Supplemental Material

CBE—Life Sciences Education

Vickery *et al*.

Supplemental Table 1 – Papers identified in literature review and utilized for coding. Of note, Kuehne et al., 2014 described multiple programs which were coded separately. Tomat, 2020 targeted both graduate and undergraduate students but was counted in the graduate student category.

Article	Student population targeted by training	Summary of training – overall goals and structure
Squier et al., 2006	STEM Undergraduate students	Science communication was integrated into a chemistry lab course. The science communication activities focused on communicating to different audiences, oral/poster skills, and interviewing skills.
Watson and Lom, 2008		Assignments were included within a developmental biology course to teach students skills to communicate results and research conclusions effectively through images. Used one-way communication.
Walton and Baker, 2009		A course for undergraduate students with an oral presentation, poster presentation, and reading primary literature. The focus was on effective communication between scientific peers.
Halversen and Tran, 2010		A course designed to teach undergraduates the theory behind science communication and pedagogy skills of teaching ocean sciences. The course acknowledged diversity and inclusion, but the framework of the course is scientist teaching a lesson with an activity.
Cronje et al., 2011		A Science Writing Heuristic lesson with the goal to inform and persuade audiences of both scientists and the general public.
Brownell et al., 2013a		A writing intensive structure was integrated into neuroimmunology to teach students how to communicate with lay audiences.
Lemus et al., 2014		A course on communicating ocean sciences that included community partnerships with Indigenous experts and scholars.
Goldina and Weeks, 2014		A two-semester course in biology, designed to encourage students to develop public outreach events while engaging the public in two-way dialogue.
Whittington et al., 2014		A Science communication module was incorporated into an advanced biochemistry course. It focused on effective oral communication strategies to improve communication with the public.
Train and Miyamoto, 2017		Undergraduate Biology students had required curriculum that included science writing assignments such as lab reports, group and individual oral presentations, scientific review, and paper and poster presentations.
Adler, 2018		Students wrote feedback letters to a sports reporter with data analysis – the activity was focused on quantitative literacy. The activity incorporated practice for STEM literacy and communication to "non-experts" through writing exercises.
Aune et al., 2018		A "Nature of Science" - themed English composition course, designed to improve science literacy through non-fiction science themed narratives. No two-way dialogue or participation was practiced.
Beason-Abmayr and Wilson, 2018		A workshop for students in a laboratory course that focused on producing scientific writing with less technical jargon and improved graphical abstracts.
Begley, 2018		A capstone project that required students to give short, informal presentations at three points in a mock research grant proposal. This was coupled with feedback from other scientist peers.
Clement et al., 2018		A meal event incorporating 149 species/ingredients that illustrated a scientific message communicated through interaction with undergraduate biology students, informational signs, and an interactive website. It used two-way dialogue, worked with the public to brainstorm, and considered multiple points of views.
Grzyb et al., 2018		A writing-intensive course that provided an opportunity for students to practice writing fictional case studies.
Kimber et al., 2018		A training for students to communicate through diverse methods such as flowcharts, diagrams, and graphics. It focused on improving science literacy of the lay audience.
Lancor and Schiebel, 2018		A course on science outreach that encouraged taking public perspective into consideration, and placed students in community settings to directly interact with the general public.
Lopes et al., 2018		An outreach effort involving college students and adults with intellectual and developmental disabilities who worked together to make biological and multimedia art. It explicitly valued the backgrounds and goals of both groups and drew on active two-way communication as a productive way to learn and retain new information.
Mayfield et al., 2018		An activity within an organismal biology course in which students located primary literature and created posters to communicate with the lay public.
Mehltretter Drury et al.,		A module within an introductory biology course which engaged with the socio-scientific issue of gene editing. There was a focus on unique

2018		audiences and considering multiple perspectives of stakeholders and positions.
Petzold and Dunbar, 2018		Communication practice was implemented to the non-scientific community through describing various narrative passages. The "lay" group was not exposed to knowledge and was asked to identify when they did not understand a word or concept, forcing those explaining to change their message until it is understandable.
Pruneski, 2018		A short web-based activity which facilitated the writing and revising of text using only the 1,000 most used words in English. It was aimed towards eliminating jargon and making scientific writing easier to interpret by the lay public.
Rauschenbach et al., 2018		An inquiry-based poster project designed to improve student scientific communication skills through graphical abstracts and scientific writing.
Schwingel, 2018		A project designed to overcome the obstacle of communicating scientific content effectively with the public. Students practiced elevator speeches with a real non-scientific audience, followed by a peer interview with journalism students.
Kothari et al., 2019		A project within a laboratory course in which students created infographics (for the general public) that connected scientific content to compounds found in daily life.
Vollbrecht et al., 2019		Undergraduate students participated as instructors during a science outreach event that contained presentations and hands-on learning activities. Despite engaging 6-8 grades in hands-on science, the program was unidirectional in its description.
Hoover et al., 2020		Students (chemistry, engineering and art) created art installations based off chemical concepts and displayed work in a gallery-like setting at the end of the program.
Métris, 2020		Activities were incorporated into courses to provide students practice engaging in communication with the public through online sources and considering the needs of different audiences.
Garza et al., 2021		An activity in which students wrote a summary of a biochemistry seminar for a general audience.
Kelp and Hubbard, 2021		Semester-long courses focused on teaching various methods for communicating with different audiences and considering ethical concerns when approaching audiences.
Wack et al., 2021		A lesson for biology students in which they produced a product that communicated science with nonexperts.
Wrighting et al., 2021		A semester-long course for undergraduate researchers that illustrated concepts and strategies that contribute to STEM persistence. The course taught skills for: 1) scientific communication; 2) maximizing the effectiveness of research mentoring relationships; and 3) navigating scientific culture and its interactions with multiple social identities.
Trumbull, 2002	STEM Graduate Students	An outreach program that incorporated "service-learning" placing science students into direct work with the community to improve the public's understanding of science and create two-way dialogue for a range of audiences.
Stamp and O'Brien, 2005		A program paired graduate students with K-12 educators to work with young students while developing communication skills to better interact with the public.
Laursen et al., 2007		An outreach program hosted by graduate students introduced hands-on science-related activities to K-12 Students.
Trautmann and Krasny, 2009		Students learned to collaborate with K-12 educators, while also working directly with K-12 students to develop communication skills.
Crone et al., 2011		A course that provided a structured framework and experiential learning about informal science education, which included two-way dialogue with public.
McBride et al., 2011		A program model designed to train graduate students with the skills needed to interact with a variety of audiences and disciplines.
Webb et al., 2012		A program for graduate students that introduced them to informal science education settings and discussing their research with different audiences.
Bishop et al., 2014		Graduate students blogged about their research and sustainability to a general audience.
Goodwin et al., 2014		A program focused on responsible communication of science.
Kohler et al., 2014		A workshop that trained students to communicate science clearly to the public through presentations where peers provided feedback as to whether there is too much jargon.
Kuehne et al., 2014		A seminar course that taught graduate students to effectively communicate through the development of a seminar on their own research for a general audience. Included audience consideration, group discussion, and feedback.
		A program that coached graduate and post-doctoral researchers on improving their presentation skills. It focused on building confidence and enhancing clarity for the audience.
		Workshops that taught graduate students the skills they need to communicate emotions that motivate them to do research and provided

		training in science writing, creating blogs, and recording podcasts.
		A leadership program where students interviewed experts and stakeholders about a real-world issue and collaborated on a project aimed at informing the public. Participants developed communication skills for diverse audiences and entrepreneurship.
		A summer program where students, working as reporters, researchers, or editors, gained the practical skills needed to communicate their research through media.
		A professional development training where graduate students learned to effectively communicate science to the media and public and consider other disciplines.
Neeley et al., 2014		Different graduate student workshops that emphasized an interdisciplinary approach to science communication and multiple entry points into science.
National Research Council, 2014		A two-part workshop that promoted public engagement with a two-way dialogue approach and consideration of historical perspectives.
Baker Jones and Seybold, 2016		A professional development course for chemistry graduate students that trained them to communicate formally with other scientists.
LaRocca et al., 2016		A graduate course that split its focus between understanding how physiological functions change with age and what interventions could help prevent these changes, and public communication. The students created written summaries and presentations for nonscientific audiences.
Rohde et al., 2016		An interdisciplinary curriculum focused on storytelling, public speaking and improvisation, design, and the distillation of complex topics to clear and accessible forms.
Clarkson et al., 2018		A student-led training program in which students practiced public presentations, received feedback from peers and instructions, and simulated questions from the public.
Gruss, 2018		A course project in which students gave poster presentations to "non-technical" audiences.
Irizarry-Barreto et al., 2018		A mobile STEM Lab designed to increase participation in STEM of under-represented groups, as well as STEM literacy.
Johnson and Fankhauser, 2018		Graduate students helped in the peer-review process of articles submitted by middle/high-school authors.
O'Keeffe and Bain, 2018		An annual workshop in which students worked to improve oral and written communication skills to promote SciComm to non-scientists. The students practiced interacting and listening.
Ponzio et al., 2018		A course in which students did improvisation to simulate audience feedback and questions. The goal was to help students develop an advanced ability to communicate their research clearly and accurately, while emphasizing its value and significance to diverse audiences.
Rodgers et al., 2018		A training in which students communicated directly with non-scientists, who then relayed feedback to SciComm trainers, who use the feedback for development during the training. However, the feedback was not given from the general public audience to the graduate students in a dialogue format.
Smith-Keiling et al., 2018		In a writing-intensive lab course, a software was used to assess the scientific thinking skills of English Language Learners who had science knowledge, but not grammatical writing skills, and to quantify the effect of writing practice activities.
Gillian-Daniel et al., 2020		A practicum that taught students to communicate more effectively using improvisational techniques. There was a strong focus on listening to the needs of others and adjusting messages for different groups.
Hendrickson et al., 2020		A K-12 outreach program carried out by graduate and undergraduate students that aimed to enhance public awareness and understanding of science. Dialogue amongst groups was included.
Kompella et al., 2020		Graduate students presented their research to middle/high school students. They then mentored students to create and present "white board posters" about the research topic. This provided opportunity for idea exchange and a long Q&A session with parents that was led by the middle/high school students.
Tomat, 2020		A two-part course in which students experienced a lecture and preparation of engagement activities, and then interacted and dialogued with middle-school audiences.
Derreth and Wear, 2021		A service-learning course that incorporated dialogue between students and non-scientists, cross-contextual reflections, and positioning scientists as allies of the general public. The course taught scientists to engage in public social issues.
Osmond et al., 2010	Scientists	An interface organization where regional scientists developed a consensus synthesis document on an environmental issue and facilitated communication to policy makers, NGOs, media, and public along with dialogue and feedback.

Bang et al., 2010		A research partnership amongst tribes and university that encouraged local community lay experts to lead activities to improve science achievement among Native American children.
Mayhew and Hall, 2012		A model of science communication where scientists used non-traditional means of outreach to high school students via direct engagement.
Bik and Goldstein, 2013		A formatted guideline to online resources that scientists can use to improve public science literacy, as well as directly engage in two-way dialogue. This isn't a formal training, but it is publicly accessible.
Crall et al., 2013		A citizen science program that engaged the public in science by collecting data and promoting dialogue between the public and scientists.
Kuehne et al., 2014		A workshop in which participants learned to communicate their research effectively to both scientific and nonscientific audiences.
Clark et al., 2016		Educational outreach programs in which scientists presented their research to children.
Greer et al., 2018		An online course that aimed to improve one-way communication skills in an oral format.
Stylinski et al., 2018		A program in which scientists engaged directly with non-scientists, participating in two-way dialogue.
Stofer et al., 2019		A program in which scientists had casual conversations with non-scientists in public spaces.
MacArthur et al., 2020		Various programs for scientists to learn how to apply science communication in a cultural context.
Benedetti and Crouse, 2021		Science communication workshops that focused on oral communication skills and graphic design.
Lorke et al., 2021		A citizen science program in which scientists engaged with the public to collect data and create a biological record.
Weber et al., 2021		A program that allowed scientists to research non-traditional venues and to introduce science to directly engage with specific audiences.

Supplemental Table 2

Examples of language (quotes in italics) from articles that received codes in deficit, dialogue, or inclusive models, as driven by the three categories in our codebook. While quotes are organized into the feature of each model they are most clearly demonstrating, there are definite overlaps that enabled the coders to reach a conclusion about the main model being demonstrated in the article. For example, the quote from Lopes et al about co-creating with individuals with disabilities is also related to scientist perception of their audience. The quote from Osmond et al about communicating about regulatory and policy issues is also relevant to what the scientists are being taught to do (namely, work with an interdisciplinary group to solve a socioscientific issue).

	Deficit Model	**Dialogue Model**	**Inclusive Model**
What the student/scientist is being taught to communicate about	Settled science *"For the infographic assignment, the students were asked to create an infographic that is visually appealing, quick to read, easy to understand, and contains information about at least one organic molecule present in a consumer product." (Kothari et al., 2019)*	Science including uncertainties *"Students reported discussing "the positive and negative effects of gene editing" and the "pros and cons of the three choices while thinking deeply on the real-world consequences of each." The survey responses and facilitator and instructor observations suggested that students expressed and listened to a number of perspectives, even beyond the those presented in the issue guide." (Mehltretter Drury et a., 2018)*	Science plus ethical, regulatory, sociological, and political considerations; recognizing cultural funds of knowledge *"The Science-Links program functions as an interface organization because it helps the scientists to develop a consensus synthesis document on an environmental issue; facilitates the communication of these findings to policy makers, natural resource managers, nongovernmental organizations (NGOs), the media, science educators, and the public; and promotes exchanges and dialogue about the issue of concern between the project team and all the stakeholders." (Osmond et al., 2010)*
How the student/scientist is being taught to perceive their audience	A monolithic public *"Their posters were to inform nonscientists about biological collections." (Mayfield et a., 2018)*	Many "publics" – focus on targeting a unique audience *"The content of the practicum builds week-to-week, and covers the following topics: … Week 6: Framing a message for different audiences." (Gillian-Daniel et al., 2020)*	Focus on diversity of audience both in terms of expertise/discipline but also in terms of identity, culture, etc. *"Ciencia Puerto Rico is a dynamic non-profit organization democratizing science and transforming science education in Puerto Rico and training young scientific leaders from underrepresented backgrounds. Their work revolves around developing strategies and resources that make science more engaging and culturally relevant to Puerto Rican and Latinx audiences." (MacArthur et al., 2020)*
How the student/scientist is being taught to communicate	Skills such as: -one-way communication -removing jargon for a lay audience -producing communication only for scientists in their own field *"Overcoming the complex and technical language used in science is a major barrier to scientists being able to communicate their work with the general public… This short classroom activity takes advantage of a free, web-based tool, called Simple Writer, which facilitates the writing and revising of text using only the 1,000 most commonly used words in English." (Pruneski, 2018)*	Skill such as: -two-way communication and receiving feedback on their communication from audiences -targeting unique, specific audiences *"Each presentation was followed by a question and answer session, which was mostly answered by the young students with occasional help from their respective graduate student mentor. This format allowed a substantial opportunity for interaction and exchange of ideas between the graduate students and the participating students during the chalk-talk and science poster presentations."* (Kompella et al., 2020)	Skills such as: -explicitly recognizing the valuable perspectives of those from diverse backgrounds -valuing interdisciplinarity; working with those outside their own scientific field to discuss or solve an issue *"While traditional science outreach efforts have often focused on a one-way transfer of information from "experts" to "learners," we recently experimented with an alternative outreach model that prioritizes building a reciprocal relationship between formally trained and outsider scientists…. We experimented with this model of reciprocal outreach through "Symbiosis: Art, Science, & Community," a collaboration between college students and adults with intellectual and developmental disabilities (IDD)." (Lopes et al., 2018).*