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GRADUATE STEM EDUCATION FOR THE 21ST CENTURY

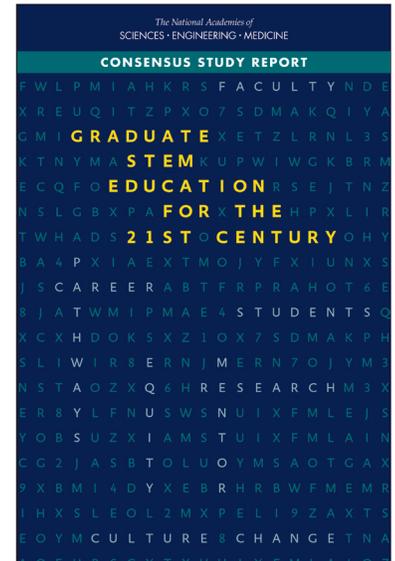
The U.S. system of graduate education in science, technology, engineering, and mathematics (STEM) has served the nation extremely well. In many ways, it is the “gold standard” for graduate STEM education in the world as evidenced by, among other measures, the substantial number of international students coming to the United States to study. Over the course of their education, graduate students develop skills to advance the frontiers of discovery, contributing to the growth of the U.S. economy, its national security, and the health and well-being of its people. However, dramatic innovations in research technologies, changes in the nature of work, shifts in demographics, and growth in occupations needing STEM expertise all raise questions about how well the current STEM graduate education system can adapt to these changes to continue meeting the nation’s needs. Indeed, recent surveys of employers and graduates and studies of graduate education suggest that many graduate programs do not adequately prepare students to translate their deep, technical knowledge into the skills and expertise needed across the full range of STEM-related careers.

This report proposes a U.S. graduate STEM education system that better enables students of all backgrounds to meet the highest standards of excellence in 21st-century STEM fields and to use their knowledge and sophistication across the full range of STEM-related occupations to address global societal needs. Building on the strengths of the current graduate enterprise, the report describes the attributes of an ideal STEM graduate education system, identifies core educational competencies for both master’s and Ph.D. students that are common across all STEM fields, and recommends a broad range of changes in the graduate education enterprise to make the system more student-centric and better prepare students for the careers that lie ahead.

AN IDEAL STEM GRADUATE EDUCATION SYSTEM

An ideal, student-centered STEM graduate education system would include several attributes that are currently lacking in many academic institutions. In an ideal STEM graduate education system:

- Prospective graduate students would be able to select their graduate program aided by fully transparent, easily accessible data about costs incurred and viable career pathways and successes of previous students, at the level of the institution and its departments.



- Students would acquire broad technical literacy coupled with deep specialization in an area of interest. As they acquire this knowledge base, students would have multiple opportunities to understand better and to learn to consider ethical issues associated with their work, as well as the broader implications of their work for society
- Students from all backgrounds would fully participate and achieve their greatest potential during their educational experience through institutional actions to enhance diversity and promote inclusive and equitable learning environments.
- Students would encounter a variety of points of view about the nature, scope, and substance of the scientific enterprise and about the relationships between science, engineering, and society, and they would be encouraged to understand and grapple with differences of opinion, experiences, and ideas as part of their graduate education and training.
- Students would have opportunities to communicate the results of their work and to understand the broader impacts of their research. They would have opportunities to present their work and have exposure to audiences outside of their department, ranging from peers in other departments to the broader scientific community and nontechnical audiences.
- Students would be encouraged to create their own project-based learning opportunities—ideally as a member of a team—as a means of developing transferable professional skills such as communication, collaboration, management, and entrepreneurship.
- Students would be encouraged and given time and resources to explore diverse career options, perhaps through courses, seminars, internships, and other kinds of real-life experiences.
- Graduate programs and departments would develop more efficient channels for students to communicate with the administration and faculty regarding processes and decisions that affect graduate student education.
- Graduate programs would develop course offerings and other tools to enable student career exploration and to expose students to career options.
- Institutions would help students identify advisors and mentors who can best support their academic and career development. Faculty advisors would not stigmatize those who favor nonacademic careers.
- Institutions would provide faculty with training, resources, and time both to improve their own skills as mentors and to provide for quality mentoring and advising to the graduate students they supervise.

In order to fulfill the Ideal STEM Graduate Education system, students should have the opportunity to obtain the following core competencies in their master's or Ph.D. program.

CORE COMPETENCIES FOR THE STEM MASTER'S DEGREE

These elements should be common among all STEM 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.
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, learn about and understand the importance of research responsibility and integrity, and engage in work-based learning and research in a systematic manner.

CORE COMPETENCIES FOR THE STEM PH.D. DEGREE

These elements should be common among all STEM Ph.D. programs:

1. **Develop Scientific and Technological Literacy and Conduct Original Research**
 - a. Develop deep specialized expertise in at least one STEM discipline.

- b. Acquire sufficient transdisciplinary literacy to suggest multiple conceptual and methodological approaches to a complex problem.
- c. Identify an important problem and articulate an original research question.
- d. Design a research strategy, including relevant quantitative, analytical, or theoretical approaches, to explore components of the problem and begin to address the question.
- e. Evaluate outcomes of each experiment or study component and select which outcomes to pursue and how to do so through an iterative process.
- f. Adopt rigorous standards of investigation and acquire mastery of the quantitative, analytical, technical, and technological skills required to conduct successful research in the field of study.
- g. Learn and apply professional norms and practices of the scientific or engineering enterprise, the ethical responsibilities of scientists and engineers within the profession and in relationship to the rest of society, as well as ethical standards which will lead to principled character and conduct.

2. *Develop Leadership, Communication, and Professional Competencies*

- a. Develop the ability to work in collaborative and team settings involving colleagues with expertise in other disciplines and from diverse cultural and disciplinary backgrounds.
- b. Acquire the capacity to communicate, both orally and in written form, the significance and impact of a study or a body of work to all STEM professionals, other sectors that may utilize the results, and the public at large.
- c. Develop professional competencies, such as interpersonal communication, budgeting, project management, or pedagogical skills that are needed to plan and implement research projects.

KEY RECOMMENDATIONS

Achieving what the authoring committee sees as the ideal, modern graduate STEM education will require substantial cultural change throughout the system. The system must become more student-centric and must increase the value it places on best practices of mentorship and advising. Educating students at the master's level must take a higher priority. The mind-set that seems to most heavily value preparing students at the Ph.D. level for academic research careers must readjust to recognize that some of the best students will not pursue academic research but will enter careers in other sectors, such as industry or government.

These cultural changes will only come about if there are changes in the incentive system that appears to drive so much of academia. The current system is heavily weighted toward rewarding faculty for research output in the form of publications and the number of academic scientists produced. It must be realigned to increase the relative rewards for effective teaching, mentoring, and advising. Unless faculty can receive increased support, training, and recognition for their contributions to graduate education—and changing the incentive system is critical in that regard—the status quo will remain. With these challenges in mind, the committee urges all relevant stakeholders—federal and state policy makers, colleges, universities, employers, faculty and administrators, students, national scientific and educational organizations, advocacy groups, and the public who supports and benefits from advances in STEM fields—to unite behind the recommendations in this report and, going forward, to continuously assess whether STEM graduate education in the United States is meeting the needs of both a fully modern science and technology enterprise and the nation it serves. Among the key recommendations are the following:

- **Rewarding Effective Teaching and Mentoring:** Advancement procedures for faculty, including promotion and tenure policies and practices, should be restructured to strengthen recognition of contributions to graduate mentoring and education.
- **National and Institutional Data on Students and Graduates:** Graduate programs should collect, update, and make freely and easily accessible to current and prospective students information about master's- and Ph.D.-level educational outcomes. In addition, to make appropriate future adjustments in the graduate education system, it is essential that comprehensive datasets about the system, its participants, and its outcomes be collected in a standard format, be fully transparent, and be easily accessible and transferable across multiple computer and statistical analysis platforms.

- **Ensuring Diverse, Equitable, and Inclusive Environments:** The graduate STEM education enterprise should enable students of all backgrounds—including but not limited to racial and ethnic background, gender, stage of life, culture, socioeconomic status, disability, sexual orientation, gender identity, and nationality—to succeed, by implementing practices that create an equitable and inclusive institutional environment.
- **Career Exploration and Preparation for Graduate Students:** Students should be provided an understanding of and opportunities to explore the variety of career opportunities and pathways afforded by STEM degrees.
- **Structure of Doctoral Research Activities:** Curricula and research projects, team projects, and dissertations should be designed to reflect the state of the art in the ways STEM research and education are conducted.
- **Funding for Research on Graduate STEM Education:** The National Science Foundation, other federal and state agencies, and private funders of graduate STEM education should issue calls for research proposals to better understand the graduate education system and outcomes of various interventions and policies.
- **Stronger Support for Graduate Student Mental Health Services:** Institutions should provide resources to help students manage the stresses and pressures of graduate education and maximize their success. Institutions of higher education should work with their faculty to recognize and ameliorate behaviors that exacerbate existing power differentials and create unnecessary stress for graduate students.

COMMITTEE ON GRADUATE STEM EDUCATION FOR THE 21ST CENTURY

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For More Information . . . This Consensus Study Report Highlights was prepared by the Board on Higher Education and Workforce based on the Consensus Study Report Graduate STEM Education for the 21st Century (2018). The study was sponsored by the Burroughs Wellcome Fund, the Institute for Education Sciences, the National Science Foundation, and the Spencer Foundation. Any opinions, findings, conclusions, or recommendations expressed in this publication do not necessarily reflect the views of any organization or agency that provide support for this project. Copies of the Consensus Study Report are available from the National Academies Press, (800) 624-6242; <http://www.nap.edu> or via the Board on Higher Education and Workforce web page at <http://www.nationalacademies.org/PGA/BHEW>.

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