GRADSCICOMM

REPORT AND RECOMMENDATIONS

Mapping the Pathways to Integrate Science Communication Training into STEM Graduate Education

COMPASS

COMPASS is a nonprofit organization dedicated to helping scientists build the communications skills and social capital they need to effectively engage in public discourse about environmental issues. We are a boundary organization founded in 2001 to offer targeted training and coaching to help researchers understand and effectively interact with policymakers and the media.

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SUMMARY

In 2007, Alan Leshner, then Chief Executive Officer of The American Academy for the Advancement of Science, wrote in an editorial in *Science*, “We need to add media and communications training to the scientific training agenda.” He continues, “If science is going to fully serve its societal mission in the future, we need to both encourage and equip the next generation of scientists to effectively engage with the broader society in which we work and live” (Leshner 2007). While some graduate students, faculty, administrators, granting agencies, and nonprofit organizations have enthusiastically embraced this charge, such efforts have largely been conducted in isolation and on the periphery of graduate education. To overcome systemic disincentives, such training must become an integral component of graduate education in the science, technology, engineering, and math (STEM) disciplines. Strong science communication skills will benefit the next generation of scientists wherever their career paths may lead, within or outside academia.

Achieving this vision will require changes in funding streams and institutional structures. This necessitates leadership at every level: from agencies and administrators to faculty and students themselves. This report provides a roadmap for achieving systemic improvements in providing science communication skills training to STEM graduates. We review the current state of science communication trainings offered around the country, offer case studies in success, and synthesize the expert opinions of scholars, trainers, and students.
We present five core recommendations for the federal agencies, funders, universities, and graduate leaders who hope to shape a strong scientific workforce for the future:

1. Expand access to science communication training
2. Foster a community of practice
3. Define core competencies in communication skills
4. Develop integrated evaluation practices
5. Create career incentive structures

We recognize that progress in these domains is likely to be asynchronous. What we already observe and hope to accelerate are complementary changes occurring at the level of funders, institutions, faculties, and graduate students themselves. This roadmap functions as a navigational guide, with the goal that each individual student will graduate having:

- Achieved proficiency in a set of core communication competencies common to all graduate students.
- Received opportunities for advanced training appropriate to their personal career goals (e.g. academia, science policy, or industry).

Recognizing that long-term national prosperity is dependent on innovation and technological advancements, the United States has significantly invested in STEM education. However, scientific knowledge cannot reach its full potential without a cadre of scientists who are effective communicators of their work. With this roadmap, we hope to foster culture change in academic science that will support the health, wealth, and well-being of future generations.

BACKGROUND

Newly minted scientists face unprecedented demands and opportunities in a world grappling with complex problems. The health and well-being of humanity urgently depends on the insights and solutions generated by academic science. Nationally, innovations from the science, technology, engineering and math (STEM) disciplines are a critical economic asset. While social media and open access journals are positive trends for interconnectivity and public accessibility, the simple availability of scientific knowledge alone cannot ensure its effective use in society. In fact, presenting scientifically sound information can deepen ideological divides around ideologically charged issues (D. Kahan 2010). The stakes have never been higher for dialogues among and between natural and social scientists, decision-makers, and the public. This reality challenges the next generation of researchers to train across disciplinary silos and to effectively share their knowledge with each other and with the broader world.

CHALLENGING CAREER PROSPECTS

In recent years, media coverage of the state of American research funding and employment prospects has painted a bleak scene:

> *"Traditional academic jobs are scarcer than ever. Once a primary career path, only 14 percent of those with a PhD in biology and the life sciences now land a coveted academic position within five years."* (Vastag 2012)
>
> *"The pattern reaching back to 2001 is clear – fewer jobs, more unemployment, and more post-doc work – especially in the sciences."* (Weissmann 2013)
>
> *"Many scientists hold out hope for a simple solution: more money. But the current U.S. Congress has no appetite to spend more — even on health research that has broad, bipartisan public support."* (Harris and Benincasa 2014)
>
> *"The problem is that any researcher running a lab today is training far more people than there will ever be labs to run. Often these supremely well-educated trainees are simply cheap laborers, not learning skills for the careers where they are more likely to find jobs — teaching, industry, government or nonprofit jobs, or consulting."* (Johnson 2014)

However, an estimated 1.1 million new and replacement jobs are expected to require a master's or PhD by 2022, a 17% increase over current positions (U.S. Bureau of Labor Statistics 2013). The specific skillset required in these careers will vary by discipline, industry, and organization, but will most certainly exceed the disciplinary expertise graduate education currently confers. Unfortunately, a recent survey found that more than half of graduate school deans reported being somewhat or very dissatisfied with their university's ability to support graduate student career goals and provide guidance, or preparation for nonacademic careers (Council of Graduate Schools and Educational Testing Service 2012). **The graduate students of today are not receiving training in all the professional skills they will need to succeed tomorrow.** We argue that science communication skills – defined throughout this report as the knowledge, skills, and attitudes involved in effectively transmitting complex or technical information - are crucial to achieving both personal and national goals.

INCREASING DEMAND FOR COMMUNICATIONS TRAINING

Most graduate student skillsets evolve as they progress through their classwork, research program, and into careers. Initially, they need to develop their knowledge base and to demonstrate their mastery of concepts and techniques. Communication skills are applied in synthesizing the relevant literature, writing papers, submitting project or fellowship proposals, and establishing their relationship with their advisors and committees. As they progress beyond the bounds of coursework requirements and begin to shape their research paths, students frequently find they must navigate situations of increasing ambiguity or conflict, requiring greater emphasis on interpersonal dynamics. Reconciling and managing competing demands, conceptualizing and securing funding for research, managing supervisory and collaborator relationships, and publishing and presenting results are all essential for successful careers within academia. Though the specific tasks may vary considerably, these abilities are equally important outside of academia. According to the annual survey conducted by the National Association of Colleges and Employers, the top three attributes employers seek in candidates are leadership, the ability to work in a team, and written communication skills (The National Association of Colleges and Employers 2014).

Though rigorous analysis is sparse, anecdotal evidence of demand among graduate students for training in communications skills abounds. We see this in broad trends, for example, in the scheduling assumption that large crowds are regularly drawn to the public engagement and science communication plenaries, symposia, and workshop sessions at the American Academy for the Advancement of Science's Annual Meeting. We see this appetite reflected in the programming decisions of other science conferences, such as the Ecological Society of America and the American Geophysical Union. More pointedly, we saw marked evidence of unmet demand for communication skills training when the first ComSciCon workshop (http://comscicon.com) hosted by Harvard and MIT received more than 700 applications for just 50 available positions. The 2013 National Science Foundation "Innovation in Graduate Education Challenge" confirms that interest in science communication is running high. The Challenge received over five hundred entries from masters and PhD students at 150 institutions across the country. Of these, 'transferable professional skills training' was by far the most commonly identified target for improvement. More than 50% of all entries discussed this issue, and science communication training was the single most common specific skill raised by graduate students (http://www.nsf.gov/news/special_reports/gradchallenge). Similar conversations continue on the NSF Graduate Education Forum (http://nsfgradforum.wordpress.com).

While the emphasis on developing communication skills is a recent development in some STEM disciplines, others, particularly medical fields, have a long-standing investment. Hulsman & Visser (2013) report that communication skills were designated as a core competency by the American Accreditation Council for Graduate Medical Education (ACGME) and by The Royal College of Physicians and Surgeons of Canada (RCPSC) in the 1990s. Decades of pedagogy, program development, and research into program effectiveness form a valuable foundation for integrating such skills into STEM graduate program curricula more broadly.

CONTEXT OF GRADUATE EDUCATION MODERNIZATION

In his first inaugural speech, President Obama signaled a commitment to educational reform, promising, "We will restore science to its rightful place and wield technology's wonders... And we will transform our schools and colleges and universities to meet the demands of a new age" (Obama 2009). While much of the national debate has focused on testing standards in elementary schools, higher education figures substantially in economic discussions and projections. A number of recent national reports and recommendations for graduate education reforms have highlighted key policy issues related to improving graduate student training. These include:

- *The Path Forward: The Future of Graduate Education in the United States,* Commission on the Future of Graduate Education in the United States (2010)
- *Pathways Through Graduate School and Into Careers*, Council of Graduate Schools (2012)
- *Biomedical Research Workforce Working Group Report*, National Institutes of Health (2012)
- *Research Universities and the Future of America*, National Research Council (2012)
- *Advancing Graduate Education in the Chemical Sciences*, American Chemical Society (2013)

Collectively, these reports identify low rates of PhD completion and fault a narrow focus on academic careers for the misalignment of graduate education with workplace, societal, and student needs. While the reports offer varied recommendations, they generally advocate transforming graduate education, training, and the associated federal support of graduate students. Although the National Institutes of Health (NIH) and National Science Foundation (NSF) fund the majority of graduate research and education (Tilghman et al. 2012), the distributed nature of science education is considerable, involving dozens of government agencies, hundreds of universities, and thousands of administrators.

Leadership from the White House Office of Science and Technology Policy (OSTP), which has a mandate to advise the President and Executive Branch and to lead interagency efforts to develop and implement sound science and technology policies and budgets, has helped catalyze coordination around graduate education reform. In 2012, the National Bioeconomy Blueprint's Request for Information process prompted the OSTP, NSF, and NIH to convene an informal Graduate Education Modernization Working Group (GEM-WG). Discussions were subsequently broadened to include groups such as the Department of Energy (DOE), the Smithsonian, the American Association of Universities (AAU), the Association of Public and Land-grant Universities (APLU), and the National Postdoctoral Association (NPA). Collectively, the informal discussion group considered requirements, possible actions, and outcomes for graduate education modernization. In 2013, the efforts of the GEM-WG were subsumed by the Federal Coordination in STEM Education (FC-STEM) Task Force, chartered by the National Science and Technology Council (NTSC) Committee on Science, Technology, Engineering, and Math Education (Blazey 2014).

The FC-STEM Task Force was tasked with creating a five-year strategic plan for STEM education, which outlined five Priority Goals (National Science and Technology Council Committee on STEM Education 2013):

1. Improve STEM instruction
2. Increase and sustain youth and public engagement in STEM
3. Enhance STEM experience of undergraduate students
4. Better serve groups historically underrepresented in STEM fields
5. Design graduate education for tomorrow's STEM workforce

In 2014, the FC-STEM Task Force convened an Interagency Working Group on this fifth goal, under the direction "Provide graduate trained STEM professionals with basic and applied research expertise, options to acquire specialized skills in areas of national importance and mission agency's needs, and ancillary skills needed for success in a broad range of careers". With leadership from NIH and NSF, the Working Group has three major strategies: 1) recognize and provide financial support to students of high potential; 2) provide opportunities for fellows' preparation in areas critical to the Nation; 3) combine and enhance mechanisms that evaluate the impact of fellowships to inform future federal investments. Initial deliverables are expected in early 2015 (Federal Coordination in STEM Education Interagency Working Group 2014).

The broader context for these discussions is an energetic conversation defining the challenges of science communication and offering advice to scientists who would engage. In the past five years, numerous popular books and countless blog posts, interviews, articles, keynote speeches, and workshops have sprung up to address the growing demand for advice. With such an enthusiastic community of practice, support and leadership at both administration-level and grassroots levels, and a skillset that can be leveraged across a broad variety of professional development issues, science communication is a singularly valuable and tractable target for initial investment in far-reaching graduate education reform.

LANDSCAPE ANALYSIS & WORKSHOP SUMMARY

In late 2012, COMPASS received NSF grant number 1255633, "A Workshop to Explore Building Systemic Communication Capacity for Next Generation Scientists." Known in shorthand and on twitter as #GradSciComm, the work comprises three major components, culminating in this report:

1. To assess the current landscape of science communication workshops, courses, and trainings available to graduate students in the STEM disciplines,
2. To convene a workshop of science communication trainers, scholars, science society leaders, funders, administrators, and graduate students, and
3. To provide concrete recommendations to agencies, institutions, and individuals for integrating science communication skills into STEM graduate education.

SCIENCE COMMUNICATION TRAINING INVENTORY

Between January 2013 and December 2014, we worked to capture a snapshot of the kinds of trainings available to STEM graduate students within their universities, at the annual meetings of their scientific societies, and through other independent events. We limited our search to programs intended to bolster the ability of scientists-in-training to effectively connect with non-peer audiences. To this end, we excluded both science writing programs designed to help researchers transition to careers as professional journalists as well as technical writing or grant writing workshops. Candidate programs ranged from hours to months in duration, taking the form of lectures, seminar series, webinars, intensive workshops, fellowships, and for-credit courses. Some are regularly offered year-to-year, while others are offered more sporadically or just happened once. Rather than attempting an exhaustive effort to catalogue the ever-changing landscape, our work was focused on identifying trends, consistent themes, and influential institutions and individuals.

We began with two existing directories of similar programs, the first compiled by Dr. Sharon Dunwoody and her colleagues at University of Wisconsin Madison, and the second by Dr. Patrick Logan at University of Rhode Island. These two provided a strong foundation for capturing university courses, allowing us to focus on non-credit earning programs. Our work had three stages:

1. Semi-structured snowball interviews to start mapping out the network of players;
2. A word-of-mouth and online crowdsourcing effort;
3. Longer interviews for program details.

All told, we are aware of more than forty workshops and training programs available to graduate students in the STEM disciplines, in addition to hundreds of university courses (see Logan 2014). Our list is available at http://compassblogs.org/gradscicomm-list. We find the national picture to be an uneven patchwork of offerings with large geographic and disciplinary variations in access to and depth of available university resources, private and government-funded programs, and self-organized events. It is perhaps even more important to note that even within a single university, offerings tend to occur in a haphazard and uncoordinated fashion, with little connection among programs or departments. **We encourage every institution to catalogue, publicize, and encourage collaboration among its own science communication programs as a critical first step in building capacity.**

In a positive sign, we found evidence of leadership at all levels in the higher education landscape. We highlight success stories and key lessons from established programs in three categories of case studies throughout this report:

- Top-down efforts led by deans, provosts, or other department leadership,
- Bottom-up efforts led by graduate students or their advisors,
- Independent efforts led by nonprofit, for-profit, or government entities.

Though we find that successful programs exist in many different structures and formats, they face similar challenges and share a number of factors that contribute to stability and longevity: strong leadership, innovative funding mechanisms, new training approaches, and faculty buy-in.

CASE STUDIES

BOTTOM-UP MODELS: STUDENT LEADERSHIP

We would like to thank Jessica Rohde, Clare Fieseler, and Ardon Shorr for their contributions to this case study.

At universities across the country, motivated graduate students have channeled their enthusiasm for science communication skills into self-organized curricula and entrepreneurial activities. These grassroots efforts take a variety of forms, but encounter similar challenges in creating and maintaining momentum. The need for validation, administrative champions, seed funding, and exit plans is captured by three successful grassroots programs: Engage, founded at the University of Washington; Public Communication for Researchers (PCR), founded at Carnegie Mellon University; and Scientists with Stories, founded at Duke University and University of North Carolina Chapel Hill.

Collectively, these students found that their stories of founding and growing their programs shared several thematic elements. The first was the emotional dimension of realizing that their priorities did not align well with their university's priorities. They report struggling with feelings of isolation, saying it was painful: "our vision of what it means to be a scientist did not match the values expressed in our education". The pressure to hide or dampen their passion felt like a denial of the spark of greater purpose in their ambitions. Research shows that issues of identity, security, and conflict, especially with advisors, are uniquely important to the mental health of graduates, many of who struggle to navigate intersecting roles and conflicting demands (Grady et al. 2013). Though the student leaders in the GradSciComm project note that their collective experience was not one of active resistance, but best characterized as "institutional inertia," the value of social support and supportive mentoring are clear.

The experience of designing courses for the first time, largely from scratch and without pay, was flagged as a shared hardship. During the volunteer phase of each program, students found it necessary to distribute the work across teams of three to five students. Even then, these highly motivated groups found it difficult to juggle the demands of creating content, finding funding, and navigating the bureaucratic systems that control funding and resources. They report in retrospect, "We suspect that much of our administrative struggle was born out of our own ignorance of university structures." In each case, internal faculty or staff champions who helped them orient to and find support in university structures were key.

Engage, Scientists with Stories, and PCR have each followed distinct paths toward viability and sustainability. Engage was operating entirely out-of-pocket for two years while PCR was able to secure seed funding of $500. Scientists with Stories was launched with a $5000 award from the Duke University and North Carolina at Chapel Hill Kenan-Biddle Partnership Grants. In each case, these initial investments allowed the programs to demonstrate proof of concept in the form of successful and visible content creation, as well as student interest and positive feedback. They were then able to move into a second stage of fundraising for amounts in the range of $10,000. These came from varying combinations of student government, departmental, college, and university-level sources, as well as private donors and crowd-funding campaigns. These investments allowed students to recruit new course instructors, invite higher-profile guest speakers, host live events, produce videos, and travel to conferences, which increased their profile, reach, and legitimacy. However, in each case, the search for funding support and partnerships took a substantial amount of time, which interfered with running the program.

	Engage	Scientists with Stories	Public Communication for Researchers
Initiated	2010	2011	2012
Format	For-credit course	Intensive workshops	Recurring workshop and seminar series
Focus	Public speaking, storytelling, and improvisational skills	Storytelling in visual formats	Broad variety of science communication skills
Duration	Ten three-hour classes over academic quarter	Stand alone seven-day workshops	As many as fourteen two-hour events over the course of two years
University	University of Washington	Duke University and UNC Chapel Hill	Carnegie Mellon University
Arrangement	Funded Teaching Assistantship position for student-run group	Initiated as student group, became independent 501(c)3	Student group transitioning to a campus center
Taught by	Students, featuring invited speakers	Students, contracted instructors	Invited speakers and faculty
Extras	Capstone 30 minute public lecture	Live storytelling, video projects for clients	Live storytelling, blog, reading group, science café
Founders	Cliff Johnson, Eric Hilton, Rachel Mitchell, Phil Rosenfield	Clare Fieseler, Rachel Gittman, Yasmin von Dassow, Heather	Jesse Dunietz, Adona Iosif, and Ardon Shorr
URL	www.engage-science.com	www.scientistswithstories.com	www.cmu.edu/student-org/pcr/about/index.html

Finally, each program has had to address the question of long-term sustainability. Engage secured year-to-year support in the form of a Teaching Assistantship from the Dean's Office of the College of the Environment at the University of Washington and has successfully survived the original founders' graduation thanks to a rotating leadership structure and board of advisors staffed by program alumni. Scientists with Stories was incubated by the University of North Carolina Morehead Planetarium and then transitioned to an independent, non-profit organization with the support of the University of North Carolina's Chancellor's office. PCR has found support within the Office of the Vice Provost for Graduate Education at Carnegie Mellon, and currently has a proposal under consideration for the creation of a Public Communication Center. In each case, the longevity of programs requires not just financial support but leadership planning and dedicated human resources.

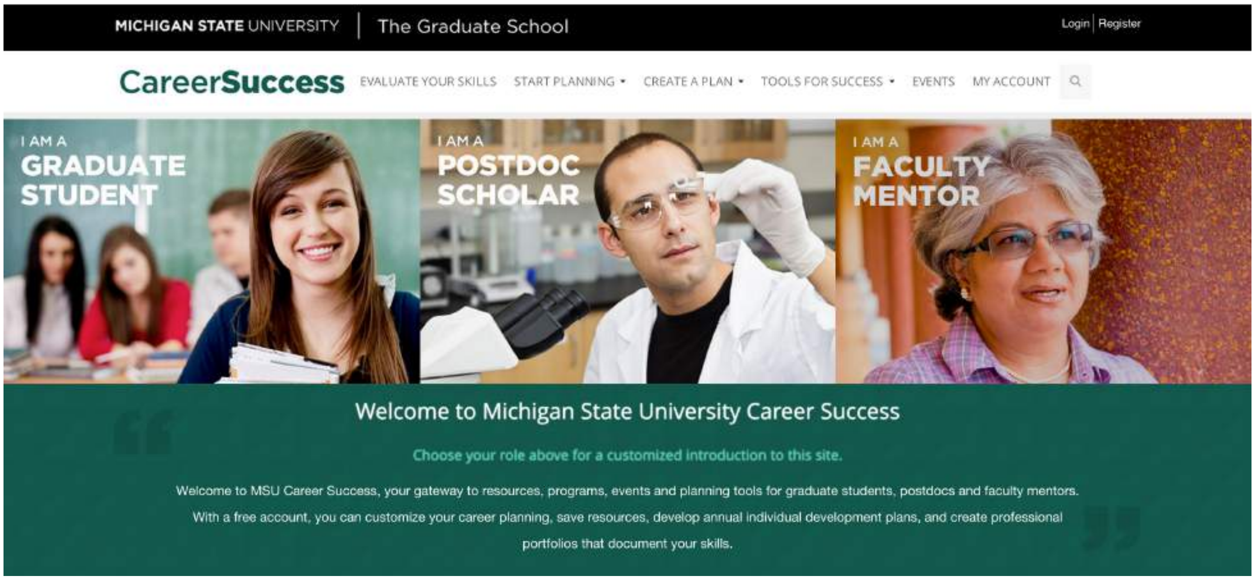
We applaud the initiative and tenacity of graduate students who throw themselves into creating the programs they need. Universities should foster this entrepreneurial spirit, listen to the concerns of their graduate student body, and support self-determination in supplementing and improving the curriculum.

INSTITUTIONAL MODELS: UNIVERSITY PROGRAMS

Since the 1970s, the overall tone of science and higher education discourse has shifted considerably. Instead of assuming that knowledge follows a linear flow from basic research through applied research into society, we understand that universities are important nodes in a lively network of knowledge creation. As the major themes of this report reflect, "stronger links between science and society through open exchange are advocated; participation and hybrid organizational forms are recommended; and evaluation and interdisciplinary research are fostered" (Krücken 2003). Yet, as is often the case, the rhetoric far outpaces the reality of institutional changes. Conflict, bureaucracy, and resistance to change can stymy even modest reform efforts, much less the considerable work we propose here. For professional development and science communication trainings, Michigan State University and Stony Brook University provide illuminating case studies in what is possible on campus and beyond.

Michigan State University (MSU)

In 2010, MSU won the second annual Award for Innovation in Promoting Success in Graduate Education sponsored by the Council of Graduate Schools and Educational Testing Service. Dr. Karen Klomparens, Associate Provost for Graduate Education and Dean of the Graduate School, accepted it for a project designed to bring together four projects across as many as ten departments. Among other goals, the award recognized their commitment to "developing professional development plans from the first semester of the doctoral experience through the early years of the first job placement; and providing writing development at key transition points in the doctoral program." (Woods 2010) Now, the MSU Career Success portal (http://careersuccess.msu.edu) provides an integrated platform for graduate students, postdocs, and faculty to access tools, resources, and events to: evaluate their professional skills; explore options for career pathways; create an individual development plan (IDP); strengthen their teaching, communication, and conflict management skills; and support their personal wellness.



The Michigan State University CareerSuccess Portal landing page has resources for graduate students, postdoctoral scholars, and faculty mentors. http://grad.msu.edu/rcr

Program materials acknowledge common concerns and address them constructively. With respect to IDPs, for example, "At first glance this appears to be another bureaucratic mandate that adds to the burden of faculty competing for grant funding. However a review of the literature on goal setting supports the view that the IDP is likely to serve as an effective mentoring tool." Furthermore, MSU has established faculty guidance for negotiating IDPs with students, and has tied IDPs directly to their Responsible Conduct of Research (RCR) program (http://grad.msu.edu/rcr). Other notable aspects of the logic behind the Career Success portal include the attempt to plan workshop offerings on a two year calendar, the creation of certificates that can go on student transcripts, and the scheduling of workshops at non-traditional times to accommodate student schedules.

Two other contributions to the culture of engagement at Michigan State are the tenure and promotion criteria adopted in 2001 and the Provost's annual Outreach & Engagement Measurement Instrument (OEMI) survey (Doberneck and Fitzgerald 2008; Glass, Doberneck, and Schweitzer 2008). Collectively, MSU has created an online platform and offline culture around communication as a professional skill that encourages strategic planning, evaluation, and ongoing discussion. Perhaps most importantly, they have explicitly aligned mentoring expectations and career incentives with stated goals. As Dr. Klomparens quips, "Sticks don't work with faculty, but carrots matter a lot to everyone." MSU is now working on disseminating this model through the Council of Graduate Schools, in publications, and in pre-conference workshops.

Stony Brook University

From 1993 through 2005, actor Alan Alda infused curiosity and humor into his hosting role for the PBS program Scientific American Frontiers. Throughout the filming, he noticed that the scientists he interviewed tended to freeze up and switch into an incomprehensible "lecture mode" when the cameras were turned on (McManus 2011). His task was to "coax them back" into warmer and more engaged conversations, often using his own genial curiosity to tap into shared excitement. At a film festival dinner in 2006, Alda met then-president of Stony Brook University, Shirley Strum Kenny, who was a literary scholar and enthusiastic audience for his ideas about making communication training a component of science education. Together, they hatched a plan that led to the creation of the Center for Communicating Science in conjunction with Brookhaven National Laboratory and Cold Spring Harbor laboratories in 2009 (Basken 2013). Located within the Stony Brook School of Journalism, the Center is led by a multidisciplinary steering committee of science and humanities faculty. The school officially renamed the center after Alda and honored him at a celebrity gala that raised over two million dollars for the program. The Alan Alda Center for Communicating Science (AACCS) now offers a large variety of coaching services, for-credit courses, free lectures, and fee-for-service workshops and conferences. Their priorities include curriculum development, program assessment, and establishing a clearinghouse and supportive network for best practices.

AACCS Director Liz Bass says, "Our aspiration is for every science graduate student to receive at least some formal training in communication skills" (Bass 2012). AACCS links these skills not just to public communication, but also to graduate teaching performance, which has spurred them to develop a new program focused specifically on Teaching Assistants. In Fall 2014, AACCS offered seven graduate-level courses through the Stony Brook School of Journalism. The curriculum is deliberately designed as "bite-size" modules to encourage students to explore everything from writing to video production to improvisational theater techniques. The multidisciplinary nature of training also helps build support, with participation by faculty from the natural sciences, engineering, and medicine, as well as journalism, theatre arts, and the writing program. Much of this content and approach is replicated in the more than twenty workshops AACCS staff led for faculty and students at other universities around the country in 2013 and 2014.

Finally, Stony Brook has created The Alda Center Summer Institute to build a network of affiliated programs and share their insights about how to design communication trainings. Since 2011, the annual three-day conference convenes researchers, communication specialists, and university administrators to experience core elements of the AACCS training and collectively learn how to find institutional champions, assess instruction methods, and manage evaluation and funding issues.

INDEPENDENT MODELS: EXTERNAL EXPERTISE

Over the past fifteen years, a small community of dedicated individuals, nonprofit organizations, and government programs has strongly influenced the science communication trainings landscape. In many cases, authors have collected the perspectives and advice from their lectures and workshops in popular books. Notable contributions include those by Cory Dean (Am I Making Myself Clear? 2009), Dennis Meredith (Explaining Research 2010), Randy Olson (Don't Be Such a Scientist 2009; Connection: Hollywood Storytelling Meets Critical Thinking 2013), and Nancy Baron (Escape From the Ivory Tower 2010). In this section, we highlight three prominent and ongoing training programs: COMPASS, the AAAS Communication Science Workshops, and NSF's Science: Becoming the Messenger series. Collectively, these three groups have trained some ten thousand American scientists.

	COMPASS	AAAS	Becoming the Messenger
Initiated	2000	2008	2010
Format	Short (half-day) and intensive (1-5 day) workshops; For-credit courses (University of Washington, Oregon State University)	Half-day and one-day workshops	Half-day, one-day, and two-day workshops
Typical group size	Varies - intensive workshops capped at 25	Varies – 10 to 100	Varies – 100+ on day 1, <20 for day 2
Available to	Universities, science conferences, fellowship programs	Universities, science conferences	Individuals in Experimental Program to Stimulate Competitive Research
Focus	Communication theory	Social media	Communication theory
Targeted audiences	Journalists, policymakers	General, journalists	General, journalists
Trainers	Nancy Baron, Liz Neeley, Heather Galindo, Karen McLeod, Chad English, Erica Goldman, Heather Mannix plus working journalists and/or policymakers	Tiffany Lohwater, Jeanne Braha	Ninja Communications - Joe Schreiber, Dan Agan, Chris Mooney
Website	COMPASSonline.org/communications/Trainings	AAAS.org/page/communicating-science-workshops	nsfmessengers.wordpress.com/about and http://ninjacoms.com

Although they employ different exercises and tools, the groups have each built their reputations by investing hundreds of hours of content development and refinement into agendas that blend sound scientific principles with experienced professional perspectives. COMPASS, AAAS, and the Becoming the Messenger workshops all share a number of features:

- **Transferable skills** – Although the workshops focus on a relatively small set of science outreach and engagement contexts, in each case trainers emphasize foundational skills and knowledge. If scientists can convey complex concepts in an effective and engaging manner, this supports them in everything from teaching, grant writing, and manuscript publication to media interviews, Congressional testimony, and public forums.

- **Audience orientation** – Many of the most urgent issues in science and society are also among the most contentious. Research shows that many scientists' most common tactics, such as introducing as much data as possible or debunking misinformation by highlighting errors, can inadvertently reinforce misunderstandings and exacerbate conflicts (e.g. Cook and Lewandowsky 2011; D. M. Kahan et al. 2012; Betsch and Sachse 2013). Furthermore, scientists tend to misunderstand public attitudes – despite available data – because they regard nonscientists as hostile "others" who are non-rational, ill-informed, and highly susceptible to media messages (Besley and Nisbet 2013). The workshops emphasize helping scientists understand their audiences because addressing these hostilities, building empathy, and understanding the psychology that underpins how people process information and determine what they believe to be true are essential components of planning effective communications.
- **Hands-on learning** – Finally, all the workshops are built around interactive learning and personal feedback, with special emphasis on role-playing in mock interview scenarios. In general, both students and teachers agree that hands-on activities increase both motivation and engagement (Bergin 2010). Specifically, role-playing exercises help students bridge theoretical and practical knowledge, while simultaneously learning skills for coping with nerves and performance anxiety. Workshop evaluations agree with published data indicating that students find role-playing to be one of the most valuable elements of communications trainings (Silva and Bultitude 2009).

GRADSCICOMM WORKSHOP

On December 5-6, 2013, COMPASS convened the #GradSciComm workshop, bringing together a select group of 30 science communication trainers, scholars, science society staff, funders, administrators, and graduate student leaders at the National Academy of Sciences in Washington, D.C. The group focused on how we might align incentives to give graduate students the motivation and permission to include science communication in their training. We identified that students will need to know what options are available to them and have tools at their disposal, such as individual development plans (IDPs), that allow them to tailor their skill development to their preferred career trajectories. The group also discussed the critical importance of monitoring and evaluation as a cornerstone of effective practice in communication training.

The workshop participants agreed that investing in integrating science communication into graduate training is justified by the benefits that accrue to individuals, to the research enterprise, and to society as a whole. At the broadest scale, improved science communication can serve society by improving education, increasing science literacy, and informing policy decisions. More proximally, it can help facilitate effective interdisciplinary science and collaboration. Finally, it can pay career dividends for individuals via improved grant writing, scientific publications, and technical presentations. Such communication and leadership skills increase the competitiveness of candidates within academia as well as in many alternate science careers. We construct our theory of change around this core proposal of multiple, nested benefits of science communication training.

THEORY OF CHANGE

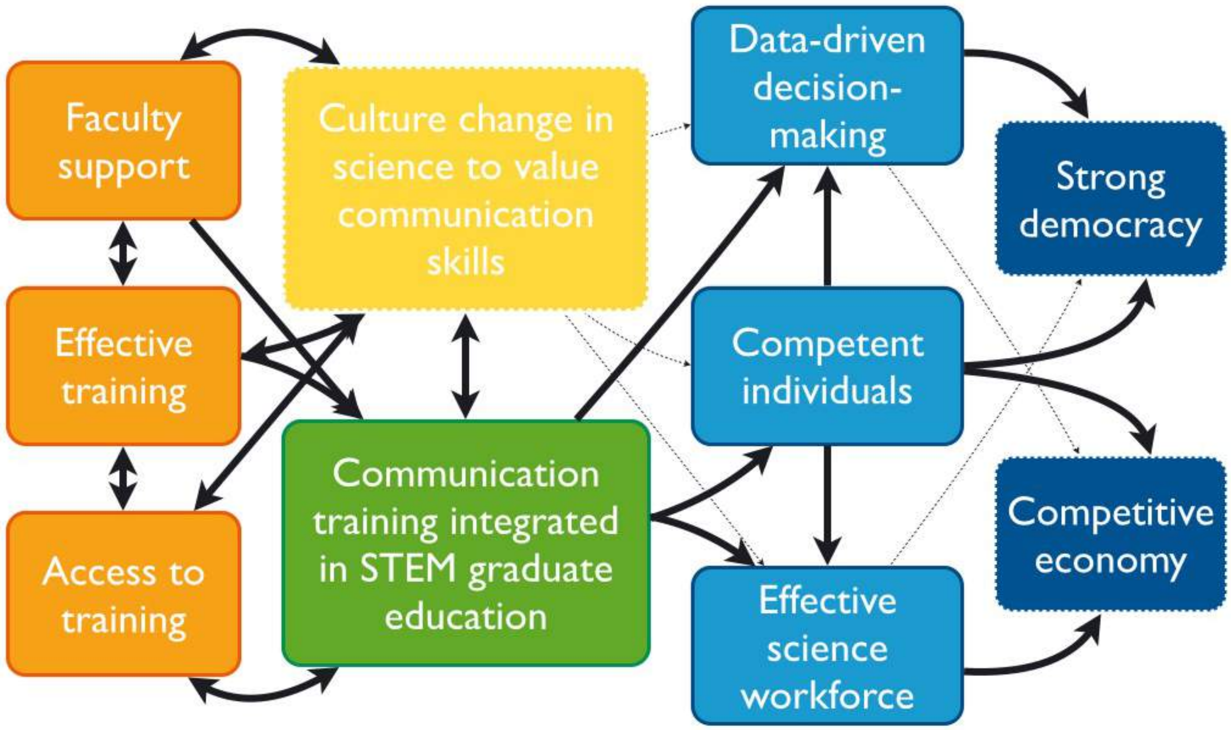
Science is an integral element of a functioning democracy, and it functions as both an instrument and an object of public policy. Citizens of the United States engage in a social contract assuming that in return for taxpayer support, scientific research will produce knowledge and technology that directly enhance our individual and collective welfare. Critically, the social contract also depends on those citizens to perform a variety of civic duties, which explicitly include staying informed of issues and participating in the democratic process (U.S. Citizenship and Immigration Services 2014). We assume that being informed by the best available evidence and expert advice will help us, as a society, make decisions in service of public health, safety, and well-being.

In addition to ensuring our collective well being, we look to scientific progress to drive economic competitiveness and national wealth. In 2005, the National Academies received bipartisan requests from the US House of Representatives and Senate to conduct a formal study examining the current and future position of the United States in the global knowledge and technology enterprise. The resulting report, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* (Committee on Prospering in the Global Economy of the 21st Century: An Agenda for American Science and Technology 2007), argued that the nation's security and prosperity depend on maintaining scientific competitiveness. The report's four recommendations formed the basis of the 2007 America COMPETES Act (America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science Act, Public Law No. 110-69).

The ultimate goals in our theory of change are **a strong democracy and a competitive economy**. Incorporating science communication into STEM education at the graduate level creates three interrelated preconditions for these goals:

1. **Capable individuals** – holders of STEM graduate degrees are able to ensure that their knowledge and intent are accurately represented in the understanding and meanings audiences construe from their interactions;
2. **An efficient science workforce** – the process of discovery proceeds rapidly and efficiently because knowledge and information readily flow across disciplinary, professional, and institutional boundaries;
3. **Data-driven decision-making** – the best available information about costs, benefits, and consequences is valued and used to inform deliberations at every level, from individual choices to government policy.

We note that "increased scientific literacy" is a likely consequence of these conditions, if we define effective science communication as successfully "providing lay audiences with the information needed to demonstrate knowledge, make logical inferences, and show consistency in preferences" after Wong-Parodi & Strauss (2014). However, we have chosen to exclude 'scientific literacy' from our map of causal linkages and caution against the assumption that public antagonism, apathy, or disagreement with science can often be attributed to a knowledge deficit or solved by simply providing facts (see e.g. Bauer, Allum, & Miller, 2007; Nisbet & Scheufele, 2009).



The GradSciComm Theory of Change: building faculty support for, improving the quality of, and increasing access to science communication training as an integrated element of STEM graduate education will produce competent individual scientists, an effective science workforce, and data-driven decision-making, all of which contribute to a strong democracy and a competitive economy.

Ultimately, science is a human endeavor conducted by individuals interacting with others in the scientific community. As with any community of practice, science has a culture – implicit and explicit agreements about how we know anything, about how we decide what is worth knowing, and about how we add to our collective body of knowledge. When we consider how we achieve our three preconditions, we emphasize **the culture change** that must necessarily occur to allow for the integration of science communication skills into STEM graduate education. This means that beyond simply defining which skills and knowledge should be included, we must consider how they are positioned and linked among STEM professionals and educators by: values (the beliefs we collectively hold); identity (how members of the community see ourselves); and epistemology (how we make decisions and justify our choices). This approach is grounded in the 'epistemic frame' theory of learning (Shaffer 2004).

Finally, this leaves us with the obstacles and limitations to address in order to integrate communication skills into STEM graduate education. Although budget constraints and limited resources are common challenges for fledgling science communication programs, we have conceptualized funding as strategic filter for identifying priority investments, namely:

1. **Access to training** – the formal inclusion of science communication options in graduate programming;
2. **Effective training practices** – the quality of pedagogy in science communication offerings;
3. **Faculty support** – the permission and approval of graduate student advisors and mentors.

This report synthesizes pre-event interviews, workshop discussions, and group activities, as well as subsequent strategy and writing sessions with GradSciComm Project participants and advisors. From the broad consensus represented in those discussions, we offer five major recommendations to guide the financial and human resource investments necessary to achieve the goal of integrating science communication into graduate education:

1. Expand training access
2. Foster a community of practice
3. Define core competencies
4. Develop integrated evaluation
5. Increase career incentives

RECOMMENDATIONS

RECOMMENDATION 1: EXPAND TRAINING ACCESS

Provide access to formal communication training opportunities for all STEM graduate students.

While most graduate education programs target the cognitive and technical skills required in STEM disciplines, emotional and communication skills are gaining wider recognition for their contributions to leadership and career success. Although associated traits like charisma and innate abilities vary from person to person, communication skills can be improved with a combination of training, feedback, and practice (Silva and Bultitude 2009; Berkhof et al. 2011). Training is particularly important since people tend to chronically overestimate their communication effectiveness (Keysar and Henly 2002; Kruger et al. 2005; Keysar 2007), and not only does communication ability not improve with time and experience alone (Moore et al. 2013), it may even degrade (Ha et al. 2010).

Our snapshot of communication trainings and courses suggests that graduate students encounter wildly variable access to communication resources depending on their department, discipline, university, and geographic location. While not all students require or will take advantage of the expertise and coaching available to them, all students should have the ability to enroll in graduate-level coursework and/or professional development programming.

IMPLEMENTATION ACTIONS:

- ***Require Individual Development Plans (IDPs)***
- ***Catalogue and publicize existing institutional offerings***

- ***Support collaboration and outsourcing while building institutional capacity***
- ***Develop or modify funding mechanisms***

Graduate programs should strongly encourage every doctoral student to complete and periodically update an Individual Development Plan (IDP). An IDP is an iterative tool designed to help users:

- Consider their existing skills, interests, and future academic and professional needs;
- Communicate their concerns and goals with their mentors; and
- Develop a personalized plan for developing their skills, and track their progress.

Each institution should customize their IDP template in accordance with their offerings and expectations, but a standardized version is available at http://myidp.sciencecareers.org. The myIDP tool was developed by a collaboration of the Federation of American Societies for Experimental Biology (FASEB), the Medical College of Wisconsin, the University of California, San Francisco (UCSF), the American Association for the Advancement of Science (AAAS), and Science Careers. It was supported by the Burroughs Wellcome Fund, which also provided support to this project.

As career planning tools, IDPs have generated considerable support among research-training institutions and have been formally endorsed by the American Chemical Society, NIH, The National Postdoctoral Association, and others. For graduate students, they are particularly valuable in supporting self-reflection and encouraging an ongoing conversation about needs and progress with advisors and committee members. Similarly, aggregated IDPs could provide useful data about student demand and support curriculum decisions at the department and university level.

In the immediate future, graduate students should use IDPs as a mechanism for defining the full array of training options currently available to them. Based on national trends, we anticipate that webinar or workshop offerings such as those provided by scientific societies like AAAS, programs like NSF's Becoming the Messenger, or nonprofit organizations like COMPASS, will be needed to supplement institutional capacity in the near term (see Case Study #3). Over time, these external programs should evolve to focus on innovations, for example bridging theory and practice or offering more specialized skills. Ultimately, if science communication competencies are to become a routine expectation of STEM graduate education, the responsibility for providing basic knowledge and skills is incumbent on universities.

Institutions might allocate resources for these programs by making them part of the research enterprise or by making them part of the curriculum. Course offerings could be embedded within science departments, offered through communication or arts departments, or centralized in dedicated institutes. We encourage every institution to catalogue, publicize, and encourage collaboration among its own science communication programs as a critical first step in building capacity. Given the reliance of graduate funding mechanisms on research grants, changes to educational programming are likely to have significant financial ramifications and require close coordination among university administrators, development offices, and program officers. Federal agencies and private funders should explore competitive "graduate program grants" focused on support for educational program innovation.

As with the process of science itself, sharing the results of educational experiments is essential. Well-connected knowledge networks support efficient innovation (Hua and Wang 2014) and are therefore a priority when resources are limited. This brings us to the next recommendation.

RECOMMENDATION 2: FOSTER A COMMUNITY OF PRACTICE

Improve connections among trainers, faculty, and administrators to enhance the exchange of knowledge and best practices for how to teach science communication skills.

The phrase 'community of practice' arises from influential work on learning as a social process, rather than one that happens inside an individual brain (Lave and Wenger 1991). The term continues to evolve, but its foundational premise is that adults learn from interactions with other people during the application of concepts in context. We define a community of practice as a group of people with a common interest in a topic that interacts on an ongoing basis to solve a shared set of problems and advance a domain of expertise. Communities of practice support participants in four ways (Hoadley 2012):

1. Connections – helping individuals identify and connect to others;
2. Content – providing access to shared repositories of information;
3. Conversation – offering both structures and technologies that facilitate discussions;
4. Context – providing awareness of the context of information resources.

Through the GradSciComm project, we have identified an informal and poorly connected network of individuals and organizations currently offering science communication trainings for STEM graduate students. Their interest in connecting to each other should be supported so the network can transition to a robust community of practice, in which knowledge is *personalized* via increasing member participation and connectivity, and is *institutionalized* via the creation and compilation of archived resources.

IMPLEMENTATION ACTIONS:

- ***Support both technology and social infrastructure***
- ***Create and connect networks of individuals online and off***
- ***Collect and curate resources***

Communities of practice are dynamic social entities with needs that vary as they emerge and mature. Formally, these phases include: Inquiry, Design, Prototyping, Launch, Grow, and Sustain (Wenger, McDermott, and Snyder 2002). The GradSciComm workshop, interviews, and relationship cultivation have initiated the Inquiry stage. The Design and Protoyping stages will need to define activities, technologies, group processes, and roles, and then test assumptions and refine choices as necessary to gain commitment to a single, national network. This work has implications for both technology platforms and the human capital needed to create community coherence.

Subgroups are a natural feature of healthy communities (Andriessen 2005) and we encourage their development around specific issue areas like data visualization or risk perception. However, communities of practice are subject to certain network effects – for some measures like total degrees of separation or robustness, a single large network can be much more valuable than several separate smaller networks. To reduce duplication and increase efficiency, we encourage funders and agencies to champion and support a single collaborative undertaking over multiple, competing efforts. One promising candidate is Trellis, a free, online platform being developed by AAAS to support communication and collaboration across the scientific community (Woodley 2015). This effort follows years of investment in formal training and community convening around the issues of science communication and community engagement. Scheduled for a beta launch by the end of 2014, the development of the platform was informed by network theory and practices, audience research, and dialogues with other professional societies. An alternate model of resource aggregation and peer learning is the Informal Science Education Evidence wiki (http://informalscience.org/research/wiki). Hosted by the Center for the Advancement of Informal Science Education (CAISE), the wiki hosts an online community and collection of project descriptions, evaluation reports and products, and research materials. The resource collection is particularly notable as a dissemination tool because while many informal engagement activities are evaluated or assessed, the results are generally not published in formal outlets. The rigor, resources, and reach represented by the Trellis platform and CAISE wiki offer a benchmark for the national community of practice we envision.

However, for as vital as virtual communities are in bridging geographic distance, in-person convenings remain a powerful means for deepening personal connections and strengthening a shared sense of identify. User resistance to new knowledge management systems can be traced to their perceptions of high switching costs, a lack of personal rewards, and a bias toward the status quo (Kim and Kankanhalli 2009). We encourage a blended strategy of online and offline connection opportunities to increase trust and status incentives, and reduce the psychological resistance and perceived burden of involvement.

A vigorous community of practice focused on how to teach science communication skills will galvanize knowledge sharing, learning, and organizational change. Given the wildly interdisciplinary nature of science communication approaches and academic debate about its validity as a discipline (Gascoigne et al. 2010), one of the first critical tasks for the community will be to build consensus around a shared set of expectations about what, exactly is meant by "teaching science communication skills".

RECOMMENDATION 3: DEFINE CORE COMPETENCIES

Define essential science communication knowledge and skills, so students achieve minimum proficiencies and institutions can identify and fill key needs.

In education, the concept of competency is the premise that professionals must possess specific knowledge, skills, and abilities to be properly qualified for their work. Competency-based programs have attracted considerable buzz, and were legitimized in 2013 when the Department of Education approved the award of federal student aid to students based on competencies, rather than credit-hours (Field 2013). The emphasis a competency approach places on performance, rather than on abstract knowledge or merely hours of instruction, makes it particularly useful for communication training. Though defining and demonstrating competencies can be complex, they are particularly compelling in the context of effectiveness and accountability. Extensive theoretical and practical guidance are available from the fields of medicine, psychology, and engineering, where competency-based education and assessment are already the norm.

One of the most striking findings of the GradSciComm project was the broad and inconsistent set of definitions of what science communication training is intended to achieve. Our initial attempt to categorize content revealed a pastiche of skills (verbal, written, graphic), audiences (K12, lay public, journalists), and channels (live events, social media, video). At the GradSciComm Workshop, we sought greater consistency via an exercise to elicit, prioritize, and rank essential skills. Participants generated the following priorities:

1. Knowing your audience (including social science constructs)
2. Providing context (explaining the salience, or "so what?")
3. Using language appropriately (avoiding jargon)
4. Using narrative appropriately (storytelling)
5. Writing clearly

Whether these are valid or appropriately ranked requires much deeper vetting. Those teaching workshops, trainings, and courses should work with academics in the discipline to develop consensus and make the core expertise of science communication explicit.

IMPLEMENTATION ACTIONS:

- ***Develop consensus around foundational and functional competencies***
- ***Involve education planners***
- ***Integrate with Individual Development Plans (IDPs)***

From competing for funding to expectations for public engagement, large-scale social and technological trends increasingly require STEM graduates to be better equipped and more broadly educated than before. Investing in the integration of science communication into STEM graduate education requires consistency about what, exactly, is expected of such training and how success is measured. Previous work has shown that practical skills-focused exercises are more valued by trainees and easier for trainers to deliver (Miller and Fahy 2009), but that the most common focus of training is in basic communication theories and models (Besley and Tanner 2011). We need to establish agreement around minimal expectations for:

- Knowledge – the concepts, theories and foundational information
- Skills – the application of theory to hands-on practical tasks.
- Attitudes – the values and judgments that underpin analysis, evaluation, and synthesis

Discussions would further benefit from following the American Psychology Association in building a "culture of competence" (Roberts et al. 2005) by distinguishing between cross-cutting foundational competencies and functional competencies that are related to specific roles or tasks (Fouad et al. 2009; Rodolfa et al. 2005). Arriving at those determinations should be the outcome of a large-scale deliberative process involving science communication practitioners, educators, and scholars.

Defining core competencies as we recommend here is amenable to, but does not require, implementing a full competency-based education system. Individual institutions and programs should find their own best solution, like incorporating the learning goals defined by our competencies into their existing standards-based approaches, for example. Implementing any kind of education reform is time- and resource-intensive, and requires expert knowledge to appropriately design theoretical and program-specific models (Dilmore, Moore, and Bjork 2011). We encourage institutions to explore existing resources such as the Competency-Based Education Network (C-BEN at http://www.cbenetwork.org/) and The Center for the Integration of Research, Teaching, and Learning (CIRTL) Network (http://www.cirtl.net/).

Regardless of formal structures, focusing on competencies requires a focus on the progress of individual learners. Some will need more instruction or practice to develop a satisfactory level of competence; others may find better success with different sequencing of knowledge and skills. We argue that this is precisely the kind of conversation that implementing individual development plans (IDPs) is intended to support. The specificity and personalization of a competency-based IDP may be particularly valuable for the graduate students for whom English is a second language. Finally, a competence-driven approach to science communication training will likely shift emphasis away from end-of-term assessments and require instructors to continually evaluate their students' progress, and develop interventions to help those who are not achieving competence. These can be very difficult conversations, and all involved might reasonably worry about the rigor and fairness of such assessments. This leads to our recommendation about the need for rigorous evaluation practices.

RECOMMENDATION 4: INTEGRATE COMPREHENSIVE EVALUATION

Develop best practices in evaluating pedagogy and impact to continually improve student, instructor, and institutional performance.

Effective education requires the continuous consideration of two fundamental questions: How well are students learning? How effectively are instructors teaching? (Dooley and Lindner 2002) For the task of integrating science communication skills, we argue that the questions expand to include: Do the skills we teach achieve their intended communication impacts? To illustrate, consider clarity in writing as one instance of a communication skill to be developed. We should be able to evaluate investing in this skill at multiple levels:

1. **Impact** – Does clarity in written materials demonstrably improve metrics such as audience comprehension and/or retention?
2. **Teaching** – Does a specific training program demonstrably improve students' ability to write clearly? (Summative evaluation)
3. **Learning** – How is an individual student progressing on dimensions of clarity, use of jargon, readability, and type of explanation? (Formative evaluation)

To date, existing survey data suggest that few science communication training programs conduct any evaluation at all, and those that do typically focus on feedback about instructor skill or course organization, rather than evaluating learning outcomes (Baram-Tsabari and Lewenstein 2012). We found the same pattern in our discussions and interviews for the GradSciComm project. We heard a large degree of community agreement on the need for collaboration with evaluators and social scientists in theory, but very little of it happening in practice. While evaluation seems universally acknowledged as a best practice, and participants indicated awareness that relevant networks, frameworks, and professional evaluators do exist, they explained their lack of implementation citing concerns about the high perceived costs and questionable return on value, as well as a lack of personal knowledge and connections to these resources. We note that prevailing social norms likely play a role as well – given the perceived costs and challenges, trainers are unlikely to invest in evaluation as long as it remains rare among colleagues and competitors.

IMPLEMENTATION ACTIONS:

- ***Foster interdisciplinary collaboration***
- ***Strengthen evaluation requirements for funding***
- ***Provide funding support for evaluation***

Perhaps the largest barrier to the widespread adoption of evaluation practices is the fear that measuring communication skills is a fundamentally intractable problem. If trainers and practitioners believe that evaluation is impossible – or worse, somehow antithetical to the creative and human endeavor of communication – then discussions of implementation and incentives are futile. First we must establish that it can be done and that it is valuable to do.

There are very few assessment tools in circulation within the science communication training community. We are aware of only three:

- A comprehensive writing assessment instrument (Baram-Tsabari and Lewenstein 2012)
- A quantitative measure for the proportion and obscurity of jargon in written or verbal formats (Sharon and Baram-Tsabari 2014)
- The Presentation Skills Protocol for Scientists (Tankersley, Bourexis, and Kaser 2013)

Fortunately, the published literature of other STEM disciplines provides an untapped wealth of material. Health care providers must ensure the effective transfer of technical information and assessments of risk and uncertainty, often in terribly urgent and emotionally fraught conversations. With lives on the line, the moral and legal obligations of ensuring professional competency are top priorities for individual doctors, nurses, psychologists, and others as well as for practices, hospitals, insurance companies, and teaching institutions. We should undertake interdisciplinary reviews and collaborations to inform the development of best practices in evaluation of science communication training programs.

Within the health sciences, the most common techniques for evaluating and tracking student communication skills are qualitative checklists and skills-ratings forms (Dooley and Lindner 2002). Specific descriptions of desirable behaviors ("behavioral anchors") are often included to improve the reliability and accuracy of scores. From reducing performance anxiety (Meyer et al.

2009) to increasing the ability to show empathy and ask open-ended questions (Moore et al. 2013), health provider communication programs have used evaluation to demonstrate their ability to improve trainee performance in emotional and subjective dimensions of social interaction. Furthermore, these programs have shown how the validity and application of a particular evaluation tool can improve over time (Donato et al. 2008), and how we can conceptualize and evaluate the process of teaching itself as a competency (Srinivasan et al. 2011). We should capitalize on the theoretical and practical work they have pioneered, while working to improve upon noted deficiencies, such as overcompartmentalization of skills, problematic research methodologies, and a lack of assessor training (Grant and Jenkins 2014; Holmboe and Hauer 2014; Berenbaum and Shoham 2011).

At all levels, evaluation requires time, technical skill, and financial support. Across all sectors, administrators are often challenged to sufficient funding for evaluation efforts, which sets up perceived tradeoffs and perverse incentives. Accordingly, if funders and program officers desire effective evaluation for communication training programs, they must consider the dual task of writing requirements into their grant solicitation language as well as providing adequate funding to support it to be conducted. In both instances, we can look to the National Institutes of Health as a model. For example, the Broadening Experiences in Scientific Training (BEST) initiative is funded through the Common Core to provide support for institutions to develop novel ideas in training and workforce development (National Institutes of Health Office of Strategic Coordination 2014a). The BEST awards require rigorous evaluation of each individual award, including clear logic models and data collection plans. Applicants are expected to propose the most appropriate type of evaluation for their program, as well as contributing specified data to the BEST program's overall evaluation plan. The work can be performed by either internal or external evaluators, depending on the needs of the institution (National Institutes of Health Office of Strategic Coordination 2014b). At NIH, the Evaluation Set-Aside Program provides a key source of funding for program evaluations. More information is available from the Office of Program Evaluation and Performance at http://dpcpsi.nih.gov/opep/evaluation. Funding requirements and allocations tend to directly shape grantee outcomes, and they can also indirectly shape the behavior of the community overall. The role of, and need for, incentives is the focus of our final recommendation.

RECOMMENDATION 5: INCREASE CAREER INCENTIVES

Recognize and reward student, faculty, and institutional investment in communication training.

Any discussion of changes to STEM graduate education must consider both practical and cultural dimensions. Even if all the necessary infrastructure and resources were somehow immediately available to officially integrate science communication skills into curricula, a lack of faculty buy-in would stall or undermine the effort altogether. As supervisors, as issue authorities, and as role models of what it means to be successful in a discipline, faculty wield tremendous influence. Their attitudes and day-to-day habits are powerful social signals, because graduate training is not only the *explicit technical knowledge* imparted in the formal curriculum, but also the *implicit professional norms* inculcated in the myriad informal contexts of graduate school. These often run counter to each other. Negative consequences of the informal or "hidden curriculum" are well documented in the medical realm, as manifested in increases in cynicism and decreases in empathy and academic honesty measures among students as they progress through their training (Hafferty 1998; Dyrbye, Thomas, and Shanafelt 2005; Michalec and Hafferty 2013).

In the GradSciComm project and related literature reviews, we found extensive concern about advisor/advisee relationships (e.g. Hyun et al. 2006; Salguero-Gomez, Whiteside, and Talbot 2008; Kuehne et al. 2014). Multiple participants shared personal experiences of students actively hiding their enrollment in communication training courses or workshops from their advisors. There is some evidence that a lack of explicit support for engagement activities is at least as important as explicit disapproval (Andrews et al. 2005). Faculty buy-in is essential for the successful integration of science communication training into STEM graduate education. We must acknowledge and address legitimate concerns about what this entails, and we must create meaningful incentive structures for students, advisors, and their institutions.

IMPLEMENTATION ACTIONS:

- ***Create competitive grant programs***
- ***Recognize excellence within university, scientific societies, or communities of practice***
- ***Revisit key policies, legislation, and tenure and promotion criteria***

Across a wide variety of disciplines, calls for reform are remarkably consistent in their themes and recommendations, and communication skills play a central role. If we are to escape a perpetual cycle of "reform without change" (Matson, Davis, and Stephens 2014), then rhetoric and good intentions must be reinforced by potent incentives. As in our evaluation recommendation above, incentives must be considered at multiple levels. Even the process of accurately identifying – much less confronting – systemic obstacles is likely to be contentious (Hafferty 1998) and in need of incentivizing. Ultimately, if communication skills are to be truly integrated into STEM graduate education, then these skills must be explicitly acknowledged in professional values, modeled by faculty in daily life, and rewarded in meaningful ways. Beyond mere buy-in, this will require faculty leadership.

For universities, one common mechanism for eliciting ideas and inviting participation is to administer a competitive internal grants process to fund faculty, staff, or student initiatives. While those who gain support generally like these processes more than those who are denied, incentive grant programs seem relatively successful in capturing the attention of faculty and attracting additional external funding (Powers 2000). A review of institutional grants to foster interdisciplinarity found that "episodic financial incentives are important but not sufficient to cause lasting change" (Sá 2007). Given the importance of even small amounts of seed funding to grassroots projects (see Case Study #1), we also support the continuation of programs like the NSF "Innovation in Graduate Education Challenge". At the other end of the spectrum, admissions and program reform can benefit from recognition and visibility as well, like the Council of Graduate Schools' Award for Innovation in Promoting Success in Graduate Education (http://www.cgsnet.org/etscgs-award-innovation-promoting-success-graduate-education-admission-through-completion).

Similarly, we recommend taking steps to recognize individuals who are already acting as leaders, champions, and role models in science communication, such as the students and advisors identified in Case Studies #1 and 2, or simply those who embody the skillsets. CV-worthy designations should be awarded at multiple scales, including departments, universities, and professional societies. Perhaps the most powerful incentive is when such measures of communication excellence are directly incorporated into career advancement, such as those in recent revisions to the promotion and tenure recommendation guidelines at the University of Wisconsin-Madison Faculty Division of Biological Sciences (Division of Biological Sciences 2014) and the University of Illinois-Urbana Champaign (Office of the Provost 2011).

There are two areas of faculty attitudes related to science communication for which specific incentives should be explored:

- **Time**: The single most common concern among scientists considering their own engagement activities, as well as faculty advisors regarding their students', is the time investment (Andrews et al. 2005; Ecklund, James, and Lincoln 2012). Whether adding communication training requirements will lengthen time to degree is a legitimate question. It is possible that developing communication skills might speed the process of dissertation writing, or increase a student's scholarly impact (Liang et al. 2014), and Kuehne et al. (2014) propose strategies for distributing and managing communication activities over a graduate career.
- **Status** – A more pernicious aspect of resistance to embrace communication skills may be grounded in the fact that STEM disciplines feature powerful status hierarchies (Simonton 2006; Calhoun 2008; Morrison et al. 2010). Women are less likely to receive full-time faculty jobs, tenure, and full professorships as compared to men, and they earn less across all faculty ranks (Allan 2011). Women also conduct disproportionately more outreach and service work and such work typically commands relatively little prestige and respect (D. R. Johnson, Ecklund, and Lincoln 2014). If the legitimacy of communication activities is indeed contested along gender lines, it likely plays a role in graduate progress, letters of recommendation, and future job prospects. Minority students face similar disparities in career success, and intersectional studies demonstrate that women of color are the most disadvantaged in advisor support, particularly in interpersonal dimensions (Noy and Ray 2012). The work of disentangling and addressing these structural biases may be uncomfortable, but is essential for higher education institutions to reflect their true ideals.

Decision-makers should consider revisiting key policies to expand or reinforce pertinent requirements and incentives. For example, the "Responsible Conduct of Research" requirements could function as a model for adding "Responsible Communication of Research" to NSF's Broader Impacts Criteria (National Science Foundation 2013) and/or reauthorization of the America COMPETES Act (Gordon 2010). Of course, any such broad changes should consider community criticism and analysis of current grantee behaviors (e.g. Kamenetzky 2012). Administrators should also consider the structure of funding options. For example, the transition to traineeship models of graduate funding should ameliorate the financial disincentives for undertaking communication coursework, as discussed in Recommendation #1.

No matter what the specifics, in planning for communication skills training, it is critical not to impose unfunded mandates or inadvertently compromise funding for research programs (Linton 2013).

Finally, for as important as incentive structures are, we note that a considerable body of evidence suggests that they can have unanticipated and sometimes detrimental effects. In some cases, extrinsic rewards may “crowd out” intrinsic motivation and have a net negative impact by signaling that a goal is difficult, that the task is not attractive, that trust is lacking, or that social norms are not strong (Gneezy, Meier, and Rey-Biel 2011). The effectiveness of incentives depends on how they are designed, how they interact with intrinsic and social motivations, and what happens after they end. The need to comb a wide variety of literatures to understand these dynamics combined with recent findings on the importance of social networks (Valente 2012) reinforces our sense that the community of practice in Recommendation #2 will be important.

CONCLUSION

From late 2012 to late 2014, the GradSciComm Project gathered information about, and from, the leaders and organizers of science communication trainings, workshops, and courses for graduate students in the STEM disciplines. Our work culminates in a theory of change identifying current obstacles and hopeful outcomes for integrating communication skills into graduate training, as well as interventions to achieve this goal. We make five recommendations and suggest specific implementation options for:

1. Expanding training access
2. Fostering a community of practice
3. Defining core competencies
4. Developing integrated evaluation
5. Increasing career incentives

Across all themes we emphasize the importance of interdisciplinary collaboration with social scientists and the involvement of professionals who specialize in not just science communication but in pedagogy, program planning, education policy, and evaluation. We recognize that changes are necessary at the level of funders, institutions, faculty, and graduate students themselves. Further, we are clear that individuals have unique needs, reflecting the diversity of entry and exit points to graduate careers, as well as substantial differences across disciplines, institutions, and programs. This roadmap functions as a navigational guide, with the goal that each graduate student completes their degree having achieved proficiency in a set of core communication competencies and received opportunities for advanced training appropriate to their personal career goals. The integration of science communication into STEM graduate education will support a future in which well-trained scientists contribute to an efficient science workforce and informed decision-making processes to help improve the health and well-being of the nation and the world.

ACCESS						
Catalogue and publicize available training options	✓	✓	✓	✓		
Embrace individual development plans (IDPs)	✓	✓	✓		✓	✓
Organize trainings by external groups	✓	✓	✓	✓	✓	✓
Create institutional programming	✓	✓	✓	✓		
Transition funding model to graduate traineeships					✓	✓
COMMUNITY OF PRACTICE						
Create/support/ staff platforms			✓	✓	✓	✓
Participate in discussions	✓	✓	✓	✓	✓	✓
Curate resources	✓	✓	✓	✓	✓	✓
Create in-person opportunities to connect	✓	✓	✓	✓	✓	✓
CORE COMPETENCIES						
Convene interdisciplinary working group(s) to write report(s)			✓	✓	✓	✓

	Students	Faculty	Universities	Associations	Funders	Federal Agencies
CORE COMPETENCIES (continued)						
Participate in discussions about defining core skills	✓	✓	✓	✓	✓	✓
Update IDPs accordingly	✓	✓	✓			
COMPREHENSIVE EVALUATION						
Participate in discussions about evaluation expectations and implementation	✓	✓	✓	✓	✓	✓
Update funding requirements			✓		✓	✓
Provide funding support			✓		✓	✓
CAREER INCENTIVES						
Create competitive grant programs			✓	✓	✓	✓
Create awards for excellence and leadership	✓	✓	✓	✓	✓	✓
Consider revising tenure and promotion criteria		✓	✓			
Consider revised language in pertinent policies						✓

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