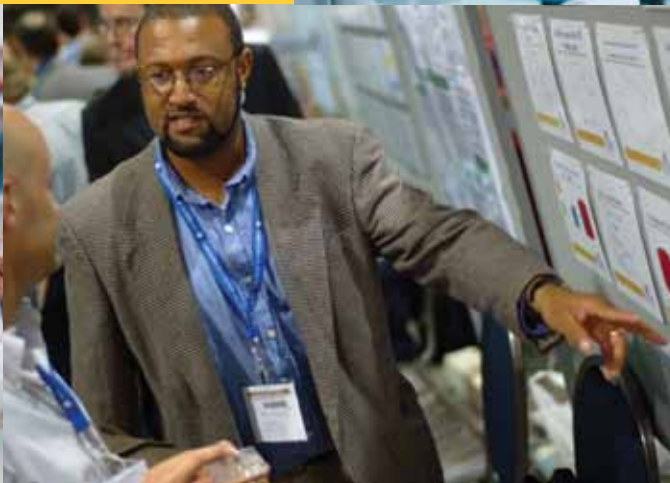


# ADVANCING GRADUATE EDUCATION *IN THE* CHEMICAL SCIENCES

*Summary Report of an  
ACS Presidential  
Commission*



*Advance the broader  
chemistry enterprise and its  
practitioners for the benefit of  
Earth and its people*



# ADVANCING GRADUATE EDUCATION *IN THE* CHEMICAL SCIENCES

*Summary Report of an ACS Presidential Commission*

*Submitted to ACS President Bassam Z. Shkhashiri  
on December 3, 2012*



AMERICAN CHEMICAL SOCIETY



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## EXECUTIVE SUMMARY

**A**merican Chemical Society (ACS) President Bassam Z. Shkhashiri appointed and charged this Commission to undertake a wholesale review of graduate education in the chemical sciences<sup>a</sup> over a yearlong period. This document is a compact rendition of the Commission's final report, emphasizing only main conclusions and recommendations. A full report, which includes extensive background and analysis, is available online at [www.acs.org/gradcommission](http://www.acs.org/gradcommission).

The Commission judges that the state of graduate education in the chemical sciences is productive and healthy in many respects, but has not kept pace with the significant changes in the world's economic, social, and political environment since the end of World War II, when the current system of graduate education was formed. Employment opportunities for chemical scientists and engineers have changed, too, and continue to do so. Collaboration across disciplines has become a hallmark of cutting-edge investigation, in which partners may be located next door or around the globe. Thus, the ability to communicate clearly across disciplinary and cultural lines has emerged as a critical skill. As technology comes to dominate more of the U.S. economy and national security interests, we look more often to scientifically trained leaders to provide guidance and advice.

Substantial changes in graduate education are recommended—not because the previous approaches were wrong—but because the technological leaders of this century must have skills crafted to meet its demands.

In this report, the Commission speaks most immediately to its individual faculty colleagues, who determine on a daily basis the content of graduate education and the requirements for completion of degrees. But there are other intended audiences, including departmental leaders, deans, provosts, and presidents in universities and colleges; leaders of funding agencies important to the chemical sciences; national policy makers; leaders of industries that employ chemical scientists and engineers; and leaders in the key professional societies, especially the American Chemical Society.

The report is organized around five major conclusions, each accompanied by specific recommendations and suggestions:

**1. Current educational opportunities for graduate students, viewed on balance as a system, do not provide sufficient preparation for their careers after graduate school.**

The Commission reaffirms the anchoring concept that a doctoral program in the chemical sciences must manifest traditional depth and must maintain a focus on mastery.

But the members also conclude that curricula need to be refreshed, and better-designed opportunities should exist for the development of critical professional skills. The Commission offers many and varied recommendations, which, briefly stated, are a) to encourage departments to undertake greater oversight over the progress of their graduate students, and b) to emphasize the need for programs to offer specific activities that would enhance students' ability to:

- Communicate complex topics to both technical and nontechnical audiences, and to effectively influence decisions;

<sup>a</sup> Throughout this report, the chemical sciences are understood to encompass chemistry, chemical engineering, biochemistry, molecular biology, materials science, polymer science, nanoscience, and other activities that focus on molecules, chemical reactions, and chemical properties.



- Learn new science and technology outside prior academic training;
- Collaborate on global teams and/or with global partners and clients;
- Effectively define, drive, and manage technical work toward a practical, significant result; and
- Clearly understand the ethical conduct of research.

Four years should be the target for completion of the doctor of philosophy (Ph.D.) degree, with the departmental median time less than five years. The Commission understands that there is inevitable tension between its recommendations that doctoral programs be shortened while also being retooled to include elements that are not generally addressed effectively in existing practice. For this reason, the members believe graduate education must become more efficient. Opportunities for improved efficiency exist in better program design, superior monitoring of student progress, use of the summer before the first year of graduate study, and fuller use of short courses and online classes.

**2. The system for the financial support of graduate students, as currently operated by private, institutional, state, and federal funds, is no longer optimal for national needs.**

The financial support system rests too heavily on individual research grants and involves serious conflicts between the education of graduate students and the needs for productivity and accountability in grant-supported research.

Federal and state funding agencies, private funders, and universities should take steps toward decoupling more student-support funds from specific research projects, in the interest of providing students the opportunity for better balance between training in research and training in other career skills, without significantly impacting the research productivity of faculty.

The goal, with perhaps a 10- to 15-year horizon, should be to decouple the preponderance of student support from specific research grants and contracts. In the near term, funders and graduate program leaders should engage in trial projects designed to prove out new mechanisms.

In particular, federal agencies and private funders should experiment with a new strategy for “graduate program grants” to support graduate students. Analogous to training grants, but with perhaps greater support for innovation in the educational program, graduate program grants should be made available to departments on a competitive basis.

Of course, the Commission would naturally welcome increased funding for graduate student stipends; however, its recommendations in this area are not mainly about more funding, but about improving the deployment of existing funding.

**3. Academic chemical laboratories must adopt best safety practices. Such practices have led to a remarkably good record of safety in the chemical industry and should be leveraged.**

Progress would afford better protection to students and other workers at all academic levels, and would better prepare students to meet the expectations of their future colleagues and employers.

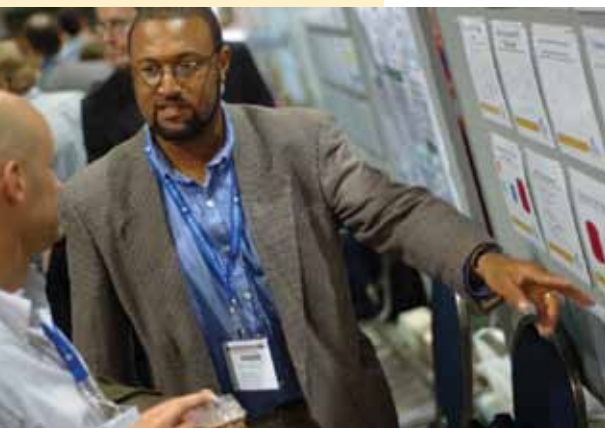


Specifically, the Commission urges that safety as a *culture* must be consistently led by example in all graduate programs in the chemical sciences.

Faculty members in the chemical sciences can and should take the lead toward best practices, and should advocate for support at the highest institutional levels.

In the end, leadership from the top of an institution is essential for a sound safety culture to take root and thrive. The hazards and issues in the chemical sciences also exist in departments and programs outside the chemical sciences all across university and college campuses. A strong safety culture must not vary across institutions, and mechanisms for managing the associated costs cannot be left to individual departments or research groups.

**4. Departments should give thoughtful attention to maintaining a sustainable relationship between the availability of new graduates at all degree levels and genuine opportunities for them. Replication in excess is wasteful of resources and does injustice to the investment made by students and society.**



Given what seems to be a permanently restructured employment market for Ph.D.s, the Commission perceives a risk that the number of career opportunities in the chemical science professions may be insufficient to accommodate those qualified for and desiring entry. Left unaddressed, an imbalance will likely be highly damaging to the talent level and traditional academic strength in the chemical sciences. The Commission urges departments to adjust program sizes in the light of truly attractive opportunities for graduates. It further recommends that this consideration be paramount in determining the scale and balance of any program.

A large undergraduate teaching need is not a sufficient justification for a large graduate program. Teaching needs that remain uncovered by graduate students in a healthy program should be addressed by faculty or other professionals hired and supervised by the department.

Faculty members and other academic leaders in every graduate program—whether at the master’s or doctoral level—are urged to reassess and to focus the program distinctively toward its competitive advantages. There is too much similarity among the nation’s graduate programs. More variety, supported by a diversity of career opportunities, will yield a more innovative, adaptable landscape.

The ACS should collect and publish aggregated, privacy-protected data, organized by graduate program, on post-degree outcomes for all graduates, including time-to-degree, types of job placements, salaries, and overall student satisfaction with the graduate experience and employment outcome. The notion is to provide prospective students with relevant information toward an informed decision in choosing a graduate school.

Programs should build the domestic fraction of their graduate enrollments as a high priority. The Commission fully recognizes and values the great contributions that have historically been made in our graduate programs and in our national technical enterprises by international citizens who were first attracted to the U.S. as graduate students. However, the Commission also notes that the balance in graduate degree production has steadily shifted toward international students. A legitimate concern is whether the nation will continue to have a readily employable technical base large enough to sustain global leadership in innovation. International students should not continue to substitute for the domestic share; instead, a mix richer in domestic students should be targeted.



The Commission has detected concern that recent enrollment trends reflect, in part, a perception that domestic applicants are not as soundly prepared for graduate school as in the past. It is beyond the charge of this Commission to review undergraduate preparation in chemical sciences programs in the U.S., so we offer no conclusion on this point, but we suggest that it is time for a serious inquiry to be made through a suitable mechanism.

To take advantage of the nation's whole talent pool, graduate programs must place an emphasis on attracting and empowering students from underrepresented groups.

**5. Postdoctoral training and education is an extension of graduate education that is important for success in a variety of career paths, particularly for faculty appointments. Postdoctoral associates should be treated as the professional scientists and engineers they are. A postdoctoral appointment should be a period of accelerated professional growth that, by design, enhances scientific independence and future career opportunities.**

Ideally, the disadvantages of career delay and lower salary are offset by several advantages of postdoctoral training and education; however, many postdoctoral associates have inadequate career mentoring, and many take such positions for reasons that do not support their professional development.

The Commission recommends that a) institutions, departments, and faculty mentors take greater responsibility for ensuring that postdoctoral associates develop professionally, b) all funding agencies require general mentoring plans of applicants seeking support for postdoctoral associates, c) funding agencies become more receptive to requests for support of more senior research associates who are regular employees of research institutions, and d) foundations and other funding agencies re-explore programs for “teaching postdoctoral associates.”



Early in its process, the Commission was charged specifically to address two central questions, with the intent that its conclusions underlie any actionable recommendations:

- What are the purposes of graduate education in the chemical sciences?
- What steps should be taken to ensure that they address important societal issues as well as the needs and aspirations of graduate students?

Charts I and II in the body of this report summarize the Commission's answers to these central questions. Contained within them are many points defining the broad importance to the nation of graduate education in the chemical sciences.

With this report, the Commission genuinely hopes to free departments and programs from feeling the need to be practically identical. There is room for greater variation in program design than has been recently typical in American graduate education in the chemical sciences. We believe that our field would benefit from more venturesome design and greater experimentation.

The Commission understands that progress on several of the dimensions addressed among its conclusions and recommendations will require modifications to the reward structure for faculty members participating in doctoral programs. The community needs to engage seriously in exploration of alternatives.

## BACKGROUND

Over the past 100 years, the chemical sciences have contributed immensely to the security, health, and economic vitality of our nation. These practical benefits have been built on enormous advances in knowledge about molecules and their behavior. In turn, command of that knowledge has risen from sound chemical education in our nation's universities and colleges, and research contributions made by university faculty members, by professional scientists, and by graduate students as part of their pursuit of advanced degrees. A vital program of graduate education in the chemical sciences is essential to assure the continued success of the enterprise and to sustain our nation in an ever more technical and globalized world.



This report is the result of a deep and thorough analysis of the current state of graduate education in the chemical sciences. Its authors are leading experts in academia, industry, and government. The report is built on extensive fact-finding by chemical scientists and engineers representing every aspect of the enterprise ranging from beginning students to members of the National Academy of Sciences.

The Commission was appointed and charged by ACS President Bassam Z. Shakhshiri to undertake a wholesale review over a yearlong period. Appendix A identifies the members of the Commission, as well as its special advisors and many additional participants invited into its topical working groups. Appendix B provides President Shakhshiri's charge letter.

The state of graduate education in the chemical sciences is healthy and productive in many respects. In universities, eager, talented graduate students are pursuing degrees in forefront areas that are destined to contribute significantly to the nation's advance. These students are on track toward taking up roles as “stewards of their disciplines”<sup>b</sup> and leaders of their generation.

However, practices of graduate education in our fields have not kept pace with the significant changes in the world's economic, social, and political environment since the end of World War II, when the current system of graduate education was formed. Employment opportunities for chemical scientists and engineers have changed, too, and continue to do so. Collaboration among disciplines has become a hallmark of cutting-edge investigation, in which partners may be located next door or around the globe. Thus, the ability to communicate clearly across disciplinary and cultural lines has emerged as a critical skill. As technology comes to dominate more of our economy and national security interests, we look more often to scientifically trained leaders to provide guidance and advice.

This report addresses the changed world and the role that graduate education in the chemical sciences must play in this century to assure the continuing success of the chemical enterprise and the vitality of our nation. Changes are recommended—not because the previous approaches were wrong—but because the technological leaders of this century must have skills crafted to meet its demands.

In this report, the Commission speaks most immediately to its individual faculty colleagues, who determine on a daily basis the content of graduate education and the requirements for completion of degrees. But there are other intended audiences, including departmental leaders, deans, provosts, and presidents in universities; leaders of funding agencies important to the chemical sciences; national policymakers; leaders of industries that employ chemical scientists and engineers; and leaders in the key professional societies, especially the American Chemical Society.

<sup>b</sup> *Envisioning the Future of Doctoral Education: Preparing Stewards of the Discipline—Carnegie Essays on the Doctorate*; Golde, C.; Walker, G., Eds. Jossey-Bass: San Francisco, CA, 2006.

## FOUNDATIONAL QUESTIONS

President Shakhshiri explicitly charged the Commission to address two large questions early in its process, with the intent that the answers underlie actionable recommendations:

- What are the purposes of graduate education in the chemical sciences?
- What steps should be taken to ensure that it addresses important societal issues as well as the needs and aspirations of graduate students?

Charts I and II summarize the Commission's views concerning these foundational questions. Contained within both charts are many points defining the broad importance to the nation of graduate education in the chemical sciences.

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## CHART I

### Purposes of Graduate Education in the Chemical Sciences

The primary purpose of graduate education is education. The proper first focus is to educate students to solve problems in society, including the effective education of the succeeding generations.

#### Purposes transcending the individual:

1. **At the doctoral level, to develop scientists and engineers** who have demonstrated the ability to design and carry out independent research leading to new knowledge.
2. **At the master's level, to develop scientists and engineers** with augmented technical knowledge beyond the undergraduate level, sometimes toward specialized professional capabilities.
3. **To prepare the technical workforce** for industry and government in the chemical sciences.
4. **To provide faculty for universities, colleges, and schools** who can capably educate and inspire students interested in chemical sciences at high school, undergraduate, and graduate levels.
5. **To involve students personally** in the advancement of the chemical sciences through the processes of investigation and discovery leading to new knowledge.
6. **To provide intellectual underpinnings** for continued national leadership in science and technology.
7. **To cultivate a professional culture and professional capabilities** fostering innovation, which, in turn, leads to job creation and enhanced living standards.
8. **To generate research and intellectual property** that leads to economic development for a region and for the country.
9. **To create solutions to societal needs**, for example in energy, health, climate change, security, and defense.

10. **To develop future business, cultural, and political leaders** who can articulate scientific and technological issues and help the nation toward wise choices in an increasingly technology-dependent, globalized society.

#### Purposes focused on the individual:

11. **To teach graduates how to enter a new field**, how to pose worthwhile problems, how to be productive in generating valuable new knowledge, and how to evaluate critically their findings and those of others. This is the first purpose of doctoral education.
12. **To prepare the student soundly**, in a reasonable period of time—preferably five years or less for a doctoral degree after the baccalaureate—for effective, rewarding careers after graduate school, both with respect to technical knowledge and skills, and with respect to other aspects of professionalism, including high standards of integrity and effective communication.
13. **To help the student understand how chemical processes are applied** to solving problems and creating products, and how new scientific knowledge is translated into practice.
14. **To foster fearlessness in approaching** new technical areas and new operational challenges.
15. **To cultivate and preserve the student's curiosity**, joy of discovery, openness to new ideas, and desire for lifelong learning.
16. **To develop—experientially**, to the greatest practical extent—personal and professional skills needed to compete in an evolving interdisciplinary and global environment.

## CHART II

### Addressing Societal Needs as Well as the Needs and Aspirations of Graduate Students

1. A strategic imperative for the nation is to assure that excellent opportunities exist for the most able students, whose careers are likely to contribute extraordinarily to national technical advancement and productivity.
2. A principal national concern continues to be with the historically low participation rates in the chemical sciences of women and students from underrepresented populations. New, effective ways should be sought to increase the appeal of careers in the chemical sciences to all groups. This is not just an issue of fairness. Without better success along this line, the United States may not be able to generate a technical workforce that can sustain technical leadership.
3. Graduate students should be advised more fully and more competently about the diverse career options meriting consideration in a dramatically changing employment marketplace.
4. Standards of laboratory safety for graduate education and research should adhere to best practices found in industry.
5. Graduate education should provide opportunities for students to explicitly contemplate, discuss, and otherwise be exposed to how chemical sciences can contribute to meeting major challenges of the 21st century, such as sustainability, health, energy, security, and quality of life.
6. Students with aptitude and interest should have educational options, within the context of graduate school, to develop entrepreneurial knowledge and leadership skills.
7. Talented young scientists and engineers in the chemical sciences may be delayed too long in reaching a stage of independent or highly responsible professional practice. Ways should be sought to provide opportunities for young people to reach this stage by their late 20s, rather than their early to mid-30s.
8. Much better use should be made of master's level education, with a focus on new programs aimed at specific competencies that can form sound foundations for a healthy career.
9. More attention should be given to systematic development of educational opportunities offering substantive experiences efficiently connected with career goals, such as industrial internships, coupled enrollment in other degree programs (e.g., other sciences or engineering, public policy, law, entrepreneurship), and international experiences.

## OVERALL CONCLUSIONS AND RECOMMENDATIONS

The Commission has reached five major conclusions, each accompanied by specific recommendations and suggestions:

**Conclusion 1: Current educational opportunities for graduate students, viewed on balance as a system, do not provide sufficient preparation for their careers after graduate school.**

The Commission reaffirms the anchoring concept that a doctoral program in the chemical sciences must manifest traditional depth and must maintain a focus on mastery. But the members also conclude that curricula need to be refreshed, and better-designed opportunities should exist for the development of critical professional skills.

The Commission's specific points in this area are as follows:

1.1. In general, the Commission encourages departments to undertake greater oversight over the progress and opportunities of individual graduate students.

1.2. Graduate programs should be more active in diagnosing and remediating deficiencies in the preparation of first-year students.

1.3. Beyond core academic competency in chemical science or engineering, additional skills are critical for a student's future career. Faculty overseeing doctoral programs need to offer specific activities that would enhance students' ability to:

- Communicate complex topics to both technical and nontechnical audiences and to effectively influence decisions;
- Learn new science and technology outside prior academic training;
- Collaborate on global teams and/or with global partners and clients;
- Effectively define, drive, and manage technical work toward a practical, significant result; and
- Clearly understand the ethical conduct of research.

The most all-encompassing approach to these needs is to significantly enhance interdisciplinary collaboration among the students.

1.4. Four years should be the target for completion of the Ph.D., with the departmental median time less than five years. Degree times greater than five years should be strongly discouraged through enforced institutional policies.

The Commission understands that there is inevitable tension between its recommendations that doctoral programs be shortened while also being retailored to include elements that are not generally addressed effectively in existing practice. For this reason, the members believe graduate education must become more efficient. Opportunities for improved efficiency exist in better program design, superior monitoring of student progress, use of the summer before the first year of graduate study, and fuller use of short courses and online classes.



- 1.5. Every department should constitute a doctoral committee for each student composed of several faculty who will be intimately involved in the student's graduate education. Graduate programs should see that the doctoral committee is involved more closely and more frequently in graduate student mentoring than is currently the norm in Ph.D. student advising. This should include, at a minimum, annual meetings, and opportunities for the student to address matters such as possible conflicts with the advisor.
- 1.6. Graduate programs should make an Individual Development Plan (IDP)<sup>c</sup> a standard part of every doctoral student experience. The structure and elements of the IDP should be developed in a tailored way at each institution, though some standardized versions are now available. These may be devised in their particulars by the student and advisor, and discussed initially and annually with the doctoral committee.
- 1.7. Faculty should encourage students to engage in projects requiring collaboration that broadens the student's field of study. In particular, faculty should encourage collaboration across disciplines as much as possible.
- 1.8. Departments should require at least two original research proposals, one with a focus outside the student's immediate field of study.
- 1.9. Departments in the chemical sciences are also encouraged to set up optimal structures that best enable and facilitate an interdisciplinary and multidisciplinary team approach to complex problem solving.
- 1.10. Students interested in entrepreneurship should have access to a curricular option providing an introduction to relevant topics, including the protection and management of intellectual property (IP), the basic economics of IP-based businesses, the financing of start-up enterprises, and selected legal concepts. This is an area in which the ACS might provide useful short courses for delivery on campuses or via the Internet.
- 1.11. The ACS should develop one or more formal courses for the more explicit preparation of students who intend to seek academic employment. The first should be focused on undergraduate curriculum development, teaching standards, and teaching methods. It should be provided on campus through specifically trained faculty or perhaps online, in part, or in whole. Academic institutions should strongly encourage all applicants for teaching positions to have résumés noting successful completion of this course or a suitable alternative.

An additional course might be developed to cover the mentoring of graduate students, grantsmanship, interactions with program officers, and other related topics.
- 1.12. The ACS is encouraged to undertake an extensive survey of representative graduate programs at selected major universities to ascertain requirements and expectations and organizational structure that best facilitate the educational goals of the Commission. Also, the ACS should assure that the Commission's recommendations on best educational practices are reflected in the work of the ACS Education Division, the ACS Graduate Education Advisory Board, and the ACS Committee on Economic and Professional Affairs.



<sup>c</sup> Austin, J.; Alberts, B. *Science* **2012**, *44*, 1149.

**Conclusion 2: The system for the financial support of graduate students, as currently operated by private, institutional, state, and federal funds, is no longer optimal for national needs.**

The financial support system rests too heavily on individual research grants and involves serious conflicts between the education of graduate students and the needs for productivity and accountability in grant-supported research.

Here are the Commission's specific recommendations and suggestions in this area:

- 2.1. Federal and state funding agencies, private funders, and universities should take steps toward decoupling more student-support funds from specific research projects, in the interest of providing students the opportunity for better balance between training in research and training in other career skills, without significantly impacting the research productivity of faculty.

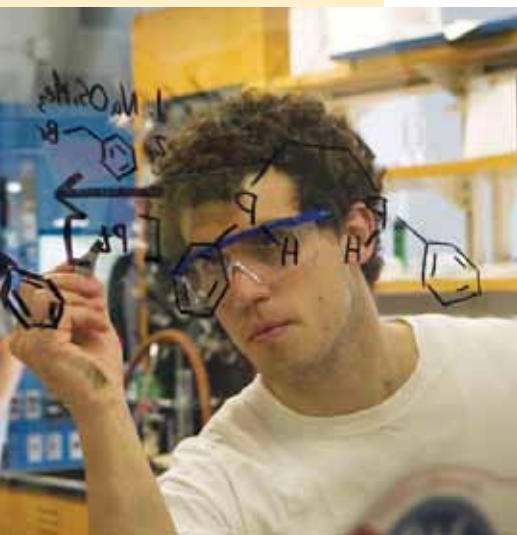
The goal, with perhaps a 10- to 15-year horizon, should be to decouple the preponderance of student support from specific research grants and contracts. In the near term, funders and graduate program leaders should engage in trial projects designed to prove out new mechanisms.

- 2.2. In particular, federal agencies and private funders should experiment with a new strategy for "graduate program grants" to support graduate students. Analogous to training grants, but with perhaps greater support for innovation in the educational program, graduate program grants should be made available to departments on a competitive basis. They could be used to:

- Provide students with semesters of support free of extensive service as teaching assistants, just as grant-funded research assistantships do now;
- Provide funding for students to begin graduate work in the summer after the bachelor's degree, so they can get a start on exploring research opportunities and have the opportunity for initial training in critical skills, such as safety, communications, pedagogy, and responsible conduct of research; and
- Reward all programs at all levels for developing curricula to serve the overall education needs of students.

While the Commission would naturally welcome increased funding for graduate student stipends, this recommendation for reshaping student support is not mainly about more funding, but about improving the deployment of existing funding.

- 2.3. The U.S. Department of Education should make the GAANN (Graduate Assistance in Areas of National Needs) Program more generally useful. The program currently provides grants to institutions of higher education for support of talented students from traditionally underrepresented backgrounds who must demonstrate financial need. If the Department of Education were to reformulate the GAANN program by making it generally applicable, it could go a long way toward supporting strong graduate students not only in the chemical sciences, but in other sciences, as well.
- 2.4. Faculty members should view work by graduate students as teaching assistants much more strategically as an opportunity—and an obligation of the program—to enhance the professional development of the student. The experience should be deliberately complementary to research. However, teaching assistantships should not be the major basis of support throughout





one's graduate career, because such a situation shifts the student's balance of time commitment too far away from essential research activities.

- 2.5. Government sources should rebalance fellowship programs to make more awards available to students in the second year of graduate school and beyond (i.e., application made after the student has begun graduate school), rather than primarily in the first year.
- 2.6. The governments of many nations sending graduate students to the U.S. have strengthened financially, so departments and programs should place increased emphasis on international students being supported by their home countries. The Commission is recommending many important changes in student support patterns, and greater ease in implementing them would arise naturally from fuller native support of international students.
- 2.7. With respect to timetable and student support, the Commission recommends the following structure for most students in most doctoral programs in chemistry departments. Graduate programs in the other chemical sciences are urged to strive toward implementing a similar pattern, modified, as needed, by departmental financing patterns:
  - *Summer before the start of courses:* This is an optimal time for students to receive initial training in professional skills, including instructional skills, and to begin exploring research opportunities. Support for all students for two months should be provided by departmental funds, including graduate program grants.
  - *First year:* Nearly all students should be supported on teaching assistantships or, where available, graduate program grants.
  - *Second year:* Most students should be supported by the department on individual fellowships or graduate program grants. Federal fellowships would also be available to some students. Teaching assistantships should be used, as needed, but should be at an advanced level (more responsibility, more training in pedagogy) compared to the first year.
  - *Third year:* Research assistantships tied to the principal investigator's specific project, graduate program grants, individual fellowships, or teaching assistantships.
  - *Fourth and fifth year:* Research assistantships and individual fellowships. If teaching assistantships are used, they should include a major component of pedagogical training and should require a reduced time commitment compared to earlier years, to allow more rapid progress to degree.



**Conclusion 3: Academic chemical laboratories must adopt best safety practices. Such practices have led to a remarkably good record of safety in the chemical industry and should be leveraged.**

Progress would afford better protection to students and other workers at all academic levels, and would better prepare students to meet the expectations of their future colleagues and employers.

Specifically, the Commission makes the following recommendations and suggestions:

- 3.1. Safety as a *culture* must be consistently led by example in all graduate programs in the chemical sciences.
- 3.2. A natural supporting step is to establish a safety performance partnership between industry and academic institutions, whereby corporations share best practices with students and faculty on a regular basis. The ACS should play a lead role facilitating training and sharing of best practices and should sponsor the development of a comprehensive safety curriculum based on best practices.
- 3.3. Leadership from the top of an institution is essential for a sound safety culture to take root and thrive. The hazards and issues in the chemical sciences also exist in departments and programs outside the chemical sciences all across university and college campuses. A strong safety culture must not vary across institutions, and mechanisms for managing the associated costs cannot be left to individual departments or research groups.



All universities and colleges should see that widespread and in-depth attention is given to the report, titled *Creating Safety Cultures in Academic Institutions: A Report of the Safety Culture Task Force of the ACS Committee on Chemical Safety*. Specific programs to implement the recommendations of this report should be established in all academic chemical science and engineering departments.

Faculty members in the chemical sciences can and should take the lead toward best practices, and should advocate for support at the highest institutional levels.

**Conclusion 4: Departments should give thoughtful attention to maintaining a sustainable relationship between the availability of new graduates at all degree levels and genuine opportunities for them. Replication in excess is wasteful of resources and does injustice to the investment made by students and society.**

Here are the Commission's specific points:

- 4.1. Given what seems to be a permanently restructured employment market for Ph.D.s, the Commission perceives a risk that the number of career opportunities in the chemical science professions may be insufficient to accommodate those qualified for and desiring entry. Left unaddressed, an imbalance will likely be highly damaging to the talent level and traditional academic strength in the chemical sciences. The Commission urges departments to adjust program sizes in the light of truly attractive opportunities for graduates. It further recommends that this consideration be paramount in determining the scale and balance of any program.  
  
A large undergraduate teaching need is not a sufficient justification for a large graduate program. Teaching needs that remain uncovered by graduate students in a healthy program should be addressed by faculty or other professionals hired and supervised by the department.
- 4.2. Faculty members and other academic leaders in every graduate program—whether at the master's or doctoral level—are urged to reassess and to focus the program distinctively toward its competitive advantages. There is too much similarity among the nation's graduate programs. More variety, supported by a diversity of career opportunities, will yield a more innovative, adaptable landscape.

- 4.3. To encourage and help guide needed changes, the Commission recommends that the ACS collect and publish aggregated, privacy-protected data, organized by graduate program, on post-degree outcomes for all graduates, including time-to-degree, types of job placements, salaries, and overall student satisfaction with the graduate experience and employment outcome.

The notion is to provide prospective students with relevant information toward an informed decision in choosing a graduate school. Other information, not identified here, might also be included. The establishment of such a resource is a large, important undertaking, meriting guidance from a dedicated task force.

- 4.4. Programs should build the domestic fraction of their graduate enrollments as a high priority. The Commission fully recognizes and values the great contributions that have historically been made in our graduate programs and in our national technical enterprises by international citizens who were first attracted to the U.S. as graduate students. However, the Commission also notes that the balance in graduate degree production has steadily shifted toward international students. A legitimate concern is whether the nation will continue to have a readily employable technical base large enough to sustain global leadership in innovation. International students should not continue to substitute for the domestic share; instead, a mix richer in domestic students should be targeted.

Many colleagues report that recent enrollment trends reflect a perception, and probably a reality, that international students are relatively more competitive for admission than in past decades, at least partly because domestic applicants are not as soundly prepared for graduate school as in the past. If so, an important step toward increasing domestic enrollments and success rates in graduate school is to achieve better preparation at the undergraduate level. It is beyond the charge of this Commission to review undergraduate preparation in chemical sciences programs in the U.S., so we offer no conclusion on this point, but we suggest that it is time for a serious inquiry to be made through a suitable mechanism.

- 4.5. To take advantage of the nation's whole talent pool, graduate programs must place an emphasis on attracting and empowering students from underrepresented groups.
- 4.6. Communications to undergraduates should point out that not only is graduate education in the chemical sciences free to them, but that they will receive a stipend, as well.



**Conclusion 5: Postdoctoral training and education is an extension of graduate education that is important for success in a variety of career paths, particularly for faculty appointments. Postdoctoral associates should be treated as the professional scientists and engineers they are. A postdoctoral appointment should be a period of accelerated professional growth that, by design, enhances scientific independence and future career opportunities.**

Ideally, the disadvantages of career delay and lower salary are offset by the advantages of postdoctoral training and education, including the opportunity to broaden one's research experience, the growth that comes from helping to lead a research group, and the desirability of working with a gifted mentor. However, many postdoctoral

associates have inadequate career mentoring, and many take such positions for reasons that do not support their professional development, e.g., to extend their residence in the United States or to engage in a holding action because of inability to obtain a more permanent position at their skill level.

The Commission makes the following recommendations:

- 5.1. Institutions and departments, as well as faculty mentors, should take greater responsibility for ensuring that postdoctoral associates develop professionally. Important steps toward achieving this goal include the use of individual development plans, regular access to multiple mentors, and the opportunity to present research at scientific meetings and departmental seminars. Institutions should appoint officers with responsibility for the well-being of postdoctoral associates.
- 5.2. All funding agencies should require general mentoring plans of applicants seeking support for postdoctoral associates. To help provide a professional path forward for postdoctoral associates, funding agencies should also be more receptive to requests for support of more senior research associates who are regular employees of research institutions.
- 5.3. Foundations and other funding agencies should re-explore programs for “teaching postdoctoral associates,” so that trained professional instructors become an alternative to the current reliance on doctoral students for so much of the teaching responsibility.
- 5.4. A feedback mechanism linking the size of Ph.D. programs to job availability is needed to minimize bulges in the career pipeline at the postdoctoral level. The Commission urges integrated thinking at the program level regarding numbers of postdocs and doctoral graduates emerging together into employment markets.



*Institutions and departments, as well as faculty mentors, should take greater responsibility for ensuring that postdoctoral associates develop professionally.*

## CLOSING COMMENTS

The concerns that led to this Commission are not limited to the chemical sciences, as one can readily discern from the burst of recent major reports on graduate education in the United States, all having appeared in the past 24 months. In chronological order, they include:

- The *Innovation, Chemistry, and Jobs* report of the ACS,<sup>d</sup> which addresses innovation in the chemical enterprise, includes recommendations for changes in the culture of research universities and the practices in graduate education.
- The summary of the 2012 National Research Council workshop on graduate education in chemistry,<sup>e</sup> which was a one-day event covering a wide range of issues relevant to the work of this Commission.
- The Tilghman Report of the National Institutes of Health Biomedical Research Workforce Working Group,<sup>f</sup> which appeared publicly in draft form and has received considerable attention for its recommendations concerning the support and education of doctoral students and postdoctoral scholars.
- The Holliday Report of the National Research Council,<sup>g</sup> which addresses many aspects of U.S. research universities, but has one of its 10 recommendations focused on changes in graduate education.
- The President's Council of Advisors on Science and Technology (PCAST) report<sup>h</sup> on changes needed to revitalize the U.S. research enterprise.

This Commission's views are consistent with the most important conclusions in these contemporaneous publications.

Overall, the Commission hopes to free departments and programs from feeling the need to be practically identical. There is room for greater variation in program design than has been recently typical in American graduate education in the chemical sciences. We believe that our field would benefit from more venturesome design and greater experimentation.

<sup>d</sup> Whitesides, G. M., et al. *Innovation, Chemistry, and Jobs*; ACS Presidential Task Force on Innovation in the Chemical Enterprise; American Chemical Society: Washington, DC, 2011. <http://web2.c2.audiovideoweb.com/va92web25028/InnovationChemistryJobsReport-PDFs/InnovationChemistryandJobs.pdf> [accessed December 2012].

<sup>e</sup> Francisco, J. S., et al. *Challenges in Chemistry Graduate Education: A Workshop Summary*; Committee on Challenges in Chemistry Graduate Education, Board on Chemical Sciences and Technology; National Research Council: Washington, DC, 2012. [http://www.nap.edu/catalog.php?record\\_id=13407](http://www.nap.edu/catalog.php?record_id=13407) [accessed December 2012].

<sup>f</sup> Tilghman, S. M., et al. *Biomedical Research Workforce Working Group: Draft Report*; National Institutes of Health: Bethesda, MD, 2012. [http://acd.od.nih.gov/bmw\\_report.pdf](http://acd.od.nih.gov/bmw_report.pdf) [accessed December 2012].

<sup>g</sup> Holliday, C., et al. *Research Universities and the Future of America: Ten Breakthrough Actions Vital to Our Nation's Prosperity and Security*; Committee on Research Universities, Board on Higher Education and Workforce; National Research Council: Washington, DC, 2012. [http://www.nap.edu/openbook.php?record\\_id=13299&page=R1](http://www.nap.edu/openbook.php?record_id=13299&page=R1) [accessed December 2012].

<sup>h</sup> Holdren, J. P.; Lander, E. S., et al. *Transformation and Opportunity: The Future of the U.S. Research Enterprise*; President's Council of Advisors on Science and Technology: Washington, DC, 2012. [http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast\\_future\\_research\\_enterprise\\_20121130.pdf](http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_future_research_enterprise_20121130.pdf) [accessed December 2012].

For this reason alone, the Commission explicitly discourages any form of checklist for graduate programs or any analogue to the ACS Committee on Professional Training, which serves usefully to approve undergraduate chemistry programs.

The Commission's charge certainly includes master's level education. The members recognize the distinctive roles that it fulfills in our society and generally believe that there is room for fuller use of this degree level in developing the professional workforce. The master's degree needs to be reconsidered as the diversity of opportunities in the chemical sciences increases.

The Commission understands that progress on several of the dimensions addressed among its conclusions and recommendations will require modifications to the reward structure for faculty members participating in doctoral programs. We do not have detailed proposals, but we acknowledge the importance of creative innovation in this area. The community needs to engage seriously in exploration of alternatives.

In this respect, as in many others, the Commission is focusing on the goal, rather than the path. Our emphasis on experimentation is acknowledgement that many new paths will need to be explored as progress is sought along various dimensions of graduate education.



In the one year available for this project, it has not been possible for the Commission to address even all important facets of graduate education, so one must view this work as an early step in a long-term process. This report is a starting point – a reconnoitering for a journey. It is not intended as a detailed guide.

In the effort to improve and reform, we expect that there will be successes and successive stages. Pioneering departments and practices will emerge and become exemplars. Subsequent commissions and task forces will be needed to address topics in greater depth or broader imagination than has been possible for us, or to revisit strategies in the light of results from actual trials. Our most earnest hope is that our field will brilliantly renew its vigor and intellectual strength.

## ACKNOWLEDGEMENTS

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## APPENDIX A. MEMBERS AND ASSOCIATES OF THE COMMISSION

### Commission Membership Appointed by President Shakhshiri

William F. Banholzer, *The Dow Chemical Company*  
Jacqueline K. Barton, *California Institute of Technology*  
Stacey F. Bent, *Stanford University*  
Ronald Breslow, *Columbia University*  
Gary Calabrese, *Corning, Inc.*  
Pat N. Confalone, *E. I. du Pont de Nemours and Company*  
Michael P. Doyle, *University of Maryland, College Park*  
Larry R. Faulkner, *University of Texas at Austin, Commission Chair*  
Marye Anne Fox, *University of California, San Diego*  
Joseph S. Francisco, *Purdue University*  
Paul Houston, *Georgia Institute of Technology, Commission Executive Director*  
Chad A. Mirkin, *Northwestern University*  
Larry E. Overman, *University of California, Irvine*  
Hunter Ripley Rawlings III, *Association of American Universities*  
Geraldine Richmond, *University of Oregon*  
Richard H. Scheller, *Genentech, Inc.*  
Joel I. Shulman, *University of Cincinnati*  
Peter J. Stang, *University of Utah*  
Matthew Tirrell, *University of Chicago*  
George M. Whitesides, *Harvard University*  
Mark S. Wrighton, *Washington University in St. Louis*  
Mary M. Kirchhoff, *American Chemical Society, ACS Staff Liaison*

### Special Advisors

Gary B. Schuster, *Georgia Institute of Technology*  
Bassam Z. Shakhshiri, *University of Wisconsin-Madison, ACS President*



## Invited Participants in the Working Groups

Hector D. Abruña, *Cornell University*  
Richard Cavanagh, *National Institute of Standards and Technology*  
Francis J. DiSalvo, *Cornell University*  
James J. Duderstadt, *University of Michigan*  
Jeffrey D. Evanseck, *Duquesne University*  
David F. Feldon, *University of Virginia*  
Carlos Gutierrez, *California State University, Los Angeles*  
Rigoberto Hernandez, *Georgia Institute of Technology*  
Anne Myers Kelley, *University of California, Merced*  
David S. Kliger, *University of California, Santa Cruz*  
Shirley Malcom, *American Association for the Advancement of Science*  
Anne McCoy, *The Ohio State University*  
Diep Nguyen, *Illinois Institute of Technology*  
Susan Olesik, *The Ohio State University*  
Peppi Prasit, *Inception Sciences, Inc.*  
Melanie Sanford, *University of Michigan*  
Ian Tebbett, *University of Florida*  
Charles M. Vest, *National Academy of Engineering*  
Isiah M. Warner, *Louisiana State University*



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October 17, 2011

**ACS Mission:** *To advance the broader chemistry enterprise and its practitioners for the benefit of Earth and its people.*

**ACS Vision:** *Improving people's lives through the transforming power of chemistry.*

## Advancing Graduate Education in the Chemical Sciences

A mission of the American Chemical Society is to promote excellence in post-secondary chemistry education and leadership in the professional training of chemists. As 2011 ACS President-elect I have appointed a Presidential Commission of influential leaders to examine the purposes of graduate education in the chemical sciences, to make recommendations for improvements, and to suggest strategies for implementing those recommendations. This examination is important in order to make efficient use of our university, government, and industrial resources, to provide exciting and meaningful careers to those in the chemical sciences, and to provide society with trained and inspired leaders who can improve the human condition.

One major task of the ACS Presidential Commission is to consider fundamental, comprehensive, and systemic changes suitable for graduate education in the chemical sciences. A second major task is to suggest actionable approaches for enhancing the quality of graduate research and education at all institutions.

The outcome of the Commission's deliberations will be the recommendation of a coherent strategy for improving graduate education in the chemical sciences by providing choices among viable models that can be adopted by a variety of institutions. For any particular institution, some models will be more appropriate than others. The choice among them and the distribution of these choices will affect research universities, comprehensive universities, graduate students, industry, and funding agencies, such as NSF, NIH, DOD, DOE, and NIST, as well as private foundations. The educational issues the Commission will discuss are common to other fields in both the sciences and engineering, and the Commission's work will not only influence graduate education in the chemical sciences, but other disciplines as well.

#### The Commission Charge

The main charge to the Commission is to address two major questions:

- What are the purposes of graduate education in the chemical sciences?
- What steps should be taken to ensure that they address important societal issues as well as the needs and aspirations of graduate students?

In preparing its report and actionable recommendations, the Commission will address additional questions including but not limited to the following:

1. Is the current structure of different types of departments in the chemical sciences (chemistry, chemical engineering, chemistry and biochemistry, chemistry and chemical biology, chemical and biomolecular engineering, materials science, etc.) a strength or a weakness with respect to graduate education?
2. What are the employment issues for graduate students in both industrial and academic settings? Are we providing the right educational opportunities?
3. What are the financial support mechanisms for graduate education in the chemical sciences? Is the current mix the best one?
4. Is the current profile of our graduates the correct one, not only in terms of domestic vs. international, but in terms of diversity along other axes as well? Do they have the proper background for the type of graduate education we want them to attain?
5. What are the expectations of graduate students, are our educational institutions meeting them, and what promises do they make to students, both explicitly and implicitly? In particular, what should be the lengths of the graduate student program and any subsequent postdoctoral training? And why is the attrition rate for Ph.D. students in the chemical sciences as high as it is (only 62% finish within ten years.)

#### **Commission Members**

Dr. William F. Banholzer, CTO, Dow Chemical  
 Dr. Jacqueline K. Barton, Professor of Chemistry, Cal Tech  
 Dr. Stacey F. Bent, Professor of Chemical Engineering, Stanford University  
 Dr. Ronald Breslow, Professor of Chemistry, Columbia University  
 Dr. Gary Calabrese, Vice President, Science & Technology, Corning Inc.  
 Dr. Pat N. Confalone, Vice President, Global R&D, DuPont, ACS Board of Directors  
 Dr. Michael P. Doyle, Professor of Chemistry, University of Maryland  
 Dr. Larry R. Faulkner, President, Houston Endowment (**Commission Chair**)  
 Dr. Marye Anne Fox, Chancellor, UC San Diego  
 Dr. Joseph S. "Joe" Francisco, Professor of Chemistry, Purdue University, ACS Board of Directors  
 Dr. Paul Houston, Dean, College of Sciences, Georgia Institute of Technology (**Commission Executive Director**)  
 Dr. Chad A. Mirkin, Professor of Chemistry, Northwestern University  
 Dr. Larry E. Overman, Distinguished Professor of Chemistry, UC Irvine  
 Dr. Hunter Ripley Rawlings III, President, Association of American Universities  
 Dr. Geraldine Richmond, Professor of Chemistry, University of Oregon  
 Dr. Richard H. Scheller, Executive Vice President, Genentech Research & Early Development  
 Dr. Joel I. Shulman, Professor of Chemistry, University of Cincinnati - formerly at Procter & Gamble  
 Dr. Peter J. Stang, Distinguished Professor of Chemistry, University of Utah  
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 Dr. Mark S. Wrighton, Chancellor and Professor of Chemistry, Washington University, St. Louis  
 Dr. Mary Kirchoff, Director, ACS Education Division (**ACS Staff Liaison**)

The Commission will establish its own timetable for its deliberations and should aim to complete its final report and actionable recommendations no later than **December 1, 2012**.

Members of the Presidential Commission will participate in three in-person meetings. Other documentation and subcommittee work will be carried out via electronic communication. Commission subcommittees will report on specific issues and/or hold focus-group discussions with all stakeholders such as students, postdocs, faculty, academic administrators, and private sector and government leaders at national and regional ACS meetings and elsewhere as well as via other means of communication.

I look forward with high expectations to the outcome of your important work. I am committed to supporting your efforts by all means available to me.

Thank you and best wishes.

A handwritten signature in black ink, reading "Bossam Z. Shakhulin". The signature is written in a cursive style with a prominent flourish at the end.

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