencies are needed for the future? What is the right balance of breadth versus depth and how can we achieve it?
2. What behavioral competencies are needed for the future? How do we incorporate the soft skills into the Ph.D. training?

There was lively discussion in both sessions, with quite a bit of agreement on basic items such as the importance of the disciplinary "deep dive" in the Ph.D. program. There were various thoughts on the relative importance of some items, but agreement that if there is to be change it will require that faculty be incented to work differently than they do now. Much of what was discussed and recommended would apply well beyond chemistry and related fields.

There were four major recommendations made by the group, though certainly these are not unanimously held priorities. Each of these has barriers to and ideas for implementation which are discussed in more depth in the full report. They include:

- **Develop a new NSF program of 5 year fellowships with input on requirements from industry and government labs.**
- **Professor of Practice –leverage retirees and other interested industry and government lab staff in graduate education**
- **Require or at least strongly encourage internships as part of Ph.D.**
- **Share industry/government lab non-proprietary training curricula on IP, ethics, safety, etc.**

This topic is clearly timely. In a January 2011 Comment in *Nature*, Whitesides and Deutch echoed many of the participants in this Roundtable when they wrote (emphasis added):

> Many subdisciplines of chemistry still use an apprenticeship model in which a professor conceives the problem and strategy, and graduate students execute the bench work. *It is hard to imagine a worse way to prepare tomorrow's chemists to work at the integration of many disciplines*. Instead, professors should teach students the tools of curiosity. An independent, engaged student, exploring as a colleague in a promising area, will do better work than a simple apprentice.
>
> Chemistry must also change its coursework, to include the hard parts (the role of solvent in chemistry, the importance of thermodynamics in biochemistry, the centrality of mathematics to the study of networks, the subtlety of catalysis and systems of coupled catalysts). *It must also include 'non-science' subjects — especially economics and corporate finance and manufacturing — useful in generating practical technologies*.

Despite dramatic changes in the world over relative to technology, business globalization and the emergence of rapidly developing economies, graduate education in chemistry and related fields such as chemical engineering and materials science and engineering has seen little change. Is this a problem? Some would argue "no", but clearly the breadth and depth of world change would argue for a fresh look at what we are doing to educate our future scientists, innovators and technology-minded business leaders.

To tackle this question, The Council for Chemical Research (CCR) sponsored a 1-day roundtable discussion on this topic and with an intention to offer some concrete ideas for changes to graduate education. Attendees were leaders from corporations who hire Ph.D. scientists and engineers in chemistry related fields, corresponding leaders from government labs, academic leaders and also leaders from government funding agencies. The scope of industrial sectors represented included pharmaceuticals, chemicals, specialty materials and gases. The basic approach was to have the people who do much of the hiring of new Ph.D.s express their views to enable a discussion of what could or should change and what new approaches might be used.

Because the topic is vast with the potential for too many ideas which might be well-meaning but have low overall impact, the session focused on two basic questions which were formulated as follows:

1. What subject matter competencies are needed for the future?

A Ph.D. degree in chemistry-related fields provides the graduate with deep technical skills, usually in one or two major areas. A Ph.D. chemist may become expert at synthesizing a particular class of organic molecules. Another might become an expert at developing computer models for small molecules at interfaces. A material scientist might become an expert at depositing and characterizing inorganic semiconductor films, and a chemical engineer might become an expert at scaling up processes for making nanomaterials. When employed by industry or government labs, Ph.D.'s are most often asked to use these competencies to solve problems of practical or commercial importance. The synthetic chemist might be asked to synthesize new drugs while the modeler might be asked to predict experimental outcomes to streamline product development, and the material scientist might be asked to find ways to deposit new types of films that might be used to make solar cells more efficient.

These are traditional examples of how Ph.D.'s have been trained and hired in the past. Economic, technological and global societal changes have had a big impact on how modern corporations do innovation in science and technology, and the challenges facing government labs continue to grow in complexity. More work is done in teams with very diverse skills, shorter time on a specific project, and more reliance on external resources such as those coming from joint development agreements or external contracts. ***With all of these changes, is the traditional deep-dive in a focused area still the best path for a Ph.D.? How do we turn out Ph.D.'s who***

can adapt well to the changes happening today as well as those in the future? How do we do this without lengthening, and preferably shortening, the time to degree?

2. What behavioral competencies are needed for the future?

Beyond technical skills, there are many behaviors and operating styles that often come from a Ph.D. education that work well in today's businesses and government labs, small or large. These include passion, bias for action, and ability to get results that demonstrate creativity and learning. While this is a great core, a common complaint is that we need not only creativity and creation of new knowledge, but results that solve problems and make money. Another common complaint is that Ph.D.'s often do not have the ability to persuade and influence non-technical decision makers, or so-called "business types". Additionally, Ph.D.'s most often work in teams in business and government labs, whereas individual creativity and experimentation is necessary to get a Ph.D. Further, these teams are often very diverse both in a technical and functional sense. Given some of these "stress points" and others, ***what are the behavioral skills missing from newly minted Ph.D.'s that could make their transition to businesses and government labs easier? How do we balance the need to show individual capability to earn a Ph.D. with the need to be able to work in a multi-functional team?***

The Roundtable used short presentations by invited speakers which contained a point of view on the questions to seed the dialog. Following each presentation, the group engaged in open discussion where further points of view were articulated and ideas for change were put forth.

Susan Butts, Interim President of CCR, began the day with these thoughts:

"There is a concern that graduate education in the US has focused on technical training whereas industry and government labs want to hire individuals with interdisciplinary training. The Graduate Education Action Network of CCR did a survey in recent years which determined that very few students participate in internships. In 2009, a soft skills study found that students lacked critical job skills like giving presentations. While some students have had exposure to teaching, few studied non traditional career paths and subjects like ethics.

The goal of today's roundtable is to develop actionable proposals that address this issue. CCR will summarize a few key findings and conclusions from today's discussion and share the results with companies and universities. (All participants are encouraged to be active in the discussion and stay on topic. The Chatham House Rule applies – no attribution.)"

Session 1: What Subject Matter Competencies Are Needed for the Future?

Moderator: Kelly Sullivan, Pacific Northwest National Laboratory
Presenter: Jim Roberto, Associate Laboratory Director, Oak Ridge National Laboratory

The following are direct and paraphrased comments from Jim's presentation:

The US is a leader in education having 12 of the top 15 research universities in the world. It is the preferred destination for international students. The average time in residence for a Ph.D. is 7 years with the average chemistry Ph.D. taking 6 years to complete. Research is becoming increasingly interdisciplinary but the traditional Ph.D. is not. Students lack innovation, entrepreneurship, team skills, and project management skills.

In interviews with industry leaders, there is clear desire for breadth of learning to apply skills across disciplines – provide research experience that allows them to work across traditional boundaries not to become an expert in multiple fields – while maintaining the deep dive experience. Interviews with University leaders revealed that while it is reasonably easy to provide a cross-disciplinary experience in undergraduate programs, it is much harder in Ph.D. programs. Additionally, Ph.D. programs do not want to “sacrifice a generation of students to trendiness.” However, NSF has restructured its chemistry programs in recognitions of the importance of crosscutting research across traditional labels.

Jim seeded the discussion with the following thoughts:

- Deep dive is essential (Ph.D.s must be expert in something)
- Individual Ph.D. programs at boundaries between disciplines are attractive
- Consider requiring computational literacy in multiscale theory and simulation as part of the Ph.D.
- Provide entrepreneurship opportunities
- Encourage interdisciplinary teams addressing problem-oriented research
- Broaden students with research experiences in other environments (national laboratories, industry, large facilities)
- Thoughtful integration can incorporate these attributes without impacting
- time-to-completion in most case; cooperation among faculty and departments essential

Open discussion followed, and what follows is a summary without prioritization. One thing was quite clear: there was unanimous agreement that the deep dive is a critical component of Ph.D. training. There was concern about the length of time to degree, though we do not want to artificially make it so short that we sacrifice the quality of the experience. There was general consensus that 5 years was reasonable.

Industry and government lab participants felt internships are important, though there was concern about the feasibility of providing internships for approximately 2000 students per year. Also, faculty members currently have no incentive in place to encourage students to participate in internships. It was clear that when an internship really advances a student’s thesis, then the faculty advisor embraces it. However, when the internship provides the student with skills or knowledge that don’t relate to the advisor’s research, then the advisor generally opposes it. If there were a way to make sure the internships led to collaborative opportunities for faculty, they would be more universally accepted. When employers review resumes, non-academic internship experiences stand out. This is especially true when industry and government lab participants discussed the difference in the safety culture between their environments and academia; knowing a student has experienced that culture already makes employers much more comfortable in the hiring process. The attention to safety is often the most surprising aspect of starting a new position in an industry or government lab.

In comparing NIH and NSF, it was noted that science and medicine are very different worlds. NIH has one very powerful tool in its training programs – and they contain requirements of cross-disciplinary collaboration. So there is good reason to believe that the careful design of funding programs can address the needs and desires of non-academic employers.

There was also support for including computational literacy regarding modeling as a normal part of Ph.D. training in chemistry and allied fields. Industry members are particularly interested in employees who can optimize processes and experimental design in order to quickly develop solutions. They also want people who understand at a reasonable level the financial side of business – for example how to read a balance sheet. Students should be taught that research is a business, and they should understand the costs of doing research.

Non-academic participants also noted that their environments have a different time scale to work with – and currently we do not teach our students how to “fail fast” and learn from mistakes. Including training on effective design of experiments could address this. In addition a researcher should not be afraid to step laterally, and know that it is acceptable to be ignorant in some areas. It is very challenging for students transitioning from doing the interesting science to doing the good science, the “making money” science.

There is a big difference between inter-disciplinary learning and operating in an inter-disciplinary environment. A Ph.D. program trains you to learn on your own, but we also need to have a workforce that understands how to work together. One example cited was Princeton University where the Chemical Engineering department requires Ph.D. students to collaborate on another thesis in addition to their own. The question is how will we achieve the interdisciplinary experience that we want? We could have a Ph.D. student be a teaching assistant in a different area or supervise undergraduate students. If Ph.D. students worked on campus in this capacity, it would integrate a broadening experience for the student into what universities do anyway. This would require faculty development and buy-in in order to change expectations and culture, but could be less disruptive overall to the current model.

Ph.D. students also should learn about different value systems an how to adapt to them. One way to do this is through multi-institutional training. Working with researchers in other countries would expose students to different value systems. There are different values in the industry and government environments as well. In the academic environment students are rewarded for activities rather than outcomes, but in the non-academic world, it is outcomes that matter. Industry wants to focus its intellectual energy on white spaces but students aren't trained to think that way. To affect change, we will have to change the reward system and influence faculty members. We might consider pilot programs through organizations such as the University-Industry Demonstration Partnership.

Session 2: What Behavioral Competencies Are Needed for the Future?

Moderator: Gary Calabrese, Corning Inc.
Presenter: Monty Alger, V.P. and CTO, Air Products & Chemicals

The following are direct and paraphrased comments from Monty's presentation:

Major changes have occurred in industry from the 1980's to the present. One significant change is how the world communicates – now it's instantly. Before, new product development was a linear process; industry would fund R&D, then make a product, sell it, and make money. The timeline for this process was10-20 years. Now, things happen iteratively and faster. Another change is how new employees are trained. In the past, senior scientists within the department would mentor new employees. Now, as R&D organizations have become leaner and work is often done in virtual teams with members in different locations it is more difficult for new employees to find local mentors. With lean operations and the retirement of senior scientists, who will teach the incoming talent the non-technical skills needed to succeed?

There is a need for students to go through "Academic decompression" where it is not enough to do what they did in graduate school in terms of diving deeply into a problem and solving it. It is important for them to also determine which problems need to be solved, in what order, and which will advance the business. After safety, the priorities are growth, margin, and speed of results - the financial measurements that are the language of business. Technical people need to learn business basics so they can share that language.

Knowing the difference in university vs. industry value systems is useful. These differences cause "gaps" that must be filled during transition from academics to business. Some key gaps are:

***Verbal and written communication skills*.** Often technical folks are too verbose in their explanations and have difficulty getting to the “punch line”. You often do not have a lot of time to explain yourself in business and therefore need to tell someone the key information and sell them on your approach in a few minutes. The way to communicate to senior managers in business is very different from how you learn to talk to faculty in school. In business, you do not start from the beginning and go through all the details; instead you have to go quickly to the conclusions and recommendations. If you cannot talk to managers, you will go nowhere.

***Globalization*.** Skills in navigating through international diversity need to be increased.

***Teamwork*.** New Ph.D.’s need to appreciate the value of co-workers with lesser degrees and to work well in teams. Teamwork and collaboration are imperative in industry, a departure from the emphasis on individual work in school.

***Safety*.** There is a very poor safety culture in academia relative to industry and government labs, and the transition comes as a shock to incoming Ph.D.’s.

***Professionalism*.** Even mundane things such as having a dress code require some adjustment.

Open discussion followed, and below is a summary without prioritization.

Soft skills (the “special sauce”) are what differentiate between the Ph.D. programs in the US and China and justify the significantly higher salaries we pay. This needs to be communicated. Social maturation is a challenge. We need to give students responsibilities – organize a seminar, recruit undergraduate researchers to do a project. They need these opportunities to demonstrate and develop these skills. One key skill is, as was often reiterated, communication. Knowing what level of information is required and the order of importance of what to present is essential in non-academic settings.

Moving from individual problem solving to collaboration is a difficult transition and those who can manage it are the most successful. They need to have the maturity level to admit, “I’m ignorant; I need help on this.” Encouraging collaboration with people outside of their own specialty while in graduate school could address this while simultaneously enhancing communication skills.

There are examples where education can “build in” a different way of thinking with respect to real world problems and help bridge the gap during transition to industry. An undergraduate engineering project was given to students that required them to build a plant but it incorporated additional problems such as the existence of a competitive company with a patent the students would need to operate their plant. The students had to deal with this common reality in their project. In short, they were tasked with a business problem, not just an engineering problem. Graduate students at least should be made aware of the costs of doing research.

A challenge to any level of change in the *status quo* is the lack of incentives for the faculty to change what currently works well for them. Administrators could change incentives by articulating expectations of including soft skills training and providing resources necessary to do it. However, faculty are not trained to teach soft skills so we need to create mechanisms that address the issue while not removing the faculty from their research interests.

Reiterated time and again during the discussions was the need for universities to adopt a culture of safety. It was suggested that funding agencies could push this forward by having it impact the bottom line in the same way it can outside of academe. “If a student is injured, you’ll never get a grant again.”

Perspectives from Alveda Williams, The Dow Chemical Company: Alveda has responsibility for new Ph.D. hiring and mentoring at Dow. To prepare for this presentation, she interviewed both managers and new hires and found alignment in their views regarding the existing gaps in Ph.D. education. Those included market focus, finance, communication/presentation, and business acumen. As before, all agreed that the disciplinary deep dive is still necessary but coupling it with experiences that broaden awareness makes for more prepared students.

Recommendations for Actions

In the final session, brainstorming was done to suggest concrete actions that might be taken. Following the brainstorming session the group prioritized the suggestions, and four recommendations emerged as the top set. Further thought was given to the barriers to implementation as well as ideas to overcome them. The top recommendations were:

Develop a new NSF program of 5 year fellowships with input on curriculum and requirements from industry and government labs.

This would be a new program where universities would apply to receive funding for fellowships to be provided to students. There would be training requirements related to soft skills and broader experiences and a requirement that students graduate in 5 years or the funding could not be renewed. There are clearly a number of barriers. A significant one is the cost of such a program. It is likely that NSF would not get additional funding to pay for these fellowships so money would have to be redirected from Principal Investigator grants. Each institutional grant for the new fellowship program would mean that 4 to 5 Principle Investigator grants would not be funded. Further, it would have to be made clear how many cohorts and of what size would be needed to try as an experiment; schools will not change their infrastructure for a single year. These barriers could be addressed in part by combining with an industry-funded grant program along the same lines. A workshop on this topic would be needed in order to flesh out this idea.

Professor of Practice – Suite of activities designed to leverage retirees and other interested non-academic staff in graduate education

This would be a set of activities that would leverage retirees and other interested industry and government lab scientists in graduate education. This might involve teaching and mentoring or other activities that help students learn from the experiences of the participants. There are geography problems because retirees may or may not be near schools. Further, someone would need to be tasked with matchmaking and assuring the quality of the volunteers as well as how much time the volunteers would commit, leading to administrative costs that cannot be ignored. However, there are programs that do similar matchmaking now, so we could learn from those. If this was seen as a benefit to industry, government labs, and others such as state economic development agencies it is possible the administrative costs would be covered by those organizations. They may even be willing to have current employees participate as a mechanism to enhance their incoming talent pool.

Require or at least strongly encourage internships as part of Ph.D.

Perhaps one of the most contentious recommendations is to require students to participate in an internship as part of their degree. It may be more accurate to say the group recognized the value of the experience to the students, but had concerns about impacts on faculty and feasibility of implementation. Nonetheless, internships are a key way for students to learn about the industrial and government lab culture and a way to make themselves more competitive when applying for regular employment.

There are a number of barriers, of course. Internship placement is beyond the control of the universities and a requirement would be an unfunded mandate placed on government and industry labs. Internships may lengthen the time to degree, but this can be minimized if the experience supports the thesis topic. Further, there are over 2000 chemistry Ph.D. students each year – it is unlikely there are enough internships available and the infrastructure does not exist to facilitate them. If internships are simply strongly recommended, then organizations like CCR could work with industry and government labs to create a clearinghouse including a mechanism for actively soliciting and vetting opportunities. It would be important that the attributes of a quality internship experience be articulated and that ongoing assessments be undertaken to assure that the internships create the value expected from the experience.

Share industry/government lab non-proprietary training curricula on IP, ethics, safety, etc.

Industry and government labs all have a suite of in-house training courses used for their own employees related to business acumen and softer skills. If the courseware were available, it might be simpler for these topics to be incorporated into the Ph.D. curriculum and be sure that the training met industry and government lab needs. It would require an organization such as CCR to collect the materials into a central location and assist in disseminating the information. Industry and government labs could provide a list of contacts for already-developed short courses (ideally 8 hours of material or less) on items such as "Protecting Intellectual Property" or "Statistical Design of Experiments" or "Communicating to Persuade". Courses could be offered at national or international meetings at modest cost or even free of charge. Further, industry and government labs could consider making speakers available to go to universities to make presentations. This would be an interim step, as it would be preferable to have this material embedded in the Ph.D. curriculum rather than an external add-on.

Additional recommendations that garnered some support during the discussions included:

- Engage graduate students as the mentor to manage undergraduate research, including handling the budget and knowing when to terminate a project that is not succeeding
- Make a Teaching Assistant experience a requirement for a Ph.D., which is not currently the case for all schools.
- Require collaboration outside student's area of expertise. Specifically, one could require a co-author for at least part of the dissertation.
- Create an award that recognizes schools that follow these recommendations or otherwise demonstrate innovative approaches to graduate education that address these topics.
- Ensure that industry communicates hiring expectations not only to students and faculty, but also to administrators.
- Encourage deans to discuss this topic with their faculty.

Information on the report is available:
http://www.ccrhq.org/articles/cto-roundtable-graduate-education-report

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