Amplify the Signal: Graduate Training in Broader Impacts of Scientific Research


Expertise in the broader impacts of scientific research is an increasingly important aspect of professional development, particularly because federal grant proposals are commonly reviewed using both the Intellectual Merit and the Broader Impacts Criteria. Unfortunately, training in broader impacts, such as science communication and outreach, is not typically part of undergraduate or graduate curricula. We initiated one of the first graduate-level biology courses on broader impacts, focusing on giving graduate students firsthand, authentic experiences with grant writing, science communication, and educational outreach. Students in this interdisciplinary course learned from experts, wrote for a broad audience about their own research, and proposed and implemented outreach in collaboration with local organizations. We outline our approach, discuss outcomes from each activity, assess our impact, and finally consider how future programs might expand on this model.

Keywords: broader impacts, outreach, journalism, writing, communication

Curiosity-driven, basic research is funded by the public because it contributes in important ways to common societal needs (Frodeman and Parker 2009). The diverse contributions that basic research makes to society have been termed broader impacts (BIs). Although scientists are carefully trained to disseminate research results through publication in the scientific literature, they are often unprepared to translate their research for the public and make a broad impact (Crone et al. 2011, Ecklund et al. 2012). In a recent graduate course, “Amplify the signal” (AtS), at the University of Illinois at Urbana–Champaign, we aimed to train the next generation of biologists to make a broad impact through public engagement, including educational outreach and science communication. We believe that scientists in training benefit from learning to communicate their science effectively, both because it is good for society and because it will enhance their own careers (Meara and Jaeger 2007, Mathieu et al. 2009, Crone et al. 2011).

Open communication between scientists and the public benefits everyone, particularly in an age in which science literacy has such important societal consequences (Dean 2009). The public needs to hear scientific results and, more generally, to understand the process of scientific inquiry in order to make informed decisions about both day-to-day life and national policy (Ziman 1992). This is true now more than ever, because our society depends on increasingly complex science (e.g., stem cell research, genetic engineering, computer and Internet technology). Scientists have traditionally relied on the popular media to communicate their findings broadly, but given the decreased emphasis on science journalism in the television, print, and online news media (e.g., the 2013 closing of the New York Times environment desk), dependence on this strategy today means that an increasing proportion of scientific findings do not make an impact beyond the primary literature. These findings are essentially hidden from the public eye because of restricted journal content (O’Keefe et al. 2011) and specialized language (Hendrix and Campbell 2001, Suleski and Ibaraki 2010). Moreover, voters who appreciate the importance of simply understanding nature (Kornberg 2001) ensure the continuation of public funding for the kind of curiosity-driven science that ultimately results in applied breakthroughs (Schimmel 2000).

Graduate training in BIs can also contribute to a successful career in research. First, future faculty benefit directly from BI experience, because proposing and enacting meaningful BIs is often a requirement for federal grant funding (e.g., through the National Science Foundation [NSF]) and...
Course philosophy: How should we train students in broader impacts?

Graduate school is a key time for a course on BIs, because graduate students are (a) being trained for research careers, (b) often funded by existing federal grants, (c) writing their own grants, and (d) actively contributing to the primary literature. Therefore, graduate students are uniquely poised to leverage science communication skills to improve their own careers. In AtS, we focused on training graduate students by promoting creativity and autonomy through a team-based experiential-learning environment (see box 1). As with nearly all learning (Kolb 1984), we think that BI training is best achieved through a hands-on, learning-by-doing approach that has been demonstrated to be effective (e.g., Crone et al. 2011). To accomplish this, we divided our activities into three main modules (see figure 1). In part I of the course, the students learned about BIs and grant writing, in preparation for the fall NSF grant deadlines (graduate research fellowships and doctoral dissertation improvement grants [DDIG]). In parts II and III, we implemented authentic experiences in our two focal BI areas—science communication and educational outreach—in collaboration with a local online magazine, a local radio show, and a local children’s science museum. The major assignments and organization of the course are described in figure 1; in table 1, we present a list of weekly activities and information on visiting speakers who provided expertise.

Part I: What is a broader impact, and why should we care?

Over the last 60 years, the NSF has continuously refined the required criteria by which proposals are evaluated. Beginning in 1997, two review criteria were established: the Intellectual Merit and Broader Impacts Criteria (see NSF 2013a). Although biological researchers have a clear understanding of what intellectual merit entails, addressing the BI Criterion has remained a challenge for both proposers and reviewers (NSB 2011). When evaluating NSF grant proposals, the BI section requires that the funded research have “the potential to benefit society and contribute to the achievement of specific, desired societal outcomes” (NSB 2011). Although this open definition has remained unaltered over its 16 years of use, it has led to a variety of working definitions and scopes of activity in the research community (Lok 2010, NSB 2011, Nadkarni and Stasch 2013).

Given decreases in available federal funds and an abundance of high-quality proposals, BIs are increasingly used to distinguish proposals during the NSF review process (NSB 2011). New guidelines released in early 2013 highlight the increased weight given to BI during the review process, stating that “both criteria are to be given full consideration.

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Box 1. Course goals.

Provide students with authentic outreach experiences
Familiarize students with the National Science Foundation’s Merit Review Broader Impacts Criterion
Train students to design better broader impacts in their proposals
Forge community connections that enhance outreach opportunities for students
Enable students to better communicate their research to a broad audience
Expose students to the design, implementation, and assessment of informal educational outreach
Education
during the review and decision-making processes; each criterion is necessary but neither is sufficient” (NSF 2013a, p. 14; emphasis in the original). With respect to training graduate students to prepare their own proposals—both DDIG proposals and future full proposals—the NSF explicitly states that “the scope of the broader impacts should be appropriate for the size and scope of the DDIG project, keeping in mind that providing improved graduate student training is in and of itself a broader impact” (NSF 2013b, p. 4).

Our first course module was focused on the NSF’s outlook on BIs and the proposal development and review process. We enhanced our general understanding of BIs through dialogues with both NSF program officers and biology faculty who had previously received NSF grants and served on NSF panels. The timing of this first course module, in the fall immediately prior to the NSF proposal deadlines, made these discussions quite relevant to the students’ research goals. The students had the opportunity to ask specific questions of their peers, their instructors, faculty panelists, and even NSF program officers (table 1).

To give the students hands-on experience with the proposal review process, they submitted proposals describing an outreach activity related to their own thesis projects that they would develop for Biodiversity Day at the Orpheum Children’s Science Museum if it were funded (see part III below). The proposals were required to be well justified and concrete, to include active learning, to be focused on biodiversity, and to include an assessment. The class then ran an NSF-style review panel to select the six projects to support using course funds. Briefly, each student was required to read and comment on three other proposals in advance of the panel meeting, then was required to leave the room when his or

Table 1. Calendar of weekly activities and visiting experts.

<table>
<thead>
<tr>
<th>Schedule week</th>
<th>Activities</th>
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<tbody>
<tr>
<td>Week 1: Introduction to course</td>
<td>Discussion of National Science Foundation (NSF) merit review and outreach theme</td>
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<tr>
<td>Week 2: The merit review criteria, according to NSF</td>
<td>Guests: NSF program officers Saran Twombly and Samuel Scheiner; lecture, question and answer session (Q&amp;A)</td>
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<tr>
<td>Week 3: Successful grant writing for broader impacts</td>
<td>Guests: Illinois biology faculty Carla Cáceres, Jim Dalling, Ripan Malhi; panel discussion and Q&amp;A</td>
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<td>Week 4: NSF merit review and readability and science journalism, part I</td>
<td>Discussion with NSF program officer Alan Tessier; peer feedback workshop for short topic descriptions</td>
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<tr>
<td>Week 5: Readability and science journalism, part II</td>
<td>Guest: Illinois News Bureau journalist Diana Yates; feedback on short topic descriptions and Q&amp;A</td>
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<td>Week 6: Writing for a local online magazine</td>
<td>Guests: Smile Politely editors Cody Caudill and Tracy Nectoux; article workshop</td>
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<td>Week 7: Science on the radio, part I</td>
<td>Guest: Environmental Almanac host Rob Kanter; Q&amp;A</td>
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<tr>
<td>Week 8: Science on the radio, part II</td>
<td>Radio spot peer feedback workshop</td>
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<tr>
<td>Week 9: Museum outreach, part I</td>
<td>Guest: Orpheum Children’s Science Museum education director Katie Hicks; field trip to museum, tour of outreach space, mock activities and discussion</td>
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<tr>
<td>Week 10: Museum outreach, part II</td>
<td>Guest: Illinois science education professor Barbara Hug; discussion of national science standards, outreach assessment</td>
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<tr>
<td>Week 11: Merit criteria and the proposal review process</td>
<td>Guests: Orpheum Children’s Science Museum education director Katie Hicks; NSF-style panel for outreach proposals</td>
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<tr>
<td>Week 12: Museum outreach, part III</td>
<td>Outreach workshop and in-class work time</td>
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<tr>
<td>Week 13: Museum outreach, part IV</td>
<td>Outreach trial run and troubleshooting; weekend activity: outreach session at the Orpheum Children’s Science Museum</td>
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<tr>
<td>Week 14: Reflection and course evaluation</td>
<td>Analysis of outreach assessments, discussion</td>
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her own proposal was discussed by the panel (the rest of the students). The education director from the Orpheum (who had hands-on experience with informal education) and the course instructors (who had experience writing and reviewing proposals for the NSF) served as program directors.

In interactions with the NSF program officers, the students discussed how a focused, concrete BI plan with one or two activities is often more meaningful than an overly broad, vague plan. They were told about the shifting landscape of proposal peer review; for example, NSF reviewers increasingly expect that scientists assess the effectiveness of their BI activities. In addition, program officers and faculty members, alike, refuted the idea that scientists must work independently to design and implement BI activities. Instead, they stressed the importance of collaborating with individuals or organizations with expertise and a strong record of success. By questioning both program officers and faculty, the students saw that the interpretation of some aspects of BI still varies widely. For example, advancing opportunities for underrepresented groups is one way to make a broad impact. Although the NSF is focused on developing this talent within the US population, reviewers appear to view collaboration with non–citizen scientists from developing nations as a valuable way to generate these opportunities.

The proposal assignment was, for many students, the first time that they had written professionally about outreach, which required them to take a step back from their research projects and consider them in a larger, more broadly relevant context. Serving as panelists on the mock NSF panel required that the students critique their classmates’ proposals, which often shed light on their own misinterpretations of BI criteria, overlooked details, or unrealistic goals. The panelists found it appealing when the outreach proposal was specific in its goals and methods and applied novel techniques to assess outcomes. In addition, the panelists favored proposals that leveraged previous experience of the author and appeared more sustainable (i.e., when materials could be reused for similar activities in the future).

Part II: Writing about science for the public

Part of our responsibility as scientists must be to reignite public excitement about biology and to justify public investment in science (Suleski and Ibaraki 2010). Writing for the public is a powerful tool to promote one’s own research and has been employed effectively by esteemed biologists to widely communicate their ideas (e.g., Edward O. Wilson, May R. Berenbaum, Stephen Jay Gould). However, relatively few scientists undertake a serious effort to write for a broad audience. Some researchers do not consider public engagement to be their responsibility (Lok 2010, Mervis 2011), whereas others might not feel prepared to deviate from scientific writing. Scientific results can be interesting and relevant to the lives of many people, but they will remain unnoticed unless they are communicated in a way that makes them accessible.

In collaboration with a local online magazine (Smile Politely, http://smilepolitely.com), the AtS students wrote articles about their own research, targeted at the local public. The students first wrote a short description of their research topic, with a broad audience in mind, then analyzed its readability using a simple online tool (e.g., the Readability Calculator, www.online-utility.org/english/readability_test_and_improve.jsp) and gathered feedback from peers and a local science journalist on their writing (table 1). After a writing workshop with magazine editors (table 1), the student articles were revised and published online. Excerpts of student writing can be found in supplemental appendix S1. The full articles are online at www.smilepolitely.com/culture/category/science_politely. The students then recorded short radio spots (archived at www.life.illinois.edu/heath/Heath_Lab/Amplify.html) based on their online articles. After the students gathered peer feedback (table 1), their revised spots were played during a weekly local current events show (Smile Politely Radio).

When polishing a scientific article for peer review, researchers carefully consider the readership of their target journal and craft arguments to engage that audience. The same concept applies when conveying research results to the public. Non-specialists are unlikely to be comfortable with technical language, so replacing or supplementing specialized terms with plain language can help the article reach a broad audience. Analyzing their first writing attempts quickly showed the students that their paragraphs were dense with complex sentence structures and jargon. Through both peer review and interactions with magazine editors and science journalists (table 1), the students were given the opportunity to revise their work to convey their research in a clear and concise way without oversimplifying the results or implications.

Most biology students lack training in creative writing. The AtS students’ initial attempts to write for the public were often rich in information but lacking in broad appeal. The students found that peer feedback and soliciting the input of family, friends, and magazine editors helped them write creatively about their own research. Finding an interesting story that appeals to the senses and emotions, as well as to the intellect, must be a primary goal of writing about science for the public. In some cases, the students focused on themselves as a specialist at work. Being the character in one’s own writing can be uncomfortable for scientists, especially after years of training to avoid subjectivity and emotion in the scientific process. Fostering these skills can translate into the professional realm, however, because the most engaging and effective scientific reports are those that have a strong unifying theme. With good professional examples of science journalism (e.g., Stocking 2011) and expert input (guest speakers and magazine editors), the students were better able to find the story in their science.

Part III: Engaging young people in science

The United States has lost footing among other nations in the STEM subjects (Kuenzi 2008, NGSS 2013). Tai and colleagues

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(2006), for example, argued that it is imperative to engage young learners in scientific inquiry, because their views and aspirations are formed during the primary years, and course choices made in middle and high school are crucial for the STEM trajectory. Beyond promoting the STEM pipeline, engaging young learners in science informs our nation’s future teachers, health professionals, and scholars. Because some public school elementary students receive less than 30 minutes of science instruction each week (Dorph et al. 2011), supplemental efforts to engage students in science through museums and after-school programs can be valuable.

We hosted an outreach event in collaboration with the Orpheum Children’s Science Museum. As a class, we developed a theme for the event (“Biodiversity!”) and designed biodiversity-themed activities that incorporated the science literacy benchmarks for our target age group (AAAS 2009). These activities were designed to improve the understanding of ecosystems, species diversity and connectivity, adaptation of phenotypes to their environment, and organism life history strategies. The AtS graduate students held an NSF-type panel to fund six projects on the basis of their outreach proposals (see part I above; also see the activity synopses in supplemental appendix S2). Thereafter, the students worked in teams to refine and implement these activities (table 1), each of which was aimed at serving 50–100 children of ages 3–8 years and their families. Each activity included clear learning goals; background information on the specific topic; an interactive component, such as a game or live specimens; and an assessment of the participants’ achievement.

We identified some unifying successes from and challenges of hosting a biology-themed outreach event for children of ages 3–8. Our greatest successes were achieved through clear learning objectives, hands-on and self-paced exploration, and a structured and well-integrated assessment (Bonney et al. 2012). The interactive, play-based component of each activity allowed exploration of the activity content and time for interaction with the AtS graduate students. While they were interacting with the children, it became clear to the students that a primary challenge of outreach design is tailoring each activity to a large range of ages and background knowledge. Therefore, our most successful activities were flexible enough to be easily adjusted to individual participants. Allowing the participants to explore the content at their own pace and with regular feedback seemed to prepare them well to demonstrate their learning under direct questioning. Our best assessments were quantitative but were incorporated into the fun of the activity, such as a final interactive challenge. One group was happily surprised to achieve a 60% success rate, across a diverse age range, for the participants’ ability to correctly match a mouthpart to its flower shape after their activity (see “Chomp, chomp! Diverse feeding strategies” in appendix S2).

Outcomes and assessment

To measure our effectiveness at attaining the course goals (box 1), we gathered three types of data: (1) postcourse student surveys (see supplemental appendix S3), (2) BI feedback on submitted or awarded student grant proposals during or after the course, and (3) graduate mentor surveys (see supplemental appendix S4). The survey respondents answered most questions using a five-point Likert scale (1, strongly disagree; 5, strongly agree). The mean responses are reported below, along with p-values where they are appropriate, to assess the difference in means between the students’ understanding before and after taking the course (using t-tests).

Postcourse student surveys. We surveyed the graduate students about their subjective impressions of how much they learned through their participation in the course approximately 9 months after the course ended. Although this long lag could exacerbate recall bias, it also made it possible to survey the students about subsequent activities, including how the course inspired them to undertake additional outreach or improved subsequent grant writing, and to collect more objective data on the results of any proposals submitted during the course (see the next section). The course instructors first separated the students’ grant feedback (which might refer to the project and thus identify the student; see below) from the students’ course evaluations, in order to analyze and interpret the latter anonymously. Nevertheless, because the students submitted all of their information on one form, our survey cannot be considered rigorously anonymous. All of the 18 students who completed the survey claimed that they would recommend the course to others.

Our course goals included providing authentic experiences. By completing the course assignments, the students attained this goal, building their BI résumés. The students agreed that the course provided them with new opportunities for engaging in outreach (mean [M] = 4.28, standard deviation [SD] = 1.02). Since the course, the graduate students have accepted invitations to continue their work, including a continuing column in Smile Politely and the development of more activities on native Illinois bats at the Orpheum Museum.

We aimed to familiarize the students with the NSF BI Criterion and to train the students to incorporate BIs in their grant and fellowship proposals. The students strongly agreed that the course improved their understanding of BIs (M = 4.83, SD = 0.38) and improved their ability to write about or propose BIs in grant proposals (M = 4.61, SD = 0.50). The students reported that the course significantly (p < .01) changed how prepared they felt for writing BI proposals.

Another course goal was to enable the students to better communicate their research to a broad audience. The students reported that the course significantly (p < .01) changed how prepared they felt for writing about science for the public. Ten of the 18 students felt not well prepared to write about science for the public before the course, whereas all 18 students felt either somewhat or very well prepared to write about science for the public after taking the course. The students strongly agreed that the course improved
their ability to communicate research to a broad audience ($M = 4.56, SD = 0.62$).

Finally, we aimed to expose the students to the design, implementation, and assessment of informal educational outreach and also to inspire them to undertake more or different outreach activities. The students reported that the course significantly ($p < .01$) changed how prepared they felt for designing and performing outreach. Nine of the 18 students felt not well prepared to design and perform outreach before the course, whereas all 18 students felt either somewhat or very well prepared to design and perform outreach after taking the course. The students also agreed that the course improved their ability to design and implement outreach ($M = 4.33, SD = 0.77$) and improved their ability to assess outreach ($M = 4.39, SD = 0.61$).

**Broader impact grant feedback.** Many students submitted proposals requiring a BI component during or after the course. As part of the surveys described above, we collected objective data on the number of proposals that the enrolled graduate students submitted and were awarded, and we rated any feedback received on their BI sections on a five-point Likert scale (1, very negative; 5, very positive). Of the 18 students who responded, 15 applied for one or more fellowships or grants requiring a BI component, and 7 were funded. Of the 10 proposals that were returned with BI feedback from reviewers, 9 proposals received positive reviewer comments (the average feedback rating was 3.9 out of 5). Six students had also received BI feedback prior to taking the course and responded to a question asking them to objectively rate the BI feedback that they received on proposals before and after the course. There was a significant difference ($p < .05$) between how their BIs were viewed before taking the course (lower) and how their BIs were viewed after taking the course (higher). Anecdotally, one student won the Chancellor's Public Engagement Student Fellowship at the University of Illinois, and another successfully proposed a symposium on science outreach for the 2013 Entomological Society of America meeting and has recently been accepted to a PhD program in science education and communication.

**Graduate student mentor postcourse survey.** We surveyed the graduate mentors of enrolled students for their impressions of our impact, because we believe that many graduate advisers are uniquely poised to comment on their students’ meaningful improvements with regard to BI motivation, design, and implementation. Eight advisers responded to our survey, and these eight respondents advise 11 of the 20 enrolled students. The advisers strongly agreed that the course improved their students’ understanding of the NSF’s BI Criterion ($M = 4.6, SD = 0.53$), inspired their students to undertake more outreach or to do outreach for the first time ($M = 4.5, SD = 0.53$), improved their students’ ability to write about BIs in grant proposals ($M = 4.7, SD = 0.49$), provided new opportunities for their students to engage in outreach ($M = 4.5, SD = 0.76$), and helped their students better communicate their research ($M = 4.57, SD = 0.53$). The advisers also agreed that the course improved their students’ ability to design, implement, or assess outreach ($M = 4.4, SD = 0.52$). Three of the eight advisers, however, responded that they did not discuss the course with their students at all, whereas three discussed the class with their students a little, and only two advisers responded that they discussed the class with their students a lot. Despite these limitations, all of the advisers responded that they would encourage other students to enroll in this course.

**Conclusions**

New scientists should be trained to effectively incorporate BIs into their research proposals, to engage with the public, and to create and implement meaningful outreach (Meara and Jaeger 2007). AtS is an innovative, interdisciplinary course designed to provide resources for graduate students as they endeavor to make a broad impact with their own research. We believe that such courses can benefit graduate students by preparing them for a competitive funding climate, by cultivating in them a positive outlook toward community engagement and interdisciplinary work in general, and by improving their communication skills. Much as training in pedagogy is increasingly being offered or even required as part of graduate training in biology, we believe that training in BIs will become more common as the importance of outreach (both to our society and as an aspect of professional development) becomes more mainstream. The landscape of biology outreach has changed rapidly, and we speculate that current graduate students often come to the table with more expertise in this area than their faculty mentors have. We would be wise to leverage this burgeoning enthusiasm and experience to benefit all graduate students as part of their professional development training.

A number of refinements could improve courses like AtS. A large gap in experience and perspective existed between many of our biology graduate students and the NSF program officers, science journalists, and magazine editors. The best interactions were hands-on and clearly linked to course assignments—notably, the writing workshop with the *Smile Politely* editors and a museum tour in which the students got to try out and discuss example outreach activities. Another challenge was tackling two very different target audiences in the course of a single semester. We aimed for an overview of science communication and informal educational outreach; however, an entire semester could ideally be devoted to each audience. For example, the students would have benefited from the opportunity to reflect, redesign, and repeat the museum activities, particularly to improve the informal assessment.

We worked with local collaborators (the online magazine and children’s science museum) to enact our authentic outreach activities; therefore, the implementation of similar courses at other institutions will require instructors to reach out to similar organizations in their own communities. We stayed local for multiple reasons. First, one of our course goals was to connect the researchers in our unit with community partners so that they could continue their outreach.
Second, we wanted to ensure that the course goals were attainable within a single semester. Finally, existing collaborations between the faculty and these local organizations made these connections even easier to initiate. We do not believe, however, that finding local outreach partners will be a hindrance to developing similar courses elsewhere; we found that scientific content by expert graduate students, at least in these informal environments, was overwhelmingly welcomed. Formal learning environments subject to curriculum standards would be more challenging, so partnering with existing university–teacher relationships would probably be a successful strategy. Nevertheless, by providing a course overview and a week-by-week example syllabus, we aim here to provide a starting place for others wishing to implement similar training elsewhere and, moreover, to stimulate a conversation about whether and how we should train graduate students as BIIs become an increasingly important aspect of a career in curiosity-driven biological research.

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Supplemental material

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