National Academies of Sciences, Engineering and Medicine
Committee on Revitalizing Graduate STEM Education for the 21st Century
Discussion Document and Call for Community Input

The members of the National Academies of Sciences, Engineering, and Medicine's (National Academies) Committee on Revitalizing Graduate STEM Education for the 21st Century are soliciting input into ways to structure U.S. graduate education programs to better serve the needs of diverse students, the scientific enterprise, and the Nation.[1] We would appreciate your reactions to some of the input the Committee has received from various stakeholders (e.g. students, faculty, scientific societies, funding agencies), as well as your own thoughts on these issues.

BACKGROUND

The National Academies created this Committee to respond to the concern that the current system is inadequately educating graduate students in science, technology, engineering and mathematics (STEM) to prepare them for productive careers in the 21st century. For example, all available evidence suggests that over 60 percent of new Ph.D. students in STEM do not pursue careers in academia.[2] However, the Ph.D. graduate education system has changed relatively little over the past 100 years, with its fundamental format directed at preparing students primarily for research careers in academia. At the master's level, there have been more significant changes over the last decade or two, but there is concern those changes may have been too few or too small in scale. Given the diversity of career paths students pursue—coupled with changes in demographics of the student populations, and with the rapid evolution in the ways science itself is conducted—we and others believe there is an urgent need to ensure that the graduate education system is better aligned with the needs of all students, as well as the needs of the scientific enterprise, potential employers, and the broader society. The National Academies charged this Committee with considering the questions of how well the current graduate education system is equipping students for current and anticipated future needs and what changes should be made to increase its effectiveness.

The Committee recognizes that many elements of the existing graduate education system are working well and serve many of the needs of an array of higher education institutions, academic departments, faculty members, and other stakeholders. The Committee will strive to ensure those benefits are not compromised. Nevertheless, evidence from students, recent graduates, and employers suggest that the system has not fully kept pace with broader changes in society, or in the ways science and engineering are practiced.[3] There is both a demand and opportunities to modernize the system to be more inclusive and to better meet the needs and interests of an increasingly diverse student body pursuing a broad spectrum of careers in a world in which labor markets, funding sources, and institutional policies are undergoing rapid change.[4]

A CALL FOR COMMUNITY INPUT

As a starting point for your thoughts, we ask you to consider a set of competencies, described in the following sections, that might serve as core educational elements or goals at both the master's and Ph.D. levels. These core educational elements would be the foundation for framing programmatic and logistic standards and considerations, such as program structure, curriculum, and how to enhance diversity within the scientific enterprise. We would like to know if the community, writ large, agrees with these core educational goals going forward or whether they should be adjusted to better reflect the context and needs of all 21st century STEM graduate students. We would value your ideas on what might be missing from these lists, and what additional knowledge, experiences, and skills should be expected of all students. We also ask for your input on other questions we are pondering, listed at the end of the document, that represent focus areas for the eventual development of our report and recommendations.

CORE EDUCATIONAL ELEMENTS: MASTER'S DEGREES

Many master's programs are characterized by flexibility and adaptability to the changing nature of scientific disciplines and to workforce demands, and they often attempt to integrate the physical, biological and social sciences, and even the humanities and arts. With a shorter time-to-degree than the Ph.D., and because many students fund their own master's degree program, institutions often establish and adapt master's programs to respond to workforce demands (sometimes in partnership with industry), and to anticipate emerging interdisciplinary fields.

To find a vision for core educational elements of master's degrees, the Committee referred to the Council of Graduate School's (CGS) *Alignment Framework for the Master's Degree*. This alignment framework was the product of a year-long dialogue that included 150 graduate school deans.[5] Of the three defining characteristics of master's degree programs, the section on competencies describes four developmental dimensions that graduate school deans believe should be common among all or most master's degree programs:

1. **Disciplinary and interdisciplinary knowledge:** Master's students should develop core disciplinary knowledge and the ability to work between disciplines.
2. **Professional competencies:** Master's students should develop abilities defined by a given profession (e.g. licensing, other credentials).
3. **Foundational and transferrable skills:** Master's students should develop skills that transcend disciplines and are applicable in any context, such as communications, leadership, and working in teams. These dimensions are especially critical as the lines that traditionally define scientific and engineering disciplines become blurred—and more scientific research and application is characterized by the convergence of disciplines.
4. **Research:** Master's students should develop the ability to apply the scientific method, understand the application of statistical analysis, gain experience in conducting research and other field studies, and engage in work-based learning and research in a systematic manner.

CORE EDUCATIONAL ELEMENTS: PH.D.

There is a consensus among graduate education leaders and faculty on U.S. university campuses that the education Ph.D. students receive should at a minimum provide them the ability to conduct original scientific research and to enhance their capacity to acquire new data, information, and knowledge. That is, the core coursework and other intensive experiences in the classroom and laboratory should prepare students to discover new knowledge, understand the implications of the new knowledge for both the scientific discipline and society at large, and communicate the impact of the research to their peers and the broader public. Taken together, the core educational elements would establish the STEM PhD educational mission: stimulate curiosity; develop intellectual capacity to recognize, formulate and communicate a complex problem; create multi-dimensional, quantitative approaches toward its solution; discover knowledge that advances understanding; and communicate the impact of the research to peers and the broader public.

Based on the input and ideas received to date, the Committee is considering some core elements of a quality Ph.D. education:

1**. Scientific Literacy, Communication, and Professional Skills**

a. Acquire basic trans-disciplinary knowledge sufficient to address a complex problem using multiple conceptual and methodological approaches.
b. Develop deep specialized expertise in at least one STEM discipline/approach.
c. Acquire an appreciation of the ethics and norms of the scientific enterprise and its relationship to the rest of society, as well as a strong and ethical character and exemplary professional conduct.
d. Develop the ability to work in collaborative and team settings involving colleagues from diverse cultural and disciplinary backgrounds.
e. Develop management, leadership, financial, and entrepreneurial skills critical to success in any 21st century career.
f. Build capacity to communicate the significance and impact of a study or a body of work to all STEM professionals, policymakers, and the public at large.

2. **Conduct of Original Research**

a. Identify an important problem and articulate an original research question.
b. Design a set of studies, including relevant quantitative and analytic approaches, to explore components of the problem and begin to address the research question.
c. Evaluate outcomes of each experiment or study component and select which outcomes to pursue and how.
d. Adopt rigorous standards of investigation and acquire mastery of the quantitative and analytic skills required to conduct successful research in the field of study.

Are these effective/appropriate core educational elements for the 21st century, or should they be modified to increase the probability of successful careers for all students? The Committee looks forward to your comments and suggestions.

ADDITIONAL QUESTIONS FOR THE COMMUNITY

The Committee also seeks your input on several issues that have arisen during our deliberations to date.

- In addition to the core capabilities described above, the Committee has been hearing about other offerings that could augment a graduate STEM degree independently of the student's educational and career goals. These might include mentoring, career exploration, personnel management, cross-cultural competency, budgeting, communication, entrepreneurship, and fundamentals of business development. This raises an array of questions on which the Committee seeks input:
    - What are the types of offerings that institutions, employers, professional societies, and other stakeholders should provide to help students acquire the skills to equip them for 21st century careers? To what degree will students and employers find value in emerging credentials offered online and by non-traditional models?
    - Should these offerings be required of all students, or should they be optional? When should they be offered? During or after graduate school?
    - How in-depth and of what duration should the additional educational experiences be?
- Many say that attitudinal and behavioral changes regarding career pathways for STEM graduates among virtually all concerned stakeholders (e.g. students, faculty, institutional leadership, funding

agencies, etc.) are necessary to ensure that graduate STEM education is effective and relevant going forward. Given that each group operates within a different context and with its own unique set of incentives and rewards, how might those incentives be adjusted to better align the behavior of various groups to achieving the goals of 21st century graduate education?

- How can the system most effectively increase the diversity of U.S. STEM graduate student and faculty populations?
- How can the system increase completion rates for all students?
- There appears to be great concern about the issue of time-to-degree. What level of priority should time-to-degree receive, and how should it be addressed?
- Since the needs for graduate STEM education will continue to evolve and change over time, what kind of monitoring system can be established to ensure continuous improvement in terms of meeting the needs of diverse stakeholders? What metrics would be used to evaluate progress?
- How might students gain sufficient familiarity with the range of careers available for STEM Ph.D. recipients so that they can make more informed decisions as their education progresses? Should the core of graduate education be in some way adjusted to align better with the perceived needs of the range of future employers? Would internships in non-academic settings or opportunities to formally mentor other students be appropriate? If so, should those internships and mentoring opportunities be offered during or after graduate school?
- The systematic collection and publication of reliable career placement data are sporadic across graduate schools and individual departments, although the Committee is aware that efforts are underway to remedy this situation. How can we best encourage uniform transparency about career outcomes for prospective students and other stakeholders at the level of individual graduate schools and departments? What would be the impact of publication of these data on prospective students and graduate schools?

You may submit your feedback online at http://nas.edu/GradEdInput by September 22, 2017,
or you may submit general comments via e-mail to STEMGradEd@nas.edu.

[1] Visit the project website for Statement of Task, list of Committee members, and project information.
[2] National Science Foundation, National Center for Science and Engineering Statistics. 2016. *Doctorate Recipients from U.S. Universities: 2015*. Special Report NSF 17-306. Arlington, VA. Available at www.nsf.gov/statistics/2017/nsf17306/. Table 46.
[3] National Academies of Sciences, Engineering, and Medicine. 2016. *Developing a National STEM Workforce Strategy: A Workshop Summary.* Washington, DC: The National Academies Press. doi: 10.17226/21900.
[4] National Science Foundation. 2016. *The National Science Foundation Strategic Framework for Investments in Graduate Education FY 2016-FY 2020*. NSF-16074. Arlington, VA. Available at www.nsf.gov/pubs/2016/nsf16074/nsf16074.pdf.
[5] Council of Graduate Schools. 2016. The Alignment Framework for the Master's Degree. Washington, DC. Available at http://cgsnet.org/january-2017-gradedge.

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