Annotated Primary Literature: A Professional Development Opportunity in Science Communication for Graduate Students and Postdocs

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Formal training in communicating science to a general audience is not traditionally included in graduate and postdoctoral-level training programs. However, the ability to effectively communicate science is increasingly recognized as a responsibility of professional scientists. We describe a science communication professional development opportunity in which scientists at the graduate-level and above annotate primary scientific literature, effectively translating complex research into an accessible educational tool for undergraduate students. We examined different types of annotator training, each with its own populations and evaluation methods, and surveyed participants about why they participated, the confidence they have in their self-reported science communication skills, and how they plan to leverage this experience to advance their science careers. Additionally, to confirm that annotators were successful in their goal of making the original research article easier to read, we performed a readability analysis on written annotations and compared that with the original text of the published paper. We found that both types of annotator training led to a gain in participants’ self-reported confidence in their science communication skills. Also, the annotations were significantly more readable than the original paper, indicating that the training was effective. The results of this work highlight the potential of annotator training to serve as a value-added component of scientific training at and above the graduate level.

INTRODUCTION

Communicating science to the public is increasingly recognized as the responsibility of professional scientists. However, the development of science communication skills remains a well-known oversight in graduate and postdoctoral training (1–3). Including communication training in graduate and postdoctoral programs presents challenges, including finding time and resources for additional training in research skills–focused programs and a lack of advisors or institutions who know how to appropriately support trainees in their science communication pursuits (4, 5).

Science communication comes in many forms, including the traditional formats of the poster, abstract, oral presentation, and primary scientific research paper (6, 7). While primary scientific research papers remain the standard form of communication between scientists, the readability of scientific literature has decreased over time, making it inaccessible to the general public, students, scientists-in-training, and even to some scientists themselves (8). As a result, primary scientific research papers in their original form are often excluded as a tool for science communication with non-experts.

Although we generally think of science communication as taking place in informal settings, one of the largest venues for science communication is the science classroom. Using primary literature in the classroom can intimidate students and instructors alike, particularly because of the use of scientific jargon and academic language (9). Despite this, a growing body of literature shows that research papers are a valuable and useful tool for science education and that primary literature can be used to teach the nature and practices of science (10–12). Previous studies have shown that teaching with scientific research papers promotes critical thinking, increases students’ experimental design ability,
and improves students’ attitudes about science and scientists (13, 14). These studies strongly support the use of primary literature in the classroom, but how do we make primary literature more accessible to undergraduate students?

Science in the Classroom (SitC) (www.scienceinthe-classroom.org/) is a collection of annotated research papers and accompanying teaching materials that makes scientific research papers more accessible to students and educators. Science in the Classroom adds layers of additional information onto the original text of research articles via a “learning lens” designed to help the reader understand the research (Fig. 1). The “learning lens” selectively highlights parts of the text that fall under seven different, color-coded categories (e.g., glossary; see all categories in Table 1). For example, when a user clicks on an annotated glossary term, a color-coded box pops up containing the definition of that term. Figure legends and the reference list are also annotated.

SitC advances science communication in two ways. First, annotations provide a set of tools for deconstructing scientific papers, giving students a better understanding of experimental design and the logical flow from results to conclusions. With the scientific jargon interpreted, students can see how the authors identified a question, collected and analyzed data, and proposed the next question(s). This introduces students to the non-linear and iterative nature of science. Second, writing annotations serves as a professional development opportunity in science communication. While annotators (graduate-level students and above) may be

**FIGURE 1.** SitC presents the original text of research articles along with a “learning lens” that highlights the parts of the text for which there are annotations. Clicking on the highlighted text reveals the annotation. For example, clicking on an annotated glossary term produces a pop-up box containing the definition of the term. Annotations are color-coded by category (see Table 1 for a description of the categories).

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glossary</td>
<td>Definitions, descriptions, explanation of acronyms.</td>
</tr>
<tr>
<td>Previous Work</td>
<td>Describes prior research used as a foundation for the current study.</td>
</tr>
<tr>
<td>Authors’ Experiments</td>
<td>Simply and thoroughly describes the methods used in the study.</td>
</tr>
<tr>
<td>Results and Conclusions</td>
<td>Summarizes or extrapolates on the experimental results and highlights major conclusions made based on evidence.</td>
</tr>
<tr>
<td>News and Policy Links</td>
<td>Links to relevant news stories related to, or based on, the research in the article. Depending on subject, can also point out policy, either used to inform the study or crafted after the article was published.</td>
</tr>
<tr>
<td>Connect to Learning Standards</td>
<td>Links to relevant learning standards such as AP and NGSS.</td>
</tr>
<tr>
<td>References and Notes</td>
<td>Annotated citations highlighting previous research used to inform the current study, focusing on landmark and foundational papers. Provides a specific description of the role of each study in building the full body of work within the field.</td>
</tr>
</tbody>
</table>

AP = advanced placement; NGSS = next generation science standards.
reasonably knowledgeable about research and content in their own fields, they are often inexperienced at communicating these concepts to a non-expert audience. In this paper, we will focus on the impact of our annotator training on graduate students’ and postdoctoral fellows’ self-reported confidence in their science communication skills. Future work will address the efficacy of the paper annotations on undergraduate students’ science understanding.

We have developed an iterative and collaborative method for annotating research papers. Annotations are written on a volunteer basis by graduate students, postdoctoral fellows, and other STEM professionals and reviewed for accuracy by the original paper’s author(s). Annotators provide the additional explanation and background necessary for non-experts to gain a deeper understanding, while paper authors make sure the original research is well-represented. Science in the Classroom staff ensure that the science is communicated at an appropriate level.

Here, we provide preliminary evidence that annotator training positively improves participants’ self-reported confidence in their science communication skills. Additionally, annotators are successful in lowering the reading level of the content of these papers to one appropriate for first-year undergraduate students.

METHODS

Annotator training

Original SitC annotator training. Between 2013 and 2016, SitC annotator training consisted of a one-hour Skype training session with the American Association for the Advancement of Science (AAAS) SitC project director, during which the annotation process was discussed and a timeline for completion was developed. An accompanying online Annotators Guide was provided to participants. As there was a small cohort of annotators at that time (approximately two annotators were trained each month for a total of 66 annotators), one-on-one training was feasible. However, as SitC grew and as the number of interested annotators increased, it was necessary to streamline and scale up the training process.

CIRTL annotator training course. The second type of annotator training began as a graduate-level course through the Center for the Integration of Research, Teaching and Learning (CIRTL) network (https://www.cirtl.net/). The course Students Reading Real Science: Bringing Primary Literature into the Undergraduate Classroom was offered as six 75-minute sessions that met weekly in the fall of 2015. The course was taught by Dr. Melissa McCartney, project director at AAAS, and Dr. Rachael R. Baiduc, Research and Evaluation Associate at Northwestern University Searle Center for Advancing Learning and Teaching. Dr. Kitch Barnicle, project manager at CIRTL/Wisconsin Center for Education Research, oversaw course logistics and adherence to CIRTL protocol. The CIRTL course was a pilot study with a small number of participants and was taught only once in the fall of 2015. Participants were graduate students and postdocs whose academic institutions belonged to the CIRTL network in the fall of 2015. Registration for the course was voluntary and the class size was capped at twelve. Fourteen students were initially enrolled based on CIRTL data of the likelihood of students dropping courses and a waitlist was generated. In the end, eight students completed the course requirements, which included annotating a research paper and submitting a post-course survey. The class met synchronously online, using web conferencing software, and course materials were hosted on a Moodle site. Topics covered in the course included learning about primary literature as an educational tool, science literacy and academic language, and addressing the content and literacy levels of a target audience (the full syllabus and additional course materials can be provided upon request).

Revised SitC annotator training. Currently, annotator training is offered via the SitC website. Interested volunteers, at the graduate level and above in their science careers, are invited to participate. This training is modeled on the best practices we established during previous annotator trainings (original SitC annotator training and CIRTL).

Survey design

Due to institutional review board (IRB) restrictions, we were not able to survey non-CIRTL SitC annotators until the spring of 2017. At this time, the SitC team designed a post-training survey adapted from several previously validated surveys on the development of communication and research skills (Florida International University [FIU] IRB approval # IRB-17-0109) (15–17). These published surveys were developed for use with undergraduate populations; however, we felt the questions were applicable to our population of graduate students and postdocs. Several additional questions were written by the SitC team to examine why annotators wanted to work with SitC, how they used the experience as a professional development opportunity, and whether they perceived any gains in their communication skills as a result of annotation training. There were eight questions in total on the survey, including four that invited a short-answer response and three that contained a total of 55 Likert-scale items (on either a 5- or 6-point scale). Two of the short-answer responses and all 55 Likert-scale items were relevant to this study and were analyzed for this report. We sent the survey link to all previous annotators whose contributions had been published prior to April 2017. Twelve previous annotators responded anonymously to our post-training survey request, a response rate of 22%. Survey questions were reviewed and edited by our FIU and AAAS colleagues who are experts in teaching and learning.

Evaluation of the CIRTL course followed standard CIRTL program evaluation protocol. Student survey responses used
a unique ID code, and data could not be traced back to any individual student. The pre- and post-course surveys were developed by the CIRTL team that designed and implemented the course. Several questions were standard items used in all CIRTL course surveys, but most of the questions were developed to assess the learning goals and objectives of this course, which, for this study, were “improve your ability to communicate written science to non-expert audiences including STEM undergraduates” and “increase your confidence in communicating science to non-expert audiences.” The pre-course survey contained 20 questions, seven of which contained multiple Likert-scale items (on either a 5- or 6-point scale). The post-course survey contained 26 questions, eight of which contained multiple Likert-scale items. Six of the Likert-scale items were relevant to this study and were analyzed for this report. Survey questions were reviewed and edited by our CIRTL and AAAS colleagues who are experts in the formal assessment of teaching and learning.

Evaluation of current SitC annotator training consists of a pre- and post-training survey that combines survey questions from both previous iterations of annotator training (FIU IRB approval # IRB-17-0109). Respondents use a unique ID code and data cannot be traced back to any individual participant. The surveys are divided by discipline (biology, chemistry, and physics) due to a communication-skills question asking the respondent to evaluate vocabulary words from each specific discipline. We chose to separate these surveys by discipline to truly measure the communication skills that were being developed, i.e., if we asked a physicist to evaluate a biological term and the physicist did not know the term, the physicist could not accurately respond to the prompt. Aside from differences in this one question, the surveys are identical. The pre-training survey consists of 11 questions: eight demographic questions, the discipline-specific vocabulary-based question, and two Likert-scale questions on communication and research skills (on either a 5- or 6-point scale). The post-training survey consists of five questions: the discipline-specific vocabulary-based question, two Likert-scale questions on communication and research skills (on either a 5- or 6-point scale), and two questions relating to what participants gained from completing the annotation training (i.e., credentials for their résumé and/or a chance to explore an interest in science communication).

Survey analysis

Survey invitations were distributed via e-mail (SitC annotators prior to spring 2017), through the course listserv (CIRTL), and through website links (current SitC annotators). The anonymous surveys were administered online through Qualtrics. This study was approved by the IRB at FIU (#17-0109) and followed the standard CIRTL program evaluation protocol. Analyses were implemented in R version 3.2.1 (18).

Readability analysis

The ease with which readers can comprehend written text is known as readability. The most popular measures of readability include Flesch-Kincaid, the Gunning Fog index, the Coleman-Liau index, and the SMOG index. These measures all consist of an algorithm applied to the text of interest that returns a number corresponding to a US grade level. For example, Flesch-Kincaid measures word length and sentence length, while the Gunning Fox index measures the number of words per sentence. A readability score of “6” corresponds to a sixth-grade reading level and a “15” corresponds to a third-year undergraduate-student reading level.

To determine whether our annotators were successfully writing their annotations at a reading level appropriate for the target audience of introductory undergraduates, we analyzed the readability levels of (i) the abstracts of the original research articles within the SitC collection, and (ii) the corresponding annotations for each research article. We focused on the abstract text because this section of the research paper is standardized across all scientific disciplines and would allow us to compare results across all our annotated papers. We calculated the average reading levels (measured in grade levels) of 72 abstracts and corresponding annotations using Readable IO (https://readable.io/), an online tool for improving the quality of one’s writing. The benefit of using Readable IO is that it analyzes text and returns scores from several readability tests, including Flesch-Kincaid, the Gunning Fog index, the Coleman-Liau index, the SMOG index, as well as the Automated Readability Index. Readable IO has been used previously to evaluate medical and financial texts (19, 20). To evaluate significant differences in readability, we used R software to perform a paired t-test on the readability levels of the abstract text and the corresponding annotation.

RESULTS

Results from SitC annotator training (to April 2017)

Annotators self-reported an increased confidence in their communication skills, with 75% agreeing or strongly agreeing that the annotation experience taught them to better communicate science to a general audience and 54% agreeing or strongly agreeing that it helped to improve their writing skills (Table 2).

Every respondent to our survey (n = 12) indicated that they listed their annotation training on their curriculum vitae (CV), with 38% responding that they described their annotation training as science communication experience (data not shown). In addition, 54% of annotators agreed or strongly agreed that annotation training taught them skills that helped their job/career, and 82% of annotators agreed or strongly agreed that annotation training provided additional credentials for their CV (Table 2). We collected short-answer responses to the following prompts: “How
TABLE 2.  
SitC annotator training survey results (n = 12).

<table>
<thead>
<tr>
<th>Did the annotation experience...</th>
<th>Pre or Post</th>
<th>Strongly Disagree (1)</th>
<th>Disagree (2)</th>
<th>Somewhat Disagree (3)</th>
<th>Somewhat Agree (4)</th>
<th>Agree (5)</th>
<th>Strongly Agree (6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>teach you how to better communicate science to a general audience?</td>
<td>post</td>
<td>8</td>
<td>17</td>
<td>33</td>
<td>42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>help to improve your writing skills?</td>
<td>post</td>
<td>9</td>
<td>37</td>
<td>27</td>
<td>27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>teach you skills that will help your job/career?</td>
<td>post</td>
<td>9</td>
<td>9</td>
<td>28</td>
<td>45</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>provide additional credentials for your CV/résumé?</td>
<td>post</td>
<td>18</td>
<td>46</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>allow you to contribute to the field of science?</td>
<td>post</td>
<td>9</td>
<td>27</td>
<td>46</td>
<td>18</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data are shown as the percentage of respondents.

did the SitC annotation experience benefit you professionally?” (Table 3) and “Please provide a testimonial on your SitC annotation experience” (Table 4).

When asked if annotator training allowed them to contribute to the field of science, 64% of SitC annotators agreed and 73% of SitC annotators reported a good or great gain in feeling like part of the scientific community (Table 5). However, when asked if annotator training resulted in gains of feeling like a scientist, 46% of annotators reported no gain (Table 5).

Results from CIRTL annotator training course

A pre-course survey of CIRTL students (n = 12) showed that 42% of participants wanted to transition into teaching-intensive STEM faculty positions, while 33% were interested in science outreach or communication careers. When asked about what type of outreach skills they thought should be taught in graduate school or during a postdoc, 67% responded with communication training (data not shown). Overall, the CIRTL course met, exceeded, or significantly exceeded expectations for 89% of post-course respondents (n = 8) (data not shown).

We asked additional questions on the post-course survey, with the goal of understanding students’ attitudes toward communicating science to a wider audience. We matched the pre-course survey data with the post-course survey data for students who completed both surveys (n = 8) to provide a pre-post evaluation of the CIRTL course. We graphed each student’s responses as a way to show how individuals changed over the course of the training (Fig. 2). In response to the prompt, “Please rate your experience with translating complicated science to a general audience,” we see a positive shift from the pre-course survey to the post-course survey (Fig. 2A).

We asked CIRTL students to rate their agreement with several statements relating to science communication. We saw no pre/post change in agreeing or strongly agreeing to the statements: “It is important for research scientists to be able to communicate their conclusions to a non-scientist audience” (Fig. 2B); “It is valuable for scientists to be able to communicate science to non-scientists” (Fig. 2C; n = 7); “I can describe the scientific and/or engineering design method with respect to my research project in ways that
engage and can be understood by non-scientists” (Fig. 2D); “I think that most scientific concepts are too complicated to explain to non-scientists” (Fig. 2E); “I am interested in training on how to communicate science to non-scientists” (Fig. 2F). It is important to note that students participating in this course already had an interest in science communication, which may underlie the lack of change.

CIRTL students also showed no change in their agreement with the statements “It is valuable for non-scientists to have a good understanding of science” (Fig. 3A) and “Engaging the public in science is personally rewarding” (Fig. 3B). Again, we believe this is due to the CIRTL students being a small, self-selected population (n = 8). We saw a slight shift from “strongly disagree” to “disagree/neutral” in response to the statement “My research is too specialized to make much sense to the public” (Fig. 3C; n = 7).

When asked how well the course met the learning objectives “increase your confidence in communicating science to non-expert audiences” and “improve your ability to communicate written science to non-expert audiences,” 100% of post-survey respondents replied with “some” or “a lot” (Table 6). Over 50% reported that the CIRTL course exceeded or significantly exceeded expectations based on their personal academic goals (data not shown).

Results from current SitC annotator training

We anticipate that the current version of the online SitC training takes approximately two hours to complete, and it takes an additional six to eight hours to annotate a paper. Because the current version of the online SitC training is so recent (launched in summer 2017), we have only two self-identified biologists who have successfully completed the process (36 self-identified biologists are currently participating in annotator training). We present preliminary data from our current annotator training with the caveat that a sample size of n = 2 is not appropriate for a complete evaluation of the training.

The main reasons annotators in the previous two groups participated in the training were “to learn skills that will help my job/career,” “to earn additional credits for my CV/résumé,” and “to learn how to better communicate science to a general audience” (pre-survey results; all responses scored a 4.5 or above on a 6-point Likert scale, n = 43). Annotators in the current training echo their predecessors: participation in the training resulted in added credentials for their CV/résumé, an increase in confidence to communicate science to a general audience, and an improvement in their writing skills (post-survey results; all responses scored a 4.5 or above on a 6-point Likert scale, n = 2).

New to this version of the training is a quantitative evaluation of participants’ communication skills. To measure this, we listed 14 discipline-specific terms (selected following the method used by Baram-Tsabari and Lewenstein) and asked participants to decide whether each of these terms needs to be “not defined” (analyzed as a 0), “defined with a basic glossary term” (analyzed as a 1), or “defined and explained with an example” (analyzed as a 2) when communicating with the general public (21). We expect that as participants complete our annotator training, they will develop a greater appreciation for words the general population might not understand, either in general or as a common word now being used in a science setting, and that their post-survey response will therefore shift from “not defined (0)” to “defined and explained with an example (2).” While again stressing that we

<table>
<thead>
<tr>
<th>Do you think this annotation experience influenced (led to a gain in) your ability to…</th>
<th>Pre or Post</th>
<th>No Gain (1)</th>
<th>A Little Gain (2)</th>
<th>Moderate Gain (3)</th>
<th>Good Gain (4)</th>
<th>Great Gain (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>feel part of the scientific community?</td>
<td>post</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>55</td>
<td>18</td>
</tr>
<tr>
<td>feel like a scientist?</td>
<td>post</td>
<td>46</td>
<td>27</td>
<td>9</td>
<td>18</td>
<td></td>
</tr>
</tbody>
</table>

Data are shown as the percentage of respondents.
only have a sample of \( n = 2 \), we did see a shift in participant responses to this question, with the pre-survey response being 0.39, indicating a majority of “not defined” answers, and the post-survey response being 1.14, somewhere between “defined with a basic glossary term” and “defined and explained with an example.” We anticipate that data from additional participants will support this preliminary shift in annotators realizing more words should be defined when communicating to the general public.

Readability levels of written annotations

As the goal of SitC annotations is to make original research more accessible to an undergraduate audience, we examined whether annotations were easier to read than the original text. Using Readable IO (https://readable.io/), an online tool for analyzing the readability of written text, we analyzed 72 abstracts and their corresponding annotations to evaluate their reading level. Readable IO analysis provides a computer-calculated index which estimates the level of education someone would need to read the source text. Several readability tests are run in parallel (Flesch-Kincaid, the Gunning Fog Index, the Coleman-Liau Index, the SMOG Index, and the Automated Readability Index), and an average readability score is returned. The readability score is roughly equivalent to the grade levels found in traditional US education systems, i.e., a readability level of 12 is roughly equivalent to the education level of a high-school senior.

The original abstracts were analyzed first. The average reading level of the 72 abstracts analyzed was 17.33, which corresponds to the education level of a first-year graduate student. Next, the text of the abstract annotations was analyzed. We found that these annotations have an average reading level of 12.01, which corresponds to the education...
level of a high-school senior. There was a significant difference between the reading level of the raw abstracts and the annotations according to a paired t-test ($t(66) = 15.89, p \leq 0.0001$).

**DISCUSSION**

While our annotator training program is still in the early stages, we are confident that successful participants’ confidence in their ability to be science communicators increases. Feedback from both SitC annotator training and the CIRTL annotator training course suggests that there is great potential for future annotators to use this as a professional development opportunity to develop science communication skills.

Recent surveys reveal that many graduate students and postdocs in STEM fields plan to pursue careers outside of academia, yet there are insufficient professional development opportunities for these early career scientists to train for non-academic careers (4, 22). Additional data suggest that this type of non-traditional career development opportunity is optimal early in a scientist’s training (23, 24).

Both SitC annotation training and the CIRTL annotation training course were designed to give graduate students and postdoctoral fellows additional training in science communication. By providing this professional development opportunity, we aimed to equip graduate students and postdocs, early in their careers, with skills and experiences that will be applicable in virtually all career paths. The professional development centered on annotating new SitC resources as a means to help participants better understand the science concepts presented in the article as well as the nuances of communicating these concepts to a general audience. We aimed to show that this kind of training can be a value-added component of scientific training and should be considered as valuable as traditional research skills.

We received significant interest in our annotator training opportunities. To date, we have had over 80 annotators volunteer for SitC, and the CIRTL course reached full enrollment with an additional wait list. We expect this interest to continue, as every respondent to our SitC annotator-training survey indicated that they listed their annotation training on their CV. This, coupled with the responses in Tables 4 and 5, make us confident that participants were satisfied.

**FIGURE 3.** CIRTL course survey-response data for selected prompts. Pre- and post-course responses are matched ($n = 8$ for A and B, $n = 7$ for C) in order to graph how individual scores changed over the course of the training. The y-axis is the corresponding Likert scale as follows: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree. The number of students whose responses were identical pre- and post-course survey (horizontal line) is indicated by the ($n = x$) notation when it is greater than 1.

<table>
<thead>
<tr>
<th>TABLE 6. CIRTL post-course survey responses to the question “How well did this course meet the course objectives listed in the syllabus?” ($n = 8$).</th>
</tr>
</thead>
<tbody>
<tr>
<td>How well did this course meet the course objectives listed in the syllabus?</td>
</tr>
<tr>
<td>Increase your confidence in communicating science to non-expert audiences.</td>
</tr>
<tr>
<td>Improve your ability to communicate written science to non-expert audiences including STEM undergraduates.</td>
</tr>
</tbody>
</table>

Data are shown as the percentage of respondents.
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With participation in both types of training being completely voluntary, SitC annotators and CIRTL students are a self-selected population with interest in science outreach and communication. The high agreement among participants that SitC annotator training allowed them to contribute to the field of science and to feel like part of the scientific community corresponds with this self-reported interest. However, we saw strong disagreement among SitC annotators when asked if annotator training resulted in gains of feeling like a scientist. This implies that while annotator training may have made annotators more confident that they are advancing science through their annotations, this confidence appears disconnected from their role as a scientist. This suggests that this population of annotators, who voluntarily participated in science communication training, still may not see science communication as part of their professional responsibility as a scientist. An alternative explanation is that these annotators are already early-career scientists and therefore would not report additional gains in feeling like a scientist as a result of annotator training.

The interest of CIRTL students and their agreement with survey statements relating to science communication is in consensus with this self-selected population, i.e., already valuing science communication enough to enroll in a voluntary course. Therefore, seeing no shift in disagreement and strong disagreement with the statement “I think that most scientific concepts are too complicated to explain to non-scientists” is consistent with this population. While it is encouraging that our annotator training did not make CIRTL students agree with this statement, the lack of a shift in disagreement with this statement is again likely a result of a small sample size and a self-selected population.

We saw a slight shift from “strongly disagree” to “disagree/neutral” in response to the statement “My research is too specialized to make much sense to the public.” This indicates that while most students entered the CIRTL course thinking their research was not too specialized to share with the public, they left feeling less certain about this. One explanation is that some CIRTL students annotated a paper that was outside their field of expertise, and this may have altered their confidence in their ability to communicate their own research. It is possible that the annotation process showed these students how esoteric research is in general and they therefore determined that, in the absence of annotations, their research wouldn’t make much sense to the public, i.e., they realized how valuable annotations actually are and how specialized the reading of their science actually is. A second explanation is that CIRTL students assumed that they could translate their own research, but after completing the annotation process, they realized it was not as easy as they thought it would be. A final explanation is that while annotators see the value in communication science in general, i.e., they were able to annotate someone else’s research, they are not connecting this skill to their own research. This final explanation is similar to what we saw with the SitC annotators. Future iterations of annotator training will examine this area in greater depth.

Taken together, these data suggest that the CIRTL annotator training course facilitated an increase in graduate students’ and postdocs’ self-reported confidence in their ability to communicate science to non-experts in writing. Specifically, participants self-reported that the training met the course learning objectives and that the course exceeded expectations based on their personal academic goals.

Data from both types of annotator training (SitC and CIRTL) indicate that participants see a positive shift in their confidence in being able to communicate complex science to a general audience. The readability data support this shift with regard to written communication and confirm that annotators have successfully translated science content to an appropriate level, ensuring that SitC resources are a valuable and useful tool for enhancing undergraduate science education. We have taken best practices from both preliminary annotator trainings and developed the current, online version of SitC annotator training that is open to any member of the scientific community at the graduate level or above. While this training is still in its infancy (launched in the summer of 2017), we have seen great interest from biologists (n = 36). We see less interest from chemists (n = 2) and physicists (n = 5). This biologist-heavy participation has been the norm since we launched annotator training in 2009. Despite our efforts to reach all scientific communities, we struggle to identify and attract non-biologists. We encourage all members of the science community to join us as annotators and welcome any ideas to help diversify our annotator pool.

SitC annotator training is the result of best practices learned from our previous training modules. Specifically, interested annotators are encouraged to contact SitC staff to receive annotator training materials and to complete our pre-training survey. Training itself consists of watching six online videos and completing an accompanying worksheet. Once the training worksheet is completed and submitted, annotators may select a paper to annotate and begin developing annotations. The editing and review process includes SitC staff and the authors of the research paper. Once the annotations and the post-training survey are complete, that annotated paper is posted to the SitC website for use by the scientific community. An overview of the training process, plus example videos and worksheet questions, can be found at www.scienceintheclassroom.org/annotator-training-process. To discourage annotators from starting to annotate without completing the full training and pre-training survey, we do not post the full training sessions publicly on the SitC website. We encourage interested volunteers to visit the website and contact the SitC staff to properly enroll in annotator training.

Currently, annotator training is an individual endeavor. We have not further examined this training as a graduate-level course. We suggest that instructors wishing to do so...
visit www.scienceintheclassroom.org/annotator-training-process to familiarize themselves with the annotation training process. It is possible that this training can be done as a class, with, for example, the training done either together or as a homework assignment, and the annotations done in groups. Students can engage in peer-review as they edit their classmate’s annotations. As we have no data collection on our current annotation process being done as a graduate-level course, we encourage interested instructors to collaborate with us in order to develop best practices that can then be shared with the entire scientific community. Please contact the corresponding author to join us in this new direction for annotator training.

It is necessary to note that we suggest this training only be used by scientists at the graduate level and above. We have developed this training with an emphasis on professional development for early-career scientists, specifically focusing on communication skills and why they are important versus training in understanding science content and/or developing research skills. For this reason, and at this time, we do not encourage undergraduates to participate in this version of annotator training. We are currently developing and piloting a separate version of annotator training specifically for undergraduate students and their instructors. Our preliminary results suggest that undergraduates need a very different kind of training than those members of the scientific community who have already established a solid foundation in research skills.

CONCLUSION

Results from all of our annotators have allowed us to improve and refine our training protocol to ensure that we are providing useful science communication experience. We have also identified components of annotator training that can be further investigated to measure learning gains. In response to our pilot studies presented here, we have developed an online annotator training course for SitC, open to anyone at or above the graduate level. Complete instructions for completing the training and annotating a paper are available at www.scienceintheclassroom.org/annotator-training-process. Training consists of six videos covering topics such as the complexities of academic language and an introduction to science communication. Potential annotators are required to watch the videos and complete a pre- and post-training survey as well as answer additional short-answer questions. As we move forward with a more detailed analysis of the learning gains taking place through annotator training we are confident that our training will serve as a professional development opportunity in science communication with significant impact for early-career scientists.

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REFERENCES

5. Brownell SE, Price JV, Steinman L. 2013. Science communication to the general public: why we need to teach undergraduate and graduate students this skill as part of their formal scientific training. JUNE 12:E6–E10.
examination of faculty perspectives and diverse student gains.

15. Rees C, Sheard C, Davies S. 2002. The development of
a scale to measure medical students' attitudes towards
communication skills learning: the Communication Skills

Creating a better mousetrap: on-line student assessment
of their learning gains. Paper presented to the National
Meetings of the American Chemical Society Symposium,
“Using Real-World Questions to Promote Active Learning.”
SALGPaperPresentationAtACS.pdf.

a preliminary quantification of the use of jargon in science

18. R Core Team. 2016. R: A language and environment for
statistical computing. Vienna, Austria: R Foundation for

2017. Information on early menopause: is the Internet the

org/10.1016/j.frl.2017.08.003

assessing scientists’ written skills in public communication

Improving graduate education to support a branching career
pipeline: recommendations based on a survey of doctoral students

among American biomedical postdocs. CBE Life Sci Educ
14(4):ar44.

Science PhD career preferences: levels, changes, and advisor
couragement. PLOS One 7(5):e36307.