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Learning Science Communication Skills Using Improvisation, Video Recordings, and Practice, Practice, Practice †

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Doctoral students in science disciplines spend countless hours learning how to conduct cutting-edge research but very little time learning to communicate the nature and significance of their science to people outside their field. To narrow this disparity, we created an unusual course titled Communicating Science for doctoral science trainees at Rutgers University. Our goal was to help students develop an advanced ability to communicate their research clearly and accurately and to emphasize its value and significance to diverse audiences. Course design included classroom instruction supplemented with improvisation, video recordings, and ample opportunity for students to practice and receive immediate, constructive feedback in a supportive environment. A multidisciplinary faculty with expertise in science, education, communication, and theater arts taught this course. PhD students came from diverse scientific disciplines, ranging from biology and chemistry to civil engineering. Students also completed a capstone project in which they worked with a professional in the academic or private sector to explore a possible career aspiration. Assessment was in the form of feedback on students' oral and poster presentations, and written abstracts about their research. Student evaluations and comments about course format and content were mostly positive and also provided input for ways to improve the course. We discovered that the diversity of scientific backgrounds among our students enhanced their ability to learn how to communicate their science to others outside their disciplines. We are leveraging the success of our initial course offering to reach other student and faculty groups at Rutgers.

INTRODUCTION

According to the Pew Research Center, scientists and healthcare professionals are respected and ranked very highly by the public as leaders whose opinions can be trusted and relied upon (1). As such, they are in a powerful position to convey the significance and value of important information and new discoveries in science to various audiences. It is essential, therefore, that science professionals be able to effectively communicate complex ideas and concepts clearly, accurately, and understandably. In his 2007 *Science* editorial, Alan Leshner, then chief executive officer of the American Association for the Advancement of Science, issued a call for scientists "to add media and communications training to the scientific training agenda" (2).

Ten years on, there is still an underappreciated need for science trainees to learn methods of effective science communication (3–6). The curriculum in many doctoral programs does not offer sufficient opportunities for students to learn how to present scientific concepts and discoveries using easily understood language and minimal discipline-specific jargon, and to practice doing so. The understanding of scientific principles by the public and by government

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leaders influences decisions about regulating, funding, and applying scientific research. As technology advances, it is imperative for scientists to be capable of speaking about complex concepts, and comfortable doing so, using language that is understandable not only to their scientific peers but to nonscientific audiences as well.

Fortunately, it has been shown that good science communication skills can be learned (7, 8). New methods of teaching these essential communication skills must be integrated into the curriculum for students pursuing advanced scientific degrees. Such training will produce better communicators who can convey their knowledge more effectively. With better communication skills, our trainees and graduates will also gain the confidence to reach out beyond their scientific audience and will embrace the responsibility to explain their science to the public, the media, politicians, and potential funders. Moreover, learning better communication skills will enhance young scientists' professional development and growth in their chosen fields. The 2016 Job Outlook report of the National Association of Colleges and Employers rated verbal communication skills as the most important skill that employers look for in candidates – 4.63 on a scale of 5.0 (https://tinyurl.com/nace-jobs-report). Therefore, by integrating training of communication skills into the curriculum, we will better prepare our graduates for employment in these and other industries.

The 2013 merger of the University of Medicine and Dentistry of New Jersey with Rutgers University provided great opportunities to develop new initiatives in science communication that benefit graduate students and better prepare them for professional careers in academe and the private sector. To take advantage of this opportunity, and thanks to a grant from the Burroughs Wellcome Fund (BWF), we designed a new, multidisciplinary, graduate-level course titled Communicating Science for advanced predoctoral students in science programs. A target area for BWF funding is to improve science communication skills as a means to better prepare graduating PhD students for the next phase of their careers. A multidisciplinary faculty with expertise in scientific research, education, communication, and theater arts was recruited from several Rutgers schools as well as private companies to develop and teach this innovative course, which we first offered in the spring 2017 semester.

COURSE OBJECTIVES

The overarching aim of Communicating Science was for students to develop an advanced ability not only to communicate their research clearly, accurately, and vividly, but also to emphasize its value and significance to diverse audiences. The course provided classroom instruction, supplemented with improvisation exercises, to reinforce effective science communication skills. Improvisational exercises are natural, intuitive activities that encourage individuals to cooperate with others to achieve a collective goal. The exercises are open-ended and require students to interact directly with each other through a process of collaborative problem-solving. Improvisational exercises stress spontaneous connection to one's partner or audience through the understanding of the shared experience. When applied to presentations, improvisational technique encourages students to identify a particular, central idea and to express that idea in relatable terms to the audience. By taking the focus off of the self and putting it on the other, the student becomes a more effective communicator.

Some elements of the course are modeled after those used at the Alan Alda Center for Communicating Science at Stony Brook University in New York (www.aldakavlilearningcenter.org). One of us (NMP) attended the center as a visiting professor to learn their central methods of "distilling your message" (i.e., deciding precisely what you want to convey) and "knowing your audience" (i.e., who you are talking to and ways to relate to them so they can easily understand your message) (9). The success of the Alda Center speaks to the effectiveness of their teaching strategies (10). Thus, the methods we use in Communicating Science have been "road-tested" in courses and workshops at the Alda Center to thousands of students and scientists.

The feedback received by the Alda Center about the value and effectiveness of such training has been outstanding (Elizabeth Bass, personal communication). Lectures in our Communicating Science course taught students how to distill their message and know their audience, and the improvisation exercises reinforced and extended these basic communication skills. Elizabeth Bass, former director of the Alda Center, comments that the goal of using improvisation in addition to classroom instruction is to help students "learn to pay intense and dynamic attention to the other person, reading and responding to verbal and nonverbal cues, rather than following a script" (11).

The objectives of Communicating Science were as follows:

1. To complement and enhance students' communication skills, using
    a. classroom instruction;
    b. improvisational techniques;
    c. practice sessions for oral presentations, writing assignments, and real-life simulations.
2. To help PhD trainees learn and practice new methods to communicate more effectively with
    a. colleagues and collaborators in other disciplines;
    b. the public (including potential employers, policymakers, donors, students, and media representatives).

COURSE CONTENT

Table 1 shows the syllabus for the course. Classes met once per week for 15 weeks and each session was divided into two parts (Table 1). The first part was a one-hour lecture on a communication-related topic followed by a two-hour activity that reinforced learning about the lecture topic. This strategy of "seeing, hearing, and doing" promoted higher levels of thinking (12, 13) and enabled students to practice what they had just observed in lecture, facilitating the learning process and "making it stick" (14). Lectures presented information that helped students to craft and distill their message and to realize how knowing their audience

TABLE 1.
Communicating Science class schedule and topics.

Class	Lectures	Activities	Homework
1	Introduction – Course overview; What is effective communication?	Icebreakers: Improvisation exercises	Prepare a 3-minute oral presentation about your research (Due: Class 2)
2	Communicating your science	3-minute oral presentations by all students (videotaped)	Write a lay abstract about your research – 250 words (Due: Class 3)
3	Scientific storytelling	Picture exercise for telling a scientific story	Turn your 3-minute oral presentation into a 30-second elevator pitch about your research (Due: Class 4)
4	Distilling your message; Knowing your audience	Feedback on your abstract; Give your elevator pitch to a classmate	Write a short description of a plan for your capstone project; rewrite your abstract (Due: Class 5)
5	Building confidence in public speaking; Voice, presence, body language	Improvisation methods relevant to lecture content	Write a 500-word introduction about your research and select a figure of data (Due: Class 6)
6	Scientific papers; How to structure a written story	Answer questions to sections of a paper	Prepare a deck of PowerPoint slides that you would use for a 10-minute talk based on your abstract for peer editing (Due: Class 7)
7	Visualizing science; How to communicate visually with slides	Peer editing of slides; Review capstone projects	Revise slides (Due: Class 8) Practice 3-minute talk and work on capstone project
8	Speech-giving skills	Improv exercises to enhance oral presentations	Work on your capstone project and practice your 3-minute talk
9	Effective teaching; Lecture objectives, team based learning, flipped classroom	Flipped classroom	Write lesson objectives for a lecture on the background for your research, rationale for your classroom approach, and assessment method (Due: Class 10)
10	Media: how to write press releases & opinion pieces; handle media interviews	Persuasive written and oral communication	Write a press release or op-ed piece about a controversial scientific topic (Due: Class 11)
11	Communication skills to influence and persuade	Exercises relevant to lecture content	Practice a 1-minute talk asking a venture capital company to invest in your start-up or advocating for a policy on a controversial topic to a mock congressional hearing. Select a full-size poster from a previous academic meeting (Due: Class 12)
12	Scientific posters	Critique each other's old posters	Describe how you would revise your poster based on feedback from peers. Bring a copy of your abstract and introduction about your research and a résumé for a mock job interview (Due: Class 13)
13	Interviewing for a job	Mock job interviews; Dress rehearsals for final 3-minute research talks	Prepare an oral presentation about your capstone project (Due: Class 14)
14	Presentation of capstone project summaries	Professionals and faculty evaluate capstone project summaries	Practice your final 3-minute talk (Due: Class 15)
15	Graduation videotaping and viewing	View videotapes for critiques and feedback	

helps them prepare their talks. They also learned to spot nonverbal cues in their listeners and use examples, analogies, metaphors, and storytelling (15, 16) to engage their audience (8). Students prepared materials (e.g., abstracts, op-ed pieces, slide decks) as well as the other homework assignments shown in Table 1. Course faculty members, as well as enrolled students, reviewed and provided feedback as part of the post-lecture class activities.

A central component of our Communicating Science course called for each student to prepare a three-minute oral presentation about his or her research. Students refined their short talks over the duration of the semester as they learned the key elements of effective science communication. We videotaped their three-minute talk at the beginning of the course and again at the end of the course as one method to assess improvement. Each student also participated in a capstone project—a multifaceted assignment that served as a culminating practical, intellectual experience that allowed students to apply what they were learning in our course to real-life simulations. For the capstone project, students were paired with mentors in professions that they wished to explore as possible career choices. This exercise was designed to reinforce course content and also give students additional opportunities to speak and write in ways that convey the essence and significance of their research clearly and accurately. The capstone project also provided them with networking possibilities that could help in their employment search after graduation. Mentors and students were given guidelines to follow so there was uniformity in the process followed during the capstone project (see Appendix 1). The projects included working with

- the Rutgers Office of Research Commercialization, to prepare a presentation to a venture capital group;
- faculty members at local colleges, to participate in teaching undergraduate science courses;
- professionals at the U.S. Food and Drug Administration, to learn more about the regulatory approval process;
- Rutgers Eagleton Institute of Politics, to prepare a presentation to local politicians about sponsoring a bill;
- professionals in science communication fields, to prepare a presentation on a drug's mechanism in disease for physicians and other key opinion leaders;
- researchers at Rutgers University, pharmaceutical companies, and consulting firms, to prepare discipline-specific résumés and cover letters in response to advertisements for postdoctoral or entry-level job opportunities.

The deliverables for the capstone projects varied depending on the nature of each project. All students gave a presentation describing their capstone experience to the rest of the class.

Faculty and student profiles

A total of 12 faculty members and guest speakers taught the course and contributed expertise and experience in scientific research, higher education, communication, theater arts, and the pharmaceutical industry. Authors of this article comprised a core of faculty members who not only gave lectures in the course, but also attended sessions to lead and participate in the post-lecture activities and provide analysis and feedback to students. The core group of faculty was recruited from the following schools of Rutgers University: New Jersey Medical School, Robert Wood Johnson Medical School, the School of Graduate Studies, the School of Environmental and Biological Sciences, the School of Communication and Information, and the Mason Gross School of the Arts program at the School of Arts and Sciences. Additional guest faculty provided complementary course content and represented other schools and centers at Rutgers, as well as the private sector, such as the pharmaceutical industry and radio science journalism.

Table 2 presents the profile of students who were attracted to our course. These students were from diverse scientific disciplines, ranging from biological, chemical, and biomedical sciences to engineering. We wished to achieve a high faculty/student ratio, and planned to register a maximum of 20 students. Seventeen students registered for our course and two dropped out. The diversity among both pupils and teachers helped students learn how to describe and explain their research within and outside their own discipline accurately, clearly, and understandably. As students gave in-class presentations, they were encouraged to use examples, metaphors, and analogies to transform their discipline-specific jargon into language that could be easily understood by their peers. In one such exercise, we asked students to present the essence of their research to the class in a 30-second "elevator pitch." This required a clear and concise explanation of what they do and its significance. Each student presented his or her 30-second talk and then received immediate feedback from students and faculty about how to clarify or eliminate jargon by using more familiar terms. In this exercise, students also had to sharpen their own listening skills to become effective peer critics and help their classmates.

ASSESSMENT

Students were evaluated on the quality of their course-related homework assignments (manuscript abstracts and introductions, posters for scientific meetings, PowerPoint slide decks, 30-second elevator pitches), but were not "graded" per se. We ensured that each student completed and turned in the assignments via the electronic course management system. Thereafter, these assignments were used for in-class activities in which faculty and students participated in evaluating and critiquing the homework. For assignments related to a guest lecture (e.g., op-ed piece,

TABLE 2.
Diverse backgrounds of Communicating Science students.

Rutgers School	PhD Program
School of Graduate Studies (Newark Division)	Multidisciplinary PhD program in the Biomedical Sciences
School of Graduate Studies (Piscataway/New Brunswick Division)	Biochemistry
	Microbiology and Molecular Genetics
	Cellular and Molecular Pharmacology
	Neuroscience
School of Arts and Sciences	Biochemistry
	Chemistry
	Cognitive Psychology
	Endocrinology and Animal Biosciences
	Inorganic Chemistry
School of Engineering	Civil and Environmental Engineering
	Chemical and Biochemical Engineering
	Electrical and Computer Engineering
Ernest Mario School of Pharmacy	Pharmaceutical Science

press release, lesson plan), we asked the invited guest lecturer to review the homework and provide written feedback to the students.

The before and after three-minute videos were analyzed by a course faculty member and author from the Rutgers School of Communication and Information (NL) using a scoring rubric he modified for his school (15). The criteria of his rubric included evaluation of the opening statement, organization and content, audience consideration, vocal expression, nonverbal communication, and conclusion (see Appendix 2).

Table 3 shows the scores for students' initial and final oral presentations. However, the scores in Table 3 also demonstrate that all students, including the non-native English-speaking students, showed significant improvement ($p < 0.00001$) in their "graduation" videos. The capstone project presentations were included as part of student assessments, and we also asked mentors to give their professional opinions about the conduct and performance of the students during the time they worked with them. Communicating Science qualified as a three-credit graduate-level course with a pass/fail grading scheme. However, our class was comprised of doctoral students in the research phase of their programs, and they did not need or receive credits. The course does appear on their transcripts, however, and we issued each student an Attestation of Completion for the course.

COURSE EVALUATION

We asked students to complete anonymous online surveys at the end of the course. The results (Table 4)

TABLE 3.
Scoring of initial and final video recordings of oral presentations.

Student ID	Initial Presentation	Final Presentation
1	80	91
2	81	90
3	79	91
4	77	88
5	75	85
6	77	85
7	71	85
8	71	82
9	71	81
10	70	84
11	70	81
12	70	79
13	79	85
14	83	94
15	73	80
Mean ± SE	75.13 ± 1.18	85.40 ± 1.17 *

Video recordings of a 3-minute presentation by each student were made on the same topic at the beginning of the course and at the end of the course. Each recording was evaluated using the scoring rubric shown in Appendix 2. Statistical analysis of the means (± standard error) using a two-tailed t-test showed a significant difference (* $p < 0.00001$) in the scores of the final presentations compared with those of the initial presentations.

indicated that our students overwhelmingly appreciated and approved of our course as they learned to tell diverse audiences about their research in language that was clear and understandable, without unexplained jargon. In addition to quantitative data shown in Table 4, examples of student responses about the course from surveys are shown in Table 5. Students also provided comments on how to improve the course, e.g., give credits; provide examples of good three-minute talks and elevator pitches; give more structure to the capstone project and relationship with capstone mentors. We are considering all of these suggestions as we modify the course prior to its next offering. Course faculty also felt strongly that students were engaged and enthusiastic about the course format and content. Comments from the capstone mentors (Table 5) were equally complimentary.

DISCUSSION

Communicating Science fills a void in the doctoral program at Rutgers School of Graduate Studies. It provides trainees with additional ways to communicate their scientific activities more effectively. As shown in Table 2, the diverse nature of the students in the class provided an ideal classroom environment to achieve a major goal of the course, i.e., for students to learn to communicate what they do and why it's important to people outside their field. Such diversity facilitated interaction among students from various scientific disciplines and helped them understand the research of their classmates, as well as its significance. Doctoral students are so often sequestered in their scientific fields. Our course gave them opportunities to stick their heads out of their silos and get a sense of real-world complications in communicating their research.

Students realized numerous benefits from this course. They learned basic skills of effective communication—to distill their scientific message, know and engage their audience, and pay close attention to nonverbal cues from their listeners to ensure they are following. They learned to avoid scientific jargon, provide context, and use examples, analogies, metaphors, and storytelling to get their message across. They learned to be active listeners and peer critics for their classmates. They also learned to appreciate the need for feedback, reinforcement, and ample practice to improve and sustain their science communication skills. Students also had opportunities to explore possible career aspirations through the capstone project. The career exploration aspect of the course dovetails with the goals of the NIH Broadening Experiences in Scientific Training (BEST) grant (http://www.nihbest.org/about-best) that led to the creation of the iJOBS program at Rutgers (http://ijobs.rutgers.edu/). The goal of iJOBS is to expose PhD students and postdoctoral fellows to non-academic career options and to the skills necessary for success in those career paths. Communicating Science embeds the goals of the BEST grant into our curriculum for sustainability of the iJOBS program. Finally, although not specifically designed for this purpose, Communicating Science also brought together faculty from the sciences, education, communication, and the arts who may not have otherwise had the opportunity to meet and work together, but who have now established useful relationships while training our students.

The improvement shown by students in our course illustrates the value of integrating new and innovative strategies into the graduate curriculum to help students learn how to be better communicators. By the end of the course, students were noticeably more poised and comfortable when communicating their science. As such, they will have confidence to speak out beyond their peers to nonscientists who also need to understand complex, contemporary scientific technologies and discoveries, such as climate change, genetically modified organisms, and vaccinations, in order to make sound decisions for themselves and their families. Going forward, the large number of undergraduate, graduate, and postgraduate programs of Rutgers University provide fertile ground to create new educational opportunities for science communication initiatives.

TABLE 4.
Evaluation survey results for Communicating Science.

Statement	Percent who "Strongly Agreed" or "Agreed"
The course met my expectations	92.3
The lectures were informative	100
The in-class activities were useful	100
The homework assignments were useful	76.9
The 3-minute speech improved my confidence in public speaking	69.2
The 3-minute speech improved my confidence in communication skills	84.6
The capstone project helped improve my communication skills	76.9
The capstone project helped improve my career goals	100

Students (n = 15) were given an electronic evaluation survey, the results of which did not reveal their identities. The percentages shown in the table are from 13 students who completed the survey

TABLE 5.
Comments about Communicating Science from students and Capstone mentors.

Students
Continually working on our speech and getting constructive feedback when practicing it was helpful to learn what the components of a good speech are and how to make our speeches more powerful and understood by our audience. The skills will transfer over into future talks.
The 3 min speech is a challenge for me, but it helped build my confidence in public speaking, and motivated me to have the passion to share my research.
The capstone project was helpful in improving my communication skills in the following ways: 1) it helped me to get into practical exercise of knowing my audience; 2) the communication with my mentor also provided a good way to practice communication skills.
From having continual practice, I definitely feel more confident in public speaking and developing a powerful and engaging speech.
It was a great learning experience to hear other student speeches and get feedback to learn what works and what doesn't.
Multiple speakers highlighted multiple communication styles.
It was immensely informative and made me recognize how deficient my communicating skills are (despite believing the opposite for a long time!). It gave me the impetus to consciously work towards the way I communicate now and in the future.
I hope Communicating Science can become a part of regular course curriculum for STEM and more students are able to benefit from it.
I have found the philosophy of learning by doing to be a fascinating aspect of this course.
Feedback from both the written and oral assignments was very helpful. It is not often we can get feedback from our work, so I think this is the best aspect of the course.
Capstone mentors
Overall, I think the program and objectives are a great idea —not only for students to polish their presentation skills but also to gain some 'real-world' experience re: interacting with non-academic professionals.
This is an impressively practical class that I wish had been available to me in graduate school. Please keep me in mind as a future mentor.
I believe projects like capstone are very helpful for young scientists interested in industry positions often requiring extensive cross-domain collaboration.
The capstone project seems very well designed given the aims of the course. Congratulations on introducing this course!
The capstone project especially allows the student to develop skills related to the career path that most interests them, and gives them valuable experience that they can include on a CV to make themselves more marketable. I would be happy to participate as mentor for students interested in the future.

SUPPLEMENTAL MATERIALS

Appendix 1: Capstone guidelines for Communicating Science course
Appendix 2: Scoring rubric for evaluation of video recordings

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