Meeting Report

Responses to Changing Needs in U.S. Doctoral Education[1]

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During its 100-plus year history, graduate education in chemistry has responded to changing circumstances that were impelled by the changing scientific milieu. As chemistry became more specialized during that period, it inevitably divided into identifiable sub-disciplines, along with their familiar labels, and with correspondingly specialized education. While these labels have changed over time (for example, agricultural and mineral to organic and inorganic, respectively), they have fairly cleanly prescribed sharp boundaries for chemistry—both in what chemists did and how and in what they were educated. ACS President Charles P. Casey added his voice to those who see this as a time of blurring boundaries and changing needs. "I believe we are at a critical juncture," he writes in *Chemical & Engineering News (1).* "Chemistry is becoming more interdisciplinary every day and has expanded rapidly into the biosciences, materials science, and nanoscience. Our graduates will likely be working in frontier areas of chemistry alongside experts from related sciences. We need to ask whether our current Ph.D. programs address the students' needs adequately."

Significant calls to examine the state of the Ph.D. have arisen from multiple sources in the past decade in response to a consensus that today's young scholars live and work in a world different from that of past generations. Early studies and reports on graduate education *(2–6)*, graduate students' experiences *(7),* and major foundation projects *(8, 9)* have converged on a number of common themes that may be driving this introspection. Some relate to a change in cultural context: globalization, mobility, and flexibility of the scientific workforce, growth of knowledge-based economies, and the inevitable leveling off of the United States' 20th-century preeminence in idea-based science. Other suggestions are contentious, perhaps for their overt criticism by some of a system grown complacently conservative and, others argue, even exploitive instead of educative. Alvin L. Kwiram (University of Washington) indicts reform efforts as being marginalized by these forces, and suggests that "…some faculty do not take their pedagogic responsibility of graduate education as seriously as might be appropriate, and instead focus their considerable talents and energies entirely on the execution of the research process itself" *(10).* The effects from academic entrepreneurial activity in the 25 years since the Bayh–Dole Act of 1980, which was designed to "encourage the utilization of inventions produced under Federal funding," are largely unexamined, although the impacts may infuse academic institutions deeply *(11).* Against the tide that has embraced privatization, Barry Trost (Stanford University) has argued that "academic institutions are not appropriate places for drug discovery… I hope that academic institutions will not lose sight of the fact that their primary mission is indeed education and begin crossing a line where the prime mission becomes whether they can make money or not" *(12).* Language may be our most important indicator of the state of mind in graduate education because, in 25 years, Ph.D. students have gone from "working *with*… advisors" to the ubiquitously used "working *for*…bosses."

One clear message is the need for graduate chemistry to respond to the increasingly interdisciplinary nature of chemical research *(13, 14).* Indeed, prospective graduate students are beginning to use as a selection criterion the presence of a multidisciplinary environment for graduate education *(15).* As John Moore stated, there is a need "to think much more seriously about improving students' abilities to solve real, complicated problems, to ignore or transcend disciplinary insularity, to be more aware of how science and technology interact with and support society, and to succeed in careers in fields that may not yet even have been discovered" *(14).* Graduate students, themselves, can play an important role in identifying their needs and expectations for their graduate education *(16).* In addition, graduate faculty need to take more active and affirmative roles in advising students about their educational and professional opportunities *(16).*

Against this backdrop of changing needs, the ACS Board of Directors and Council Committee on Science, the Office of Graduate Education, and the Division of History of Chemistry joined Casey's call to highlight graduate education.[1] In the first of four sessions at the August 2004 national meeting, intellectual leaders provided an overview of the past, present, and possible future for graduate education. In the second session, speakers representing a diverse set of constituencies discussed an array of driving forces behind these changing needs. In the third, faculty and graduate student participants from chemistry departments in the Carnegie Foundation's Initiative on the Doctorate (CID) reported on the design, implementation, and assessment of their experiments in graduate education. Lastly, a fourth presidential session along with an accompanying symposium held in the Division of Chemical Education (CHED)—co-sponsored by CHED and comprising primarily graduate student speakers—addressed their interests, criticisms, needs, and additional initiatives for improving the educational experience. The double session was desirable because the strong interest of graduate students in the topic required more than the allotted time for the formal presidential event.

Session I: Doctoral Education. How Did We Get Here? Where Are We Going?

Margaret Cavanaugh (National Science Foundation and Chair of the ACS Committee on Science) observed that despite the diversity of U.S. colleges and universities that award the Ph.D. in chemistry, graduates have historically experienced the same educational structure and curricular requirements. Institutions now face common and pressing questions of how to deal with the knowledge explosion, how to adjust

the curriculum to include both breadth and depth of experience, how to work in teams and in different cultural environments, and how to acquire skills needed to meet the gathering competition from abroad. How can we encourage more minorities and women and other talented young people to pursue careers in science?

The first response to these challenges was from ACS President, **Charles P. Casey** (University of Wisconsin–Madison). His address was a self-contained dialog about whether current programs address current needs. Question: What are the desired outcomes of a doctoral program? Answer: Successful progression from *Novice, Apprentice, Journeyman,* to *Scientist;* acquiring expertise, breadth, problem solving, teamwork, confidence, communication skills, expertise as a learner, and growth in creativity. Question: Can you teach creativity? Answer: We think so, and investigations into questions like this are at the heart of the re-examination of doctoral programs, triggered by the CID.

George E. Walker (Carnegie Foundation for the Advancement of Teaching, Director of the CID) reminded us that while doctoral education in the U.S. is highly regarded worldwide, pre-eminence is transitory. Changes are in the wind as global competition emerges, primarily from China and Europe. Problems have emerged with U.S. doctoral programs; among them are high attrition rates, increased time to degree, failure to diversify, underachievement, isolation, lost opportunities for interdisciplinary work, and paucity of role models. Departments must re-examine their assumptions and ponder how else their goals could be achieved.

Roger Geiger (Pennsylvania State University) traced a fascinating path through the history of U.S. doctoral education relevant to chemistry and from the perspective of advancement of knowledge. He probed three themes: relationship between pursuing knowledge and training students; international transfer of knowledge; and competition and markets for graduate students. The innovation of the "teaching fellow" or TA in the 1920s was an economic response to booming (undergraduate) enrollments. Yet by the 1940s only the most talented students were encouraged to pursue graduate work. However, the post-Sputnik era in the 1960s spawned a ramping-up of federal support for research leading to more students for an increasing number of university programs. Then, faced with recession and apparent overproduction of Ph.D.s by the 1970s, TA support was cut back, enrollments declined, and the research assistantship (RA) became the primary means of graduate student support. As research funding rose again in the mid-80s, the demand for students grew, but the dearth of domestic applicants prompted acceptance of more international applicants. By 1994, six of every seven *additional* Ph.D.s in science and engineering were awarded to non-citizens. How long can we continue to recruit and retain international talent?

Perhaps the most important reality affecting graduate education is the exponential growth of knowledge, putting graduate programs and faculties under unceasing pressure to adapt. At the heart of the debate are the competing needs of breadth versus depth. Breadth runs counter to the dominant reality of knowledge proliferation. If a knowledge-based economy like ours is producing fewer doctorates in chemistry than a decade ago, there is cause for worry. The issue is not the number of jobs next year but the doubling of scientific knowledge in the next 15 years.

Harry Gray (California Institute of Technology) drew attention to the revolution in chemistry whereby the traditional divisions (physical, organic, inorganic, analytical, and bio) have blurred to become functional classifications (synthesis, dynamics, analysis, structure). Chemistry, as the "central science" of the Pimentel Report *(17),* has now invaded other sciences, spawning new fields and departments that are strongly rooted in the fundamentals of chemistry. The longevity of chemistry departments as we now know them is in question. Why has there been no comparable revolution in the education of chemists? Graduate programs must be revised. Faculty should be recruited from other departments, more joint appointments should be made, and the curriculum should be revised to teach the skill sets required for interdisciplinary research. A complete revision of the first-year of graduate school in chemistry at CalTech is being evaluated, where four–six research training modules replace formal courses. The department recently evaluated a prototype training module program comprising a skills set (detailed exposure to general laboratory practices, required use of the scientific literature, and participation in complex multidisciplinary research projects). A rough evaluation of the results suggested that approximately 10–30% of the goals were reached, leading Gray to speculate that the difficulty might be too great and the expectations might have been set too high.

Given that graduate school experiences must provide a life model for intellectual growth to all members of our educational community, why are so few women entering academic positions in research universities? **Geraldine Richmond** (University of Oregon) offered a number of explanations, including: feelings of isolation; lack of vision for a post-graduate career path; no mentors; and departments that are not always supportive of women raising families. A number of workshops, especially those offered without charge through the Committee on the Advancement of Women Chemists (COACh) program *(18, 19),* are now available to help women obtain training in leadership and self-preservation and to help them envision more-focused career pathways.

Session II: Driving Forces in Doctoral Education: People, Discovery, Economics, Funding, Assessment

The central role of graduate students in the nation's economic future, the collapsing base of economic support for universities, and the declining numbers of American students who choose to pursue careers in science and engineering were the themes developed by **Claudia Mitchell-Kernan** (University of California at Los Angeles). Indeed, "a healthy university research enterprise and a growing base of science and technology fuel[s] the economy." The current specialized nature of graduate education, focused typically on the research

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interests of the advisor–professor, works against a breadth of knowledge and involvement in interdisciplinary experiences. Mitchell-Kernan cautioned that unless reform efforts recognize the broader context in which graduate education occurs, namely the society it serves and depends on for resources, sustained support of the graduate education enterprise could be in jeopardy.

One response to the call for increased interdisciplinary experiences has been the NIH Training Grants, upon which, according to **Michael Rogers** (National Institute of General Medical Sciences, National Institutes of Health), chemists could better capitalize. Here, a group of faculty from different departments provides a group of pre-doctoral students a unique experience, for example, a "chemistry–biology interface" program. In-depth core courses are supplemented with cross training in another area, laboratory rotations, and training in the responsible conduct of research. Increased student flexibility, networking, funds for scientific meeting participation, industrial interactions, and exposures to diverse approaches are some of the outcomes for the students. Departments benefit, as well, from enhanced visibility and increased hiring.

Richard Koehn (Sentrx Surgical) stressed the need to alert graduate students to a university environment where many possible conflicts of interest may affect time-honored goals of increased knowledge and education. The potential commercial role of innovation has affected graduate education in many venues, impacting core values as well as legal liabilities. The "entrepreneurial university" has emerged, driven by economic politics and "entrepreneurial faculty." Students can provide the research results and advance their mentor's professional and economic status but, inequitably, work as an apprentice, at low wages, often without sharing the intellectual property developed. There is a need, Koehn noted, for a thorough examination of the impact of the entrepreneurial university on graduate education.

As changes in doctoral programs are initiated, the National Research Council is in the process of developing a tool to be used as a basis for knowledge assessment. **Charlotte Kuh** (National Research Council, National Academies of Science) described the complexities of creating a meaningful survey instrument to create a snapshot of the graduate education enterprise that is in constant flux. University reputations, program missions, and interdisciplinary programs will be profiled. This detailed study will begin in 2005; a report is scheduled to be released in September 2007, along with Web-accessible data to allow individual analyses to be performed.

Session III: Experiments in Transforming Graduate Education—The Carnegie Initiative on the Doctorate

George Walker opened this session with background and perspective on the Foundation's interest in graduate education and its project, the Carnegie Initiative on the Doctorate, in which chemistry is one of six participating disciplines *(8)*. In order to understand the state of graduate education, the Foundation is providing opportunities, rather than funding, for departments to examine their practices, document and report what they do, and identify areas for improvement resulting from these studies. The premise is based on the provocative idea that attrition is not a binary function, sorting cleanly those who do and do not deserve a doctorate (for a review, see *20*). Instead, based on a preponderance of exit interviews, 40–60% of those who complete Ph.D.s would, if given a second chance, select a different professional area (pathway). "The hidden disease of attrition," Walker suggests, "is that even the Ph.D.s carry as a chronic infection the problems that caused others to leave."

Reporting on experiments in the graduate curriculum, graduate student **Chad Ray** described efforts at Duke University to create a more integrated community involving domestic and international students; **William R. Roush** described the implementation of a department-wide program of research rotations at the University of Michigan; and **Arun Yethiraj** (University of Wisconsin–Madison) discussed initiatives to create better communication between the faculty and graduate students.

Improving professional development has been a common theme in a vast number of independent reports that provide recommendations for graduate education. Other recommendations for graduate students have included providing them with increased educational breadth; improved communication and leadership skills as well as pre-professional educational and research experiences; and an integrated and enhanced sense of social responsibility *(21)*.

Addressing one of these topics, Ohio State University graduate student **Jason S. D'Acchioli** presented a cogent rationale for increasing professional development activities during doctoral education and described efforts in his department for enhancing academic–industrial relations. **Veronica Vaida** (University of Colorado at Boulder) described a number of projects that expose their graduate students to career options and the advantages of cultivating the accompanying jobs skills. University of Michigan graduate student **Robyn L. Gdula** described her department's use of a training grant from the U.S. Department of Education that enables graduate students to add future faculty development activities to their chemistry Ph.D. thesis work.

Creating a positive and supportive climate for all students is a key target for promoting and sustaining a healthy and diverse academic department. University of Wisconsin's Yethiraj presented efforts initiated by a group of Wisconsin's women graduate students to achieve these goals. **Patricia A. Mabrouk** described a number of programmatic innovations at Northeastern University, including mentoring programs, coursework in research skills and professional ethics, and increased participation by graduate students in departmental governance. **Nancy S. Goroff** (Stony Brook University) emphasized shared departmental and programmatic governance by faculty members and graduate students. There are many opportunities for scientific and social interactions on a department-wide scale, and full participation by all stakeholders is significant and should be encouraged.

Although assessment methodologies used by the departments in the Carnegie Initiative have been mainly limited to survey instruments, they are producing useful data from which

participants can make more-informed choices. Ultimately, sophisticated strategies will be needed to assess items such as a student's intellectual development. During this session, results from survey work were presented by Mabrouk, Ohio State University's **Claudia Turro**, and graduate students **Andisheh Abedini** (Stony Brook University) and **Deborah Casher** (University of Colorado at Boulder). Items assessed included program requirements, departmental climate, perceived needs and interests, alumni relations, and feedback on changes that had already been made. All of the departments participating in the symposium reported using these assessment results to feed information back to their departments and to guide subsequent efforts.

Session IV and CHED Session: Creating Complete Scientists— Graduate Student Visions of Doctoral Reform

In response to an invitation initially extended through CHED, the group of graduate student authors organized a symposium on doctoral reform viewed from a student perspective. Their goal was to inform, and create a voice for, graduate students on reform needs.

The first two speakers were invited professionals who gave presentations addressing needs perceived from both inside and outside of academia. **Scott D. Hanton**, a recruiter for Air Products and Chemicals, Inc., reinforced the theme of broadening doctoral education to include communication and leadership skills. He presented a description of the ideal job applicant as one who had gained the usual high level of technical expertise found in doctoral programs, rounded out with strong interpersonal and communication skills.

Timothy M. Dore (University of Georgia) discussed results and implications from a research report written with Chris Golde on doctoral education *(7)*. Focusing on the training given to those interested in academic careers, Dore and Golde made the case that students were well prepared to conduct research but received little or no training in the teaching and service skill sets important to being successful faculty members. Both Dore and Hanton recommended changes in doctoral curriculum to incorporate course-work and opportunities to practice so-called "soft" skills.

Christopher A. Bradley (Cornell University) was the first student speaker. Following a historical examination of Cornell's curriculum, he emphasized that students at Cornell would welcome formal opportunities to develop and practice speaking and writing skills. Bradley recommended incorporating a departmental seminar for senior students. **Matthew D. Bowman** and **Gregory H. Hanson** (University of Wisconsin–Madison) described a weekly tutoring program for undergraduates in organic chemistry that they created and formalized to remedy the lack of recitation sections for these courses. This exercise added value to their graduate education, particularly since they were thinking about a faculty career.

As well as changing graduate training, the theme of building a strong and supportive community within chemistry departments arose. **Elsa Kieken** (University of Notre Dame) discussed the experiences of international students, strongly urging departments to give them more training in English language skills and U.S. educational culture, as well as urging the inclusion of international students in the social life of the department. **Deborah L. Casher** and **Melissa G. Trainer** (University of Colorado at Boulder) described their department's efforts in community building, detailing a mentoring culture built around seminars, town hall meetings, and a shadowing program that integrated new students into the department more smoothly. **Robyn L. Gdula** and **Gorka Peris** finished the session with a description of a series of efforts undertaken at the University of Michigan to build community through the research rotations described earlier, interdepartmental research collaborations, and the designation of a common physical space where all students could come together to share ideas.

The second part of Creating Complete Scientists echoed many of the themes introduced in the first session, beginning with a discussion of the soft skills that doctoral students seem to lack as they begin their professional careers. **Ron Webb** of Proctor & Gamble proposed that a new graduate's ability to succeed in industry or academia could be improved by increasing collaborations between industry and Ph.D. programs in chemistry. **Jim Hutchison** then described the University of Oregon's successful internship program as an example of the type of collaboration advocated by Webb. This program, which began as a relationship between students in the department's materials science M.S. degree program and regional industries, became so popular and successful that it is now included in Oregon's doctoral program. Ph.D. candidates can choose to include one or several internships in academic, industrial, or government laboratory settings. The internship program has become an important recruiting tool for the chemistry department. **Bevin Parks**, one of the program's participants, shared her experiences working in a national lab. She gave advice for students considering an internship and noted the positive influence this program has had on her graduate education.

Mary Wirth discussed how the University of Arizona has begun to address the soft-skills issue by incorporating a "Professional Science Masters" program into the course of study for doctoral students interested in industrial careers. Positive outcomes from the Arizona program include introducing students to the important concerns found in a business environment and enhancing students' abilities for working in interdisciplinary research teams.

Historical changes in the culture of scientific research and graduate education programs were identified by **Debra Rolison** of the Naval Research Lab. She commented that the post-September 11 atmosphere in the U.S. seems similar to that following Pearl Harbor and the launch of Sputnik; namely, the nation is poised once again to strengthen its investment in science. To realize this, Rolison says, we must also prepare ourselves to change how science is practiced. The development of nanotechnology is an example of an interdisciplinary field that could serve as a model for how to break down the existing divisional boundaries and could eventually change how our nation's scientists are trained. The session closed with

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remarks from **Natalie Carroll,** a Fellow in the NSF-sponsored Integrative Graduate Education and Research Traineeship (IGERT) program at Drexel University. She outlined the benefits of interdisciplinary research fellowships and programs, particularly how they give graduate students the opportunity (and support) to develop the appended soft skills that are implicit in carrying out this type of research.

Following the presentations, a lively discussion ensued among those in attendance. There was a consensus that Ph.D. programs in chemistry do prepare their students well for the technical aspects of their future careers. But many also agreed that these students are not as well prepared with other, increasingly necessary, skills: to work and communicate effectively in multidisciplinary teams, and to communicate their work across broad audiences.

The entire CHED session was permeated with an implicit statement that doctoral reform need not rely on the faculty alone. Graduate students showed themselves to be capable of and enthusiastic in creating initiatives to build a well-rounded Ph.D. program. Many of the talks displayed the underlying sentiment that if students saw a problem in their program, or a place for improvement, they should take an active role in pursuing it. The responsibility, however, cannot reside solely with the students. The talks also emphasized that chemistry departments themselves need to be willing to listen to students and to be open to improving their programs in response to changing needs.

Conclusions

While a single symposium cannot provide a complete response to changing needs in doctoral education, it is an important reminder that attending to grad-uate education is squarely on the national academic agenda. Throughout the symposium, numerous cogent responses appeared, based on well-established educational principles. George Walker's summary, in particular, captured many of these ideas: Graduate education should be *purposeful*—it should be designed to address explicitly stated (and debated) goals. As with all scholarly enterprises, *assessment* should form a strong foundation for evaluating and subsequently modifying how and what we do to achieve our goals. The process should be *reflective,* integrating what we know about the historical, sociological, economic, institutional, and professional contexts influencing our actions. Finally, as an educative process, what we do should be *transparent* to those with whom we work and collaborate, with society and those on whose support we rely, and especially with our students who carry the responsibility of defining "chemistry" into the future.

Philosophical discourse aside, there clearly is a genuine effort by several chemistry departments, especially those in the CID project, to re-examine their graduate programs. Less clear is how widespread and how deep the reform efforts are among the roughly 190 U.S. doctoral programs. Disciplinary leaders and professional organizations need to encourage further effort, and information about ongoing reform must be disseminated more widely. The recommendations of the Committee on Science, Engineering, and Public Policy (COSEPUP) are as pertinent today as they were in 1995: "The universities are primarily responsible for implementing the needed changes, and we believe that most university leaders will find it in their own interest to reshape graduate education to meet students' career needs better and to ensure universities' vital role in the nation's steady progress toward a knowledge-based society" *(22).*

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Note

1. This article is based on the Presidential symposium, "Responses to Changing Needs in Doctoral Education", presented at the 228th National Meeting of the American Chemical Society, Philadelphia, PA, August 23–24, 2004, and the accompanying symposium in the Division of Chemical Education, "Creating Complete Scientists: Graduate Student Visions of Doctoral Reform", August 25, 2004. Sponsors and co-sponsors are listed in the acknowledgment. In addition there were four related events at this national meeting: "Graduate Education in Chemical Informatics: Needs and Opportunities" and "Posters on Chemical Information Instruction", cosponsored with the Division of Chemical Information; "Recent Advances in Nuclear Chemistry and Technology: A Graduate Student Symposium", cosponsored with the Division of Nuclear Chemistry; and "Excellence in Graduate Polymer Science Research Symposium", cosponsored with the Division of Polymer Chemistry.

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