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Essay

Practical Science Communication Strategies for Graduate Students

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Abstract: *Development of skills in science communication is a well-acknowledged gap in graduate training, but the constraints that accompany research (limited time, resources, and knowledge of opportunities) make it challenging to acquire these proficiencies. Furthermore, advisors and institutions may find it difficult to support graduate students adequately in these efforts. The result is fewer career and societal benefits because students have not learned to communicate research effectively beyond their scientific peers. To help overcome these hurdles, we developed a practical approach to incorporating broad science communication into any graduate-school time line. The approach consists of a portfolio approach that organizes outreach activities along a time line of planned graduate studies. To help design the portfolio, we mapped available science communication tools according to 5 core skills essential to most scientific careers: writing, public speaking, leadership, project management, and teaching. This helps graduate students consider the diversity of communication tools based on their desired skills, time constraints, barriers to entry, target audiences, and personal and societal communication goals. By designing a portfolio with an advisor's input, guidance, and approval, graduate students can gauge how much outreach is appropriate given their other commitments to teaching, research, and classes. The student benefits from the advisors' experience and mentorship, promotes the group's research, and establishes a track record of engagement. When graduate student participation in science communication is discussed, it is often recommended that institutions offer or require more training in communication, project management, and leadership. We suggest that graduate students can also adopt a do-it-yourself approach that includes determining students' own outreach objectives and time constraints and communicating these with their advisor. By doing so we hope students will help create a new culture of science communication in graduate student education.*

Keywords: altimetrics, education, graduate training, outreach, professional development, science engagement, social contract, social media

Estrategias Prácticas para la Comunicación Científica para Estudiantes de Posgrado

Resumen: *El desarrollo de habilidades en la comunicación de la ciencia es un vacío bien conocido en el entrenamiento de posgraduados, pero las restricciones que acompañan a la investigación (limitaciones de tiempo, recursos y conocimiento de oportunidades) hacen complicado el obtener estas competencias. Más allá, los asesores y las instituciones pueden encontrar difícil el apoyar adecuadamente a los estudiantes de posgrado en estos esfuerzos. El resultado son menos beneficios sociales y de carrera porque los estudiantes no han aprendido a comunicar efectivamente la investigación más allá de sus colegas científicos. Para ayudar a superar estos obstáculos, desarrollamos un acercamiento práctico para incorporar la comunicación amplia de la ciencia en cualquier línea de tiempo de posgrado. El acercamiento consiste en un portafolio que organiza actividades de alcance a lo largo de un cronograma de estudios de posgrado planeados. Para ayudar a diseñar el portafolio, mapeamos las herramientas de comunicación científica disponibles de acuerdo a cinco habilidades núcleo esenciales para la mayoría de las carreras científicas: redacción, oratoria, liderazgo, manejo de proyecto y enseñanza. Esto ayuda a los estudiantes de posgrado a considerar la diversidad de*

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las herramientas de comunicación basándose en sus habilidades deseadas, restricciones de tiempo, barreras de entrada, público objetivo y metas de comunicación personales y sociales. Al diseñar un portafolio con la contribución, dirección y aprobación de un asesor, los estudiantes de posgrado pueden calibrar cuánto alcance es apropiado, dados sus otros compromisos con la enseñanza, la investigación y las clases. El estudiante se beneficia con la experiencia y tutoría del asesor, promueve la investigación del grupo y establece un registro de compromiso. Cuando la participación del estudiante de posgrado en comunicación científica se discute, frecuentemente se recomienda que las instituciones ofrezcan o requieran más entrenamiento en comunicación, manejo de proyecto y liderazgo. Sugerimos que los estudiantes de posgrado también puedan adoptar un acercamiento de hazlo-tú-mismo que incluya determinar las metas de alcance y restricciones de tiempo del propio estudiante y poderlas comunicar con su asesor. Al hacer esto, esperamos que los estudiantes ayuden a crear una nueva cultura de comunicación científica en la educación de posgrado.

Palabras Clave: Alcance, altimetría, compromiso científico, contrato social, desarrollo profesional, educación, entrenamiento de posgrado, medios sociales

Introduction

The goal of communicating scientific research with diverse audiences is rooted in many scientists' desire to share their knowledge in order to fuel discovery and encourage science literacy (Pace et al. 2010). Recently, these overarching motivations have been more formally stated as a social contract between scientists and the wider world to accelerate solutions to some of our most pressing environmental issues (Lubchenco 1998). Graduate students (and their faculty advisors) often cite time constraints as the primary obstacle to participating in science communication. The general presumption is that to be successful students and early-career scientists must focus on learning to conduct high-quality research, making the additional time and energetic demands of outreach, education, and service prohibitory (Andrews et al. 2005). However, not only is this an unsatisfying situation for many young scientists—who are often motivated by a desire to contribute—but it does not allow them the professional benefits associated with learning how to communicate broadly their own and others' research (Jensen et al. 2008; Baron 2010*b*). Further, important societal benefits go unrealized when graduate students do not engage due to constraints such as lack of time, information, or institutional support (Salguero-Gomez et al. 2009).

We believe graduate students have an important role in science communication but concurrently have insufficient resources to navigate this daunting process. For this reason, we developed a practical approach for students to learn and practice science communication during their graduate tenure in the biological sciences. Although there are many ways to define science communication, we refer to engaging with the public and promoting conversations about scientific research in ways that acknowledge and respect differences in values and perspectives (i.e., a public-engagement vs. a deficit model) (Nisbet & Scheufele 2009; Groffman et al. 2010). We considered the benefits and opportunities to graduate students and determined tools and strategies for student engagement in science communication given a student's goals and time constraints. We present examples of effective training programs that are available to graduate students and early career scientists. We developed a portfolio approach to integrating science communication into a graduate-school time line with the goal of embedding a suite of training skills into the culture of graduate school. Our overarching goal is to empower more students to overcome barriers and incorporate broad science communication into their graduate education.

Societal Benefits of Broad Science Communication by Graduate Students

A goal that many scientists share is to help develop a scientifically literate public capable of participating in complex health, environmental, and socio-economic decision making. However, traditional science communication pathways, via conference presentations and peer-reviewed publications, fail to reliably deliver information to the general public and policymakers (Shanley & López 2009; Suleski & Ibaraki 2010; Hansen 2011). A misconception persists among scientists that interactions with the public may lead to misunderstanding and conflict (Weigold 2001; Ecklund et al. 2012), but in reality sustained relationships between scientists and environmental stakeholders foster greater public access to, and trust in, the sciences (Lach et al. 2003; Pace et al. 2010). Scientists who actively engage the public can make scientific information available and more compelling to a broader spectrum of society (Nisbet & Scheufele 2009) and establish 2-way avenues of communication between scientists and stakeholders (Roux et al. 2006; Smith et al. 2013). By eliminating barriers among academic, public, and political communities, scientists can promote incorporation of science into social and environmental policy making (Meyer et al. 2010) and thus narrow the gap between research and implementation (Roux et al. 2006; Arlettaz et al. 2010; Cook et al. 2013).

Participating in science communication as a graduate student has immediate benefits of reaching nonacademic

audiences, and it serves as an important training tool for science communication later in a career (Newing 2010). More than just a preparatory exercise, however, graduate students contribute to societal benefits of science communication and even provide additional benefits for audiences not commonly targeted by mid- and late-career scientists. For example, graduate students are perhaps best suited to connect with a younger social demographic and inspire the next generation of scientists (Messinger et al. 2009). As mentors for elementary, high school, and undergraduate students, graduate students can help recruit into STEM (science, technology, engineering, mathematics) fields (Quimby et al. 2007) and enhance scientific literacy among young audiences (Beck et al. 2006). In addition, graduate research is often (though not always) highly relevant to local ecosystems or organisms; as such, graduate students may be well positioned to communicate research in the local environment to managers and the public (Pace et al. 2010). For these reasons, we believe graduate students are uniquely poised to interact with young students, local managers, and the public to achieve both research goals and societal benefits of science communication.

Benefits of Science Communication to Graduate Students

Desire to contribute to society is often a leading motivator for graduate students to engage in science communication (COSEE New England 2003; Andrews et al. 2005), but there are also appreciable professional benefits in doing so (Messinger et al. 2009; Salguero-Gomez et al. 2009). Communicating science to the general public can expand and improve writing and speaking skills, while engaging in citizen science or outreach programs will develop teaching, leadership, and management abilities (Milliman 1996). These skills are integral to most scientific careers, and developing these skills during graduate school can enhance one's marketability in the future (Cannon et al. 1996; Blickley et al. 2012; Linton 2013).

Engaging in science communication can also earn graduate students cumulative career benefits, including increased funding opportunities and recognition from peers. Establishing a record of science communication early in a career can support successful grant applications with funding agencies, such as the National Science Foundation, that value "broader impacts," including whether research promotes learning, broadens dissemination, and benefits society (Messinger et al. 2009). Furthermore, communicating effectively with the general public requires scientists to understand the perspective of their audience and frame their message in relevant ways (Groffman et al. 2010), a practice that will also improve communication with other scientists (Baron 2010*b*). Finally, science communication helps graduate researchers create networks with other scientists and environmental stakeholders, which then promotes innovative collaborations and interdisciplinary research (Pace et al. 2010; Fox 2012). Given the opportunities for career advancement, we believe the time devoted to science communication is a valuable investment.

Important personal benefits are also available to graduate students who engage in science communication activities. The first is simply confidence that comes from mastering diverse communication skills; this is especially useful given the variety of career paths in research, education, and policy that are available to graduate students in the sciences (McBride et al. 2011). Second, graduate and faculty researchers consistently cite fun, satisfaction, and enjoyment as substantial motivations for outreach, education, and service activities (Andrews et al. 2005; Salguero-Gomez et al. 2009). Members of our own lab (collectively the authors include 3 master's and 2 PhD students, 1 postdoctoral researcher, 1 research scientist, and 1 early career professor) find that the immediate feedback about their research that comes from engaging in science communication is a reinvigorating contrast to the (relatively) slow appreciation arising from the process of research, peer-review, and revision (e.g., Kareiva et al. 2002). Although it is difficult to truly quantify the importance of fulfillment and motivation, we believe they hold significant value for demanding careers in the sciences.

By participating in science communication activities over several years, graduate students in our lab have enjoyed many of the benefits outlined. However, we have found that resources for effective science communication are overwhelmingly targeted at established researchers and late career faculty. For example, guides to science communication (e.g., Baron 2010*a*; Meyer et al. 2010) provide advice for approaching members of Congress about policy matters or working with the media, but graduate students are more likely to interact with local agencies, special interest groups, and nonprofit outreach organizations. Furthermore, although models of high quality training in science communication certainly exist for graduate students, our own review of these opportunities indicates they are often in the form of highly competitive fellowships or require relatively large commitments of time or funding, circumstances that discourage widespread participation during graduate tenure. Combined with a lack of consensus as to whether and how graduate students should participate in these activities, we believe a majority of students in the sciences are navigating this important question without adequate guidance and support (Cannon et al. 1996; Newing 2010). To begin addressing these resource gaps, we developed a flexible, practical approach for students to learn and practice science communication during their graduate tenure that includes both do-it-yourself communication tools and examples of effective science communication training programs that are available to early career

scientists. Our approach accounts for realistic constraints as well as differences among students in interest or desired outcomes from science communication.

Development of Core Skills through Science Communication

Through a review of the science communication literature, we identified 5 core skills essential to most scientific careers: writing, public speaking, leadership, project management, and teaching (Cannon et al. 1996; Newing 2010; Blickley et al. 2012). Students invariably practice communicating their research with other scientists (typically through writing and, to a lesser extent, public speaking), but they may not have opportunities to develop important complementary skills in leadership, teamwork, and project management simply by completing their graduate program (DeNeef 2002; Blickley et al. 2012). Project management in particular (defined as the process of leading and implementing mission related projects) was identified as the most sought-after skill within government, nonprofit, and private job sectors (Blickley et al. 2012). Science communication offers students opportunities to develop these skills and helps them gain a competitive advantage in challenging job markets (Milliman 1996). We mapped our 5 identified core skills to available science communication tools according to recent treatises on the topic (Baron 2010*a*; Groffman et al. 2010; Bik & Goldstein 2013) and estimated time investments and certainty of reaching intended audiences (barriers to entry) for each communication tool based on our collective experience with science communication. We present this system for selecting tools as a table of traditional and nontraditional communication options, grouped by type of outlet (e.g., print vs. electronic media) (Table 1). This information is intended to assist graduate students in choosing from among the diversity of communication tools based on their desired skills, time constraints, barriers to entry, target audiences, and personal and societal communication goals.

Written communication and speaking are among the most important skills for young scientists to master; they are also the top ranked qualities expected in job applicants of biology departments in academic institutions (Fleet et al. 2006). As a matter of course, graduate students may be expected to write articles for publication in scientific journals and give presentations at conferences, but the reach of those forms of communication is generally limited to other scientists in the field (Suleski & Ibaraki 2010). By contrast, less traditional tools such as maintaining a personal website or contributing to a blog can improve writing skills while allowing nonscientists to access student research directly (Bik & Goldstein 2013). Choosing to give a presentation to a management agency, special interest group, or the general public allows students to develop their speaking skills and practice formulating their research message for different audiences (Nisbet & Scheufele 2009). Students who particularly wish to improve their writing and speaking skills may be able to effectively pair science communication efforts with courses offered through their institution (Table 2) (e.g., Newing 2010). Alternatively, national or even international training opportunities exist through nonprofit organizations (Table 2) that teach scientists to skillfully communicate their research to diverse audiences (Osmond et al. 2010; Cook et al. 2013; Smith et al. 2013). These types of opportunities are currently being assembled into a widely available database through an NSF-funded initiative (#GradSciComm; E. Neeley, personal communication).

Teaching, project management, and leadership skills are also critical to achieving success in many scientific careers (academic and nonacademic); however, these skills may remain underdeveloped after completing a traditional graduate degree (Blickley et al. 2012). Science communication and outreach can thus fill an important gap in graduate training (Milliman 1996). For example, mentoring undergraduates requires graduate students to practice leadership and teaching. Other science communication options, such as participating in or developing hands-on outreach activities, will develop time and project management skills. From implementing an experiment to managing a research team, these transferable skills are necessary regardless of career choice and stage in the sciences.

In addition to desired skills, we present key factors—namely time investment and barriers to entry—students can consider when evaluating potential communication tools (Table 1). The constraint that will be obvious to most students is time availability. In Table 1, we indicate relative time investments required to use tools or groups of tools, but recommend that graduate students also research the demands of specific opportunities. Less intuitively, the barriers to entry (i.e., likelihood that one's communication effort is distributed to the intended audience) may also influence one's ability to engage. Investing time in writing an article for a magazine, for example, does not guarantee the article will be published. By contrast, personal blogs and twitter accounts have low barriers to entry but potentially reach a smaller or unintended audience (Bik & Goldstein 2013). These trade-offs between time investment and barriers to entry can serve as additional criteria to help students tailor a personal approach to science communication.

Students may also select communication tools based on a target audience. A student's career goals or field of research may influence selection of a target audience, and certain tools lend themselves to reaching particular audiences. For example, in our freshwater ecology lab we direct our communication toward resource managers, recreationists, and conservation groups. Effective ways to reach these audiences include (respectively) agency talks and contributing to special interest newsletters and

Table 1. Science communication tools available to graduate students.[a]

Communication tool	*Core skills[b]*	*Time investment[c]*	*Certainty of outlet*	*Personal benefits*	*Societal benefits*
Electronic media					
website and social media	W	low-med	high	audience feedback (comments, email inquiries)	public interaction with scientists
innovative media (podcast, YouTube)	S	med-high	high		
personal blog	W	med-high	high		
contribution to widely read blog	W	low-med	med		
Print media					
letter to editor	W	low-med	low	raise awareness of the issue	disseminate scientific knowledge
opinion article	W	med-high	low		
print or specialty article	W	med	low		
Policy communications					
agency talk	S	med-high	med	networking	integrate science and management
newsletter for agency	W	med	med		
contact policy makers	W, S	high	med-high	increase notoriety	shorten pathway from science to policy
Traditional public outlets					
talk to special interest group	S	med	med	gain anecdotal evidence	improve volunteer conservation outcomes
newsletter for special interest group	W	med	med		
public talk	S	med	low-med	increase trust in your science	increase trust in your science
newsletter for public	W	med	med-high		
interview with university media	W, S	low	high	raise your profile as a researcher	illuminate and humanize science
interview with local media	W, S	med	med		
interview with national media	W, S	high	low		
Education and outreach					
educational programs	S, L	med-high	low-med	reinvigorate your research	inspire future scientists
hands-on outreach programs	S, L, M	low-high	med-high		
citizen science	S, L, M	med-high	med	gain data and resources for your research	increase public investment in science
crowdfunding	W, S, M	med-high	high		
teach or assist teaching	T, M	high	high	sense of fulfillment	improve science education and enrollment
mentoring	T, L	med-high	high		

[a]*Students may choose tools based on their desired outcomes (i.e., core skills, personal, or societal benefits) or on scheduling constraints (i.e., time investment and barriers to entry).*
[b]*Abbreviations: L, leadership; M, management; S, speaking; T, teaching; W, writing.*
[c]*Range of time investment and barriers to entry (i.e., likelihood that one's communication effort is distributed to the intended audience), depending on involvement (e.g., leading vs. participating) and scale of impact (e.g., local vs. national). Ranges are based on our assessment and are presented in relative terms; it is recommended that students additionally research specific opportunities they are considering.*

blogs; use of these tools helps develop the skills needed to communicate with these groups. Although the appropriate audience for communication of research may be known, students should be aware that audiences can differ greatly in their stylistic expectations of communication (Nisbet & Scheufele 2009). As scientists, for example, we are trained to present information as background, methods, results, and implications, but this organization will miss the mark for many public audiences, media, and policy makers, for whom results and implications

Table 2. Examples of effective science communication training programs available to graduate students and postdoctoral researchers.

Program	*Intended career stage*	*Time investment*	*Description*	*Science communication training and skills emphasis*
Courses and workshops				
COMPASS	all career stages	low	Scientists work with a team of communication professionals to improve the reach and scope of their research.	Workshop participants learn to communicate their research effectively to both scientific and nonscientific audiences.
ComSciCon, Harvard University	graduate students	low	During workshops, organized for and by students, participants deliver speed talks about their research and write and post articles online intended for a general audience.	Students learn to write and speak about their research to a lay audience. Select online magazines, such as Scientific American Guest Blog, publish short articles written during the workshop.
ENGAGE, University of Washington	graduate students	medium	In a seminar series, students learn storytelling, public speaking skills, and audience perspectives through presentation of their own research to the general public.	Students develop skills in translating their research for general and diverse audiences. Connects members of the public to local research and provides students with opportunities to get feedback.
Michigan State University Graduate School	graduate students	low	Students can take a range of short workshops geared toward development of leadership and diverse communication skills.	Participants learn skills relevant to careers outside academia, including those that allow them to convey information effectively to broad audiences.
Ready, Set, Go, Northwestern University	graduate students and postdoctoral researchers	medium	Students practice communication skills through improvisation, storyboarding, and public speaking.	Students build confidence in public speaking and self-expression while crafting a message that connects their research to a target audience.
Stony Brook University Alan Alda Center for Communicating Science	all career stages	low-medium	The center offers workshops, such as Improvisation for Scientists, and Using Digital Media, and graduate courses in science communication.	Workshops teach students the skills they need to communicate emotions that motivate them to do research and provide training in science writing, creating blogs, and recording podcasts.
Fellowships and collaborative research opportunities				
Emerging Leaders in Science and Society, American Association for the Advancement of Science (AAAS)	graduate students	medium-high	Prepares students to address complex challenges in society by providing hands-on volunteer programs in the areas of energy and environment and health and well-being.	Students interview experts and stakeholders about a real-world issue and collaborate on a project aimed at informing the public. Participants develop communication skills for diverse audiences and entrepreneurship.
Mass Media Science and Engineering Fellowship, AAAS	graduate students and postdoctoral researchers	medium-high	Summer internship program that places students and researchers in science, technology, engineering, and mathematics disciplines to work with national media organizations.	Through working as reporters, researchers, or editors, participants gain the practical skills needed to communicate their research through media.
Media Fellowship, British Science Association	all career stages	medium-high	Places scientists in media organizations to work with a professional journalist in national press, broadcast, or online media.	Scientists help journalists produce accurate and informed news pieces and learn the journalistic process. Journalists and scientists form relationships.

Continued

Table 2. Continued.

Program	*Intended career stage*	*Time investment*	*Description*	*Science communication training and skills emphasis*
Sustainability Leadership Fellowship, Colorado State University	graduate students and postdoctoral researchers	medium-high	Graduate and postgraduate students interested in communicating their science to the media and public are provided with training.	Students undergo professional development and acquire training in environmental communication.
David H. Smith Conservation Fellowship, Cedar Tree Foundation	postdoctoral researchers	high	Provides support for postdoctoral researchers at U.S. institutions who are pursuing applied conservation research.	Fellows receive mentorship and develop leadership and communication skills.
Liber Ero Fellowship, Liber Ero Foundation	postdoctoral researchers	high	Postdoctoral researchers study applied conservation issues relevant to Canada.	Fellows receive mentorship and develop leadership and communication skills.
Knauss Marine Policy Fellowship, Sea Grant	graduate students and recent graduates	high	Fellows work as staff of a member of the U.S. Congress or with a federal agency addressing issues in marine or Great Lakes resources.	Fellows gain policy perspectives and understand how research is integrated into decision making while working directly with policy makers, agencies, and the general public.

are generally more vital (Baron 2010*a*). Recognizing differences between audience expectations and learning to adapt communication accordingly is crucial to effectively reaching diverse audiences (Groffman et al. 2010).

In addition to the tools outlined above, graduate students who seek formal training in communication skills may participate in institutional training programs, such as for-credit courses at their universities. Although these opportunities are not yet widely available, institutions have begun to recognize the need to train students in communicating research outside of academia (Newing 2010; Linton 2013). Many universities, as well as government and nongovernmental organizations, have responded to this need by providing formal training courses and programs for graduate students and postdoctoral researchers to become leaders in science communication (Table 2). For example, the Engage Science Speaker Series and Seminar is a for-credit course at University of Washington that trains students to present their research effectively to the public, and the Sustainability Leadership Fellowship Program at Colorado State University provides doctoral and postdoctoral students with professional development and training in science communication. In addition, competitive fellowships (e.g., American Association for the Advancement of Science—Emerging Leaders in Science and Society, Sea Grant—Knauss Marine Policy Fellowship) allow students to learn these skills through real-world problem solving. In Table 2, we provide examples of effective, science communication programs, including short workshops, for-credit courses, and fellowships that are available to students and early-career researchers. These formal training programs, together with the do-it-yourself approaches outlined in Table 1, provide young scientists with a breadth of opportunities that support development of key communication skills.

The landscape of science communication is constantly changing, both in terms of available tools (Bik & Goldstein 2013) and ideas about the roles and responsibilities of scientists as communicators (Nisbet & Scheufele 2009; Marshall 2013). The process presented here is intended to assist graduate students in evaluating trade-offs in skills development, time investment, and barriers to entry, even as the science communication options evolve. Table 1 is a starting (not final) point for students to evaluate and tailor their own suite of preferred communication tools.

Integrating Science Communication into a Graduate Time Line

Once graduate students decide to engage in science communication and are prepared with an idea of their preferred time investment and the kind of interactions they seek, the next question is, where to start? Even with a good handle on the available communication tools, other barriers to engagement exist. Studies and surveys point to 3 main barriers to graduate student participation in communication and outreach: too little time, lack of information about opportunities, and no support from advisors (deKoven & Trumbull 2002; Andrews et al. 2005; Salguero-Gomez et al. 2009). Postdoctoral researchers and faculty cite the same 3 top barriers to science communication (the third is little to no departmental support) (COSEE New England 2003; Andrews et al. 2005). We have attempted to address the first 2 barriers by

presenting communication options, trade-offs, and examples of training opportunities. By pairing these with planning and communication, graduate students can overcome or reduce the third (critical) barrier of lack of support from an advisor.

The perceived lack of support from advisors is a striking element in studies of graduate student participation in science communication and outreach. In a 2008 survey of 260 student members of the Ecological Society of America (ESA), over half (57%) did not feel their advisor supported participation in activities that increased public environmental awareness (Salguero-Gomez et al. 2009). Other studies also show this is a widely held perception among graduate students (deKoven & Trumbull 2002; Andrews et al. 2005). However, in an interview survey of 48 graduate students and 12 faculty members at the University of Colorado Boulder, Andrews et al. (2005) concluded that rather than advisor indifference, lack of communication between advisors and students was to blame. The failure of advisors to explicitly bring up outreach was interpreted by students as lack of interest. Students responded by not discussing the subject, even to the extent of doing "outreach work on the sly without [their] advisor's consent." Although we acknowledge some advisors do not support students' engagement, in a majority of student–advisor relationships science communication may be suffering (ironically) from a breakdown in communication.

To aid open communication between graduate students and their advisors, we propose adopting a portfolio approach to incorporating science communication as part of a graduate degree (Fig. 1). This approach was developed based on our collective knowledge of typical graduate program time lines and communication expectations, as well as on recommendations from the literature and our experience with incorporating science communication activities into a graduate degree. Plotting outreach activities along a time line of planned graduate studies is a transparent way to communicate and tailor the desired skills and professional development to be achieved and, perhaps most importantly, the time investment in outreach activities throughout graduate school.

By communicating outreach goals to advisors, graduate students can reduce or eliminate the 3 major barriers to engagement. First, an investment portfolio approach will help mitigate the barrier of time commitment. Andrews et al. (2005) describe both graduate and faculty concerns that too much prioritization of outreach "is like doing 2 PhD theses in parallel." Students can help overcome these misperceptions by working with their advisors to develop a clear time line of communication goals (Fig. 1) that can be achieved with a manageable number of communication tools (Table 1) or formal training programs (Table 2). Ideally, these should be mutually agreed on and included in the thesis or dissertation proposal. By designing a portfolio with an advisor's input, guidance, and approval, graduate students can gauge how much outreach is appropriate given their other commitments to teaching, research, and classes (for examples of a low- or high-investment portfolio, see Fig. 1). Second, communication between faculty and graduate students regarding incorporation of outreach into a graduate road map will promote information exchange about outreach opportunities within a department. Andrews et al. (2005) found that word-of-mouth communication was a driving factor in faculty and graduate participation in many outreach activities. Finally, creating an outreach portfolio with an advisor provides an icebreaker opportunity for discussing the role of outreach in graduate studies and should help eliminate the third major barrier of minimal advisor support.

In addition to promoting a more transparent relationship, engaging advisors in science communication plans has highly practical benefits. The first is the benefit of the advisors' experience and mentorship. Even faculty who are strongly focused on their research and not actively pursuing science communication are likely to have some experience to share as a result of receiving requests from the media to comment on policy debates or requests to share their research with community members and special interest groups. Second, tremendous opportunities exist for graduate students to collaborate with their advisors on meaningful activities that forward the goals or mission of the research group. For example, in a lab doing research related to local ecosystems (e.g., a valued local species or cultural area), graduate students could initiate and update a lab blog to serve as a community educational resource. Alternatively, students and faculty involved in policy-related research might look for opportunities to write newspaper editorials or articles that deliver their research results to special interest groups or policy makers. The best suite of approaches—from blogging to crowd funding—depends on the research focus and target audience. Finally, collaboration promotes engagement and networking within a student's field of research, and the expertise of an advisor (or lab mates) is likely to result in more efficient and effective outreach (Morgan et al. 2008). A collaborative approach also allows advisors to more directly benefit from their students' activities by promoting lab research and establishing a track record of engagement (Milliman 1996).

Prospectus

The existing literature on strategies, benefits, and options for science communication is often geared toward established scientists or tenured faculty (but see Morgan et al. 2008; Salguero-Gomez et al. 2009). When graduate student participation is discussed, it is often

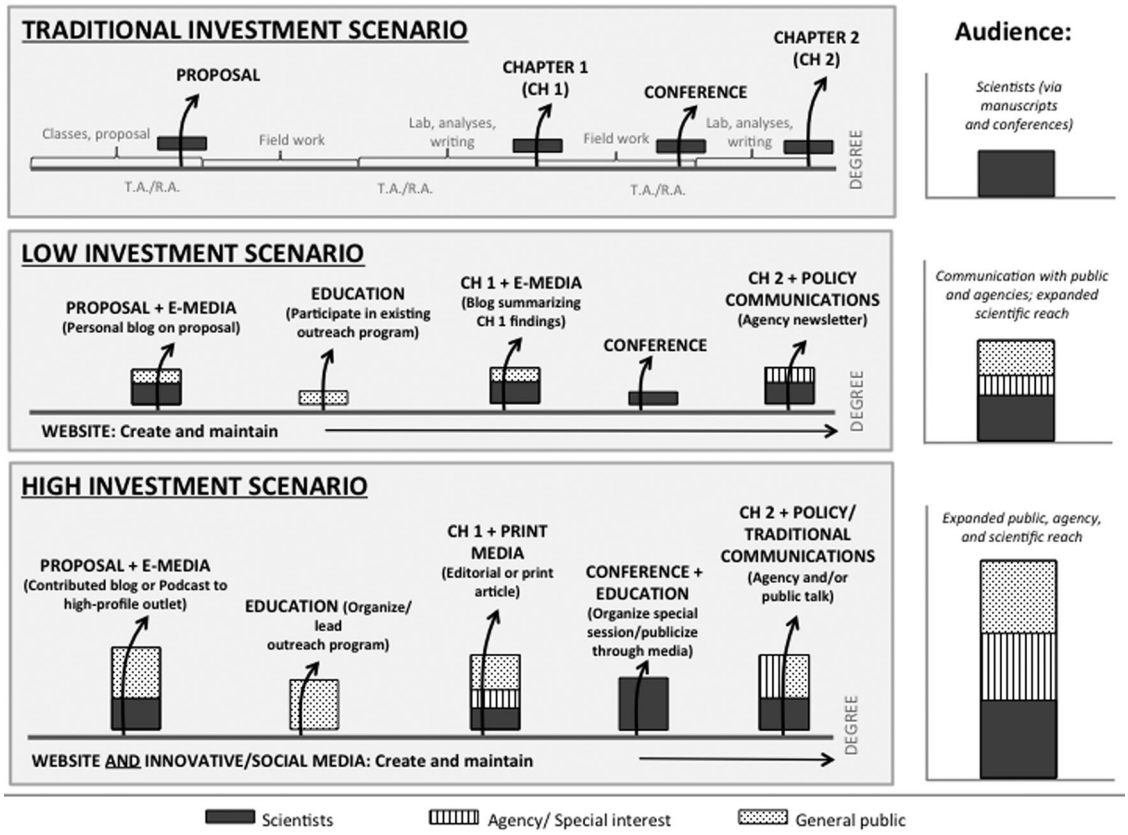

Figure 1. Three example portfolios (traditional, low, and high investment) of outreach activities plotted along a 2–3 year timeline of graduate studies to aid in communication and planning between students and advisors (CH, graduate thesis or dissertation chapter; R.A., research assistantship; T.A., teaching assistantship). The audience potential of each activity is represented as stacked bar plot.

to recommend that institutions offer or require more training in communication, project management, and leadership. We suggest that graduate students can adopt a do-it-yourself approach that includes determining students' own outreach objectives and time constraints and communicating these with their advisor(s) as an alternative or supplement to existing institutional training opportunities. This is not because we believe this path to be the ideal, and we do not wish to downplay the importance of programs and departmental initiatives that incorporate science communication into graduate training (e.g., NSF GK-12 programs, communication workshops, or interdisciplinary curricula [Table 2]). In fact, we strongly believe that science communication should be embedded in the culture of graduate education; that is, students should be supported (i.e., training opportunities) and rewarded (i.e., incentives) by their advisors and institutions for participating in this nontraditional academic realm (Smith et al. 2013).

We believe that encouraging participation and training in science communication—whether formally or informally—helps meet current challenges in graduate school modernization identified by organizations such as the Council of Graduate Schools (CGS), professional societies, and the National Science Foundation. A recent report by the NSF/CGS Dean in Residence, which synthesized key recommendations of industry, government agencies, and input from graduate deans, concluded that the future of graduate education should include "enhanced professional development" and preparation for diverse career paths (Linton 2013). Supporting science communication will help graduate schools meet the changing needs of their students and the institutions, industry, and agencies that will later employ them.

Recent calls have also highlighted a need to adjust the professional assessment criteria to account for changing modes of scholarly productivity (Shanley & López 2009; McDade et al. 2011; Piwowar 2013). Science communication is a form of graduate training and productivity that should be recognized without supplanting traditional forms of scientific output. However, the approach we outline offers graduate students manageable options for gaining science communication skills and experiences regardless of departmental support, which can be tailored to their interests and career goals. We

hope access to an expanded universe of communication tools and a concrete planning strategy will empower more students to overcome barriers to engagement and incorporate broad science communication in their graduate education.

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Literature Cited

Andrews, E., A. Weaver, D. Hanley, J. Shamatha, and G. Melton. 2005. Scientists and public outreach: participation, motivations, and impediments. Journal of Geoscience Education **53:**281–293.

Arlettaz, R., M. Schaub, J. Fournier, T. S. Reichlin, A. Sierro, J. E. M. Watson, and V. Braunisch. 2010. From publications to public actions: when conservation biologists bridge the gap between research and implementation. BioScience **60:**835–842.

Baron, N. 2010*a*. Escape from the ivory tower: a guide to making your science matter. Island Press, Washington, D.C.

Baron, N. 2010*b*. Stand up for science. Nature **468:**1032–1033.

Beck, M. R., E. A. Morgan, S. S. Strand, and T. A. Woolsey. 2006. Volunteers bring passion to science outreach. Science **314:**1246–1247.

Bik, H. M., and M. C. Goldstein. 2013. An introduction to social media for scientists. PLoS Biology **11**. DOI: 10.1371/journal.pbio.1001535.

Blickley, J., K. Deiner, K. Garbach, I. Lacher, M. Meek, L. Porensky, M. Wilkerson, E. Winford, and M. Schwartz. 2012. Graduate student's guide to necessary skills for nonacademic conservation careers. Conservation Biology **27:**24–34.

Cannon, J. R., J. M. Dietz, and L. A. Dietz. 1996. Training conservation biologists in human interaction skills. Conservation Biology **10:**1277–1282.

Cook, C. N., M. B. Mascia, M. W. Schwartz, H. P. Possingham, and R. A. Fuller. 2013. Achieving conservation science that bridges the knowledge-action boundary. Conservation Biology **27:**669–678.

COSEE New England. 2003. Education and outreach needs assessment. 11 pp. Centers for Ocean Sciences Education Excellence, Woods Hole, MA. Available from http://www.whoi.edu/cosee/lessons.htm (accessed December 1, 2012).

deKoven, A., and D. Trumbull. 2002. Science graduate students doing science outreach: participation effects and perceived barriers to participation. Electronic Journal of Science Education **7:**1–23.

DeNeef, A. L. 2002. The preparing future faculty program: What difference does it make? Association of American Colleges and Universities, Washington, D.C.

Ecklund, E. H., S. A. James, and A. E. Lincoln. 2012. How academic biologists and physicists view science outreach. PLoS ONE **7**. DOI: 10.1371/journal.pone.0036240.

Fleet, C. M., M. F. N. Rosser, R. A. Zufall, M. C. Pratt, T. S. Feldman, and P. P. Lemons. 2006. Hiring criteria in biology departments of academic institutions. BioScience **56:**430–436.

Fox, J. 2012. Can blogging change how ecologists share ideas? In economics, it already has. Ideas in Ecology and Evolution **5:**74–78.

Groffman, P. M., C. Stylinski, M. C. Nisbet, C. M. Duarte, R. Jordan, A. Burgin, M. A. Previtali, and J. Coloso. 2010. Restarting the conversation: challenges at the interface between ecology and society. Frontiers in Ecology and the Environment **8:**284–291.

Hansen, A. 2011. Communication, media and environment: Towards reconnecting research on the production, content and social implications of environmental communication. International Communication Gazette **73:**7–25.

Jensen, P., J.-B. Rouquier, P. Kreimer, and Y. Croissant. 2008. Scientists who engage with society perform better academically. Science and Public Policy **35:**527–541.

Kareiva, P., M. Marvier, S. West, and J. Hornisher. 2002. Slow-moving journals hinder conservation efforts. Nature **420:**16.

Lach, D., P. List, B. Steel, and B. Shindler. 2003. Advocacy and credibility of ecological scientists in resource decision-making: a regional study. BioScience **53:**170–178.

Linton, R. 2013. Confronting challenges in graduate education: What is the NSF role? Grad Edge **2:**1–4. Council of Graduate Schools, www.cgsnet.org.

Lubchenco, J. 1998. Entering the century of the environment: a new social contract for science. Science **279:**491–497.

Marshall, J. 2013. Kickstart your research. Proceedings of the National Academy of Sciences of the United States of America **110:**4857–4859.

McBride, B. B., C. A. Brewer, M. Bricker, and M. Machura. 2011. Training the next generation of renaissance scientists: the GK–12 ecologists, educators, and schools program at the University of Montana. BioScience **61:**466–476.

McDade, L. A., D. R. Maddison, R. Guralnick, H. A. Piwowar, M. L. Jameson, K. M. Helgen, P. S. Herendeen, A. Hill, and M. L. Vis. 2011. Biology needs a modern assessment system for professional productivity. BioScience **61:**619–625.

Messinger, O., S. Schuette, J. Hodder, and A. Shanks. 2009. Bridging the gap: spanning the distance between high school and college education. Frontiers in Ecology and the Environment **7:**221–222.

Meyer, J., P. Frumhoff, S. Hamburg, and C. De La Rosa. 2010. Above the din but in the fray: environmental scientists as effective advocates. Frontiers in Ecology and the Environment **8:**299–305.

Milliman, J. D. 1996. Integrating research and education with public outreach at coastal laboratories. Biological Bulletin **190:**278–285.

Morgan, S., J. Curtis, and A. Vincent. 2008. Axes of excellence: a role for students as community-engaged scholars. Frontiers in Ecology and the Environment **6:**105–106.

Newing, H. 2010. Interdisciplinary training in environmental conservation: definitions, progress and future directions. Environmental Conservation **37:**410–418.

Nisbet, M. C., and D. A. Scheufele. 2009. What's next for science communication? Promising directions and lingering distractions. American Journal of Botany **96:**1767–1778.

Osmond, D. L., et al. 2010. The role of interface organizations in science communication and understanding. Frontiers in Ecology and the Environment **8:**306–313.

Pace, M. L., et al. 2010. Communicating with the public: opportunities and rewards for individual ecologists. Frontiers in Ecology and the Environment **8:**292–298.

Piwowar, H. 2013. Altmetrics: value all research products. Nature **493:**159.

Quimby, J. L., N. D. Seyala, and J. L. Wolfson. 2007. Social cognitive predictors of interest in environmental science: recommendations for environmental educators. The Journal of Environmental Education **38:**43–52.

Roux, D. J., K. H. Rogers, H. C. Biggs, P. J. Ashton, and A. Sergeant. 2006. Bridging the science-management divide: moving from unidirectional knowledge transfer to knowledge interface and sharing. Ecology and Society **11:**4.

Salguero-Gomez, R., M. D. Whiteside, J. M. Talbot, and W. F. Laurance. 2009. After "eco" comes "service." Frontiers in Ecology and the Environment **7:**277–278.

Shanley, P., and C. López. 2009. Out of the loop: why research rarely reaches policy makers and the public and what can be done. Biotropica **41:**535–544.

Smith, B., N. Baron, C. English, H. Galindo, E. Goldman, K. McLeod, M. Miner, and E. Neeley. 2013. COMPASS: navigating the rules of scientific engagement. PLoS Biology **11**. DOI: 10.1371/journal.pbio.1001552.

Suleski, J., and M. Ibaraki. 2010. Scientists are talking, but mostly to each other: a quantitative analysis of research represented in mass media. Public Understanding of Science **19:**115–125.

Weigold, M. F. 2001. Communicating science: a review of the literature. Science Communication **23:**164–193.