

Communicating Chemistry Landscape Study

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Grunwald Associates LLC
Education Development Center, Inc.

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1. Introduction

Purpose and scope of the study

The National Research Council's (NRC) Board on Chemical Sciences and Technology (BCST) and Board on Science Education (BOSE) received funding from the National Science Foundation (NSF) to develop a framework for effective chemistry communication, outreach, and education in informal settings, with the ultimate goal of increasing the effectiveness of such efforts in engaging the public with chemistry.

BCST and BOSE are assembling a committee of experts to execute this work. To support their efforts, BCST and BOSE also commissioned this landscape study, which serves as background for the committee. This study aims to describe how and where chemistry is presented to the public, as well as identify the theories and rationales that guide such efforts. It identifies barriers and opportunities in communicating chemistry, and synthesizes the recommendations that have been made to date to address them.

This report is not intended to be the final word on the subject, but rather a working document to support the task of understanding current efforts in communicating chemistry. The report first includes a narrative discussion of the relevant topics and research, followed by a section that describes types and characteristics of some of the different communication efforts. Specific report sections include:

- Background on science communication and outreach: This section provides background information about existing frameworks for science communication and outreach, situating our understanding of chemistry communication in the broader context of science communication and informal science education.
- The current state of communicating chemistry: This section describes our findings with respect to current chemistry communication activities. It describes the challenges that those working to communicate chemistry face in this domain.
- Communicating chemistry going forward: This section summarizes the latest recommendations in communicating chemistry, and offers a preliminary set of themes and areas for further investigation that may be valuable to consider in future efforts to communicate chemistry to the public.
- Describing chemistry communication: This section describes some of the qualities and elements that can be used to understand and categorize the vast array of chemistry communication efforts found in the current landscape.
- Examples: This section provides in-depth descriptions of a number of chemistry communication efforts, providing portraits of the range of activities at work that highlight some of the findings described in this study. *[To be added in a final draft.]*

Methods and approach

This landscape study began with an initial literature review that identified a number of resources and publications that informed the topic. NRC staff produced an initial bibliography that included references in the following general categories:

- Science communication
- Chemistry communication
- Chemistry learning
- Chemistry and outreach programs for students and adults
- Chemistry and designed spaces
- Chemistry and arts initiatives
- Science in the media, and chemistry in the media
- Chemistry and online resources

With this bibliography in hand, Grunwald Associates LLC, and its sub-contractor Education Development Center, Inc. (EDC), worked with NRC to further refine the areas of interest. For example, most of the current research on chemistry learning addresses issues of teaching and learning chemistry in formal educational settings, which is not of relevant to this landscape study.

In addition to reviewing the literature referenced by NRC staff and conducting additional literature scans, Grunwald and EDC collected additional background information, research, perspectives, and examples of chemistry communication from a wide variety of sources. The efforts that contributed to this study are outlined below.

1. Interviews with NSF program officers. On two separate occasions, EDC and Grunwald met with NSF program officers to learn about their perspectives on communicating chemistry and to solicit recommendations for people and projects to include in the study.
2. Search and review of NSF projects, and projects listed in informalscience.org. EDC staff searched and reviewed a number of funded NSF projects that either directly or indirectly addressed the issue of communicating chemistry. The focus of these searches was the Informal Science Education (ISE) program – including Connecting Researchers and Public Audiences (CRPA) projects – and its associated web-based database of project reports on informalscience.org. Projects from the Centers for Chemical Innovation (CCI) and the Innovative Technology Experiences for Students and Teachers (ITEST) program were also included.
3. Web searches for chemistry in science media. The world of science media is enormous, and while it was in no way possible to do an exhaustive search, EDC targeted a number of popular media sites to seek out how and when chemistry was addressed.

4. Expert interviews. Following recommendations from both NRC and NSF, EDC conducted a number of telephone interviews with experts in the field about their experience with and understanding of communicating chemistry. These experts included chemists, informal science educators, and media producers. (See interview list and protocol in Appendix.)
5. LinkedIn online discussion. Grunwald manages and facilitates an active group, “NSF Media & Informal Science Learning,” on the LinkedIn social network site. This group has over 1,800 members. Grunwald, along with EDC, led a multi-week series of discussions about different aspects of communicating chemistry. This rich discussion provided a wide range of perspectives, experiences, and examples of people and projects to include in this report. (See discussion lists and prompts in Appendix.)

While this study aims to offer a some insight into the breadth of the landscape of chemistry communication, it is also just a snapshot, shaped in large part by the experts we were able to reach and interview, and the members of the broader community that took the time to participate.

2. Background on science communication and outreach

Describing science communication and education in informal settings

While the focus of this work is on the field of chemistry, it is impossible to consider chemistry communication and learning without first looking at the broader field of science communication and informal science learning. A growing body of evidence indicates that people learn science in informal, free-choice settings, and research indicates that these experiences are increasingly important in contributing to the public’s knowledge of science (NRC, 2009; Falk, 2010). However, it is a challenge to identify, let alone measure, the enormous variety of efforts and experiences that can be included in this realm. How do we describe and understand communication, outreach and informal learning? In recent decades, there have been increased efforts by various stakeholders, including both scientists and educators, to put forth frameworks, models, and definitions for describing and understanding science communication and learning in informal settings. These explorations of the different settings, goals, and premises of science communication and learning in informal settings are a useful starting point for investigating the current state of communicating chemistry to the public.

Strands of informal science learning

The National Research Council’s own publication, *Learning Science in Informal Environments* (2010) explored and synthesized the range of science learning across

informal settings, and offered what has quickly become an oft-cited and utilized framework for understanding the goals of these efforts. According to the publication, informal science learning takes place through a wide range of experiences and activities: everyday experiences, designed spaces, school and community programs, and media. These experiences contribute to a variety of kinds of outcomes, or “strands of science learning.” These strands offer a framework for understanding what can happen in science learning in informal settings.

Learners in informal learning environments:

1. Experience excitement, interest, and motivation to learn about phenomena in the natural and physical world.
2. Come to generate, understand, remember, and use concepts, explanations, arguments, models and facts related to science.
3. Manipulate, test, explore, predict, question, observe, and make sense of the natural and physical world.
4. Reflect on science as a way of knowing; on processes, concepts, and institutions of science; and on their own processes of learning about phenomena.
5. Participate in scientific activities and learning practices with others, using scientific language and tools.
6. Think about themselves as science learners and develop an identity as someone who knows about, uses, and sometimes contributes to science.

Science communication

Burns, O’Conner, and Stocklmayer (2003) explored and unpacked a number of terms and elements that inform the current understanding of science communication. They recognized that communication is complex and contextual, and noted the increase in appreciation for the dynamic and interactive nature of communication. They describe four broad domains within science communication: public awareness of science; public understanding of science; scientific literacy; and scientific culture. These domains can be distinguished by their focus, the kinds of tools they employ, and their specific intended goals. Despite these distinctions, Burns, O’Conner, and Stocklmayer (2003) proposed that these domains share a common set of personal responses by people who experience them. It is these responses to science that define science communication (p 191):

“The use of appropriate skills, media, activities, and dialogue to produce one or more of the following personal responses to science:

- Awareness, including familiarity with new aspects of science

- Enjoyment or other affective responses, e.g. appreciating science as entertainment or art
- Interest, as evidenced by voluntary involvement with science or its communication
- Opinions, the forming, reforming, or confirming of science-related attitudes
- Understanding of science, its content, processes, and social factors.”

Public engagement with science

The Center for Advancement of Informal Science Education (CAISE) convened an inquiry group to investigate the issue of public engagement with science (PES), resulting in a publication that defined the domain and explored current activities (McCallie, E., L. Bell, et al., 2009). As with the understanding of science communication mentioned above, their definition of PES also emphasized interactivity, characterized by “*mutual learning* by publics and scientists” (emphasis theirs). They offer: “PES experiences allow people with varied backgrounds and scientific experiences to articulate and contribute their perspectives, ideas, knowledge, and values in response to scientific questions or science-related controversies” (p. 12). PES experiences include both “mechanisms,” activities where mutual learning is part of the experience, and “perspectives,” experiences that do not involve direct interaction between scientist and audience, and may incorporate non-scientist perspectives to address a topic from multiple angles.

The CAISE report highlights how PES experiences contribute to broader goals of informal science education. Specifically, PES supports:

- Science literacy, and understanding of science concepts and processes;
- The development of relationships with scientists—between the public or community and scientists, as well as among scientists;
- People’s understanding of the relevance of science to their lives and society;
- The broadening and expansion of audiences and participants in science.

Further, in an effort to map an understanding PES (and differentiate from public understanding of science, or PUS), the CAISE group offered a framework based on three dimensions: 1) the role of the public; 2) the role of the STEM experts; and 3) the content focus.

These three models—the strands of informal science learning, the responses to science communication, and the description of PES—have a number of common qualities; they leave behind what has been called the “deficit model” of learning and communication and they recognize the range of possible goals and outcomes of learning and communication. While there is an overlap, the strands of science learning and the

science communication definitions focus largely on the experience of the participant—including affective responses and the development of skills and knowledge. The PES model is more attentive to the process, or what efforts and activities look like. These frameworks pay different attention to who are the providers and who is the audience. This difference points to an opportunity to think about outreach, communication, and informal learning from a more holistic or integrated perspective, as part of a larger system.

What makes good science communication and education in informal settings?

With these definitions and models in mind, we looked to both the literature and the expertise of the field to articulate some main ingredients of good science communication and learning in informal settings. First and foremost, we learned that effective communication is not simply a one-way flow of information, from scientist to audience. As made clear through the models above, there has been a shift from this “deficit model” of communication that relies on the passive transmission of knowledge, to a contextual approach that facilitates active participation and engagement on the part of the audience. This shift in approach acknowledges a mutual lack of understanding between scientists and the public, as well as the growing understanding that communication is a negotiation of understanding and meaning (Burns, O’Conner, and Stockmayer, 2003; Gregory and Miller, 1998; McCallie, Bell et al., 2009). People bring their own preconceptions and opinions to whatever science content they access. Science content is not communicated in a vacuum (Flatow, 2013).

As a starting point, Gregory and Miller’s exploration of science communication (1998) offers a protocol for communication that supports the public understanding of science. This protocol includes the following principles:

- Acknowledge the place of popularization
- Be clear about motives
- Respect the audience
- Negotiate new knowledge, understanding and attitudes
- Establish a basis for trust
- Acknowledge the social in science
- Facilitate public participation

The experience in the field echoed and further articulated these principles. Interview subjects as well as participants in the LinkedIn discussion described a number of attributes of and practices for good science communication and learning in informal settings. One LinkedIn participant succinctly stated, “All [science topics] benefit from real world examples, dramatic demonstrations, and hands-on experience.” Building on

this, the detailed aspects of good science communication that we heard from the field include the following (Interviews 2, 3, 7, 11, 12; LinkedIn):

- Make real-world connections, starting with ideas and examples that are exciting and relevant;
- Show, don't tell, and include as much participation and hands-on activities as possible;
- Know your audience(s), including what they already know and want to know, and be developmentally appropriate;
- Use accessible language and metaphor, provide 'translation' and models for difficult concepts, and don't talk down to the audience

Throughout our research and conversations, experts described the value of informal science learning in broadening the participation of underrepresented populations in science. We would be remiss if we did not note this aspect of science communication for the work at hand. Some specific notes from our research about how and why broadening participation is a concern are included below.

- Research indicates that achievement/performance gaps between advantaged and disadvantaged children can be attributed to (or a consequence of) what happens outside of school (Falk, 2010).
- Free-choice learning experiences jump-start a child's long-term interest in science topics, and improve science understanding among underrepresented populations (NRC, 2009).
- The NSF's Science and Engineering Indicators 2002 report cites a 2000 American Chemical Society (ACS) survey of public attitudes towards chemistry and chemists: When asked to think about the word "science," 11% said chemistry; those with higher education/income were more likely to mention chemistry. Respondents expressing the least negative attitudes toward the chemical industry were those who had college degrees and/or household incomes exceeding \$60,000.
- Issues such as the achievement gap and challenges in formal education and low-income communities carry over into the outreach, communication, and informal learning spaces (LinkedIn).

3. The current state of “communicating chemistry”

As we interviewed experts in the field about communicating chemistry, many of them reiterated the notion that “chemistry is everywhere!” (Interviews 4, 7, 8, 11). However, that may not necessarily be the case when it comes to outreach, education, and communication activities. As we initially looked for projects that explicitly address chemistry, we found that chemistry was less common as a subject than either biology or physics.¹ That said, the chemistry communication efforts we did encounter were incredibly diverse. Many long-standing institutions of science communication address chemistry in their work in some way: the “Marvelous Molecules” exhibit at the New York Hall of Science shows visitors the chemistry of living things; PBS’s science program *Nova* produced a 2-hour special “Hunting the Elements,” originally aired in April 2012, that explored the periodic table. Other organizations facilitate science outreach activities that incorporate chemistry, including science cafés or lecture series on a topic of interest, such as the chemistry of beer or what to know about pesticides. In addition to these more formal, coordinated activities, there has been an explosion of science and chemistry communication via the internet, with the creation of things such as YouTube videos and science blogs, and now extending into social media.

Many members of the LinkedIn “NSF Media & Informal Science Learning” group indicated that in most cases, chemistry was not explicitly attended to in their programs or mission, but rather, included under the umbrella of STEM. These activities tended to align with the informal science learning and education framework shared in the previous section. With the exception of a few organizations, such as chapters of the American Chemical Society (ACS), chemistry was just one of many STEM topics being addressed by educational programming, whether it be at a science museum or in an afterschool setting. In many cases, its inclusion depended on, or was a reflection of, the training and background of an organization’s leadership and staff. If someone on staff had training and expertise in chemistry, it was much more likely to be included; said differently, some commenters in the LinkedIn discussion noted that *unless* staff had a background in chemistry, it was unlikely to be included.

Through our interviews, we talked with a number of chemists, who, with the chemistry content in hand, were involved with various education and outreach activities. In many cases, these outreach activities were the product of funding requirements, with funders such as the NSF requiring outreach as a component of research grants. These outreach activities, conducted via research-focused academic institutions, were often creative and

¹ For example, searching on informalscience.org, key word search for “chemistry” yielded 82 projects, while physics had 194, biology 123, as of October 2013.

idiosyncratic; examples include chemistry-related podcasts, flash mobs, and science pubs. These efforts often reflected the science communication and PES models described earlier. As one chemist involved in outreach stated, “Personally I’ve made it my mission to change attitudes towards chemistry” (Interview 8).

Challenges in communicating chemistry

A persistent idea informing this project’s larger effort is that chemistry communication is subject to a particular set of challenges. This study explicitly posed the question, “Are there specific challenges to communicating chemistry?” Many experts in the literature, in interviews, and online, responded with a resounding, “Yes!”² Everyone we queried had something to say about the challenges they face in communicating chemistry. The most commonly cited challenges — from the interviews and online discussion, and supported by the literature — are listed here in the order of how often they appeared, and are further explored below.

1. Perceptions of chemistry.
2. Difficulty, and public’s current lack of knowledge of chemistry.
3. Complexity and the abstract nature of chemistry.
4. Chemistry’s lack of disciplinary unity.
5. Chemistry is messy.
6. Chemistry’s culture, and lack of interest in or incentive for communication.

Perceptions of chemistry

Perhaps the most common response to the question, “What are the challenges in communicating chemistry?” is the public’s negative perception and attitude toward chemistry. Many lament that ‘chemistry’ has become a bad word, and ‘chemophobia’ is referenced in a number of publications, and was frequently cited both in interviews and in online discussion (Gregory and Miller, 1998; Harpp, 2011; Hartings and Fahy, 2011; NRC, 2011; Ucko, 1986; Zare, 1996; Interviews 4, 8, 10; LinkedIn). The twentieth century saw shifts in perceptions of chemistry from a field that could yield new materials and innovations to one associated with weapons of war and environmental disaster, and there is a lot of suspicion when it comes to the chemical industry (Gregory and Miller, 1998; Hartings and Fahy, 2011; Interviews 2, 4). An exhibit designer noted purposefully leaving the word “chemistry” out of an exhibit title to make it more appealing (Interview 11). More recently, many participants in our interviews noted the misuse of

² Each area and discipline of science has its own set of challenges and considerations. It should be noted that we are not stating that the challenges we describe for chemistry are necessarily unique only to chemistry, but rather that these are the challenges the field of chemistry has identified for itself.

the word “chemical” in the marketing of organic and environmentally friendly food and cleaning products. “How many times do you see something labeled as ‘chemical-free’?” was a common refrain in these conversations.

It seems that many people have had bad experiences with chemistry in formal education, and have a negative image of chemists (Interviews 7, 8, 11). One interview subject submitted that chemistry needed to invest in a new marketing campaign (Interview 10). One LinkedIn participant posted, “It doesn't have the touchy-feely aura of biology, the clean feel of physics, the great outdoors of geology, or the wistful nights of astronomy. It scares people and intimidates them with endless lists of elements, chemicals, and reactions.”

In addition to these stories, there are data that quantify the extent of the public's negative view of chemistry. The NSF's Science and Engineering Indicators 2002 report cites a 2000 American Chemical Society (ACS) survey of public attitudes towards chemistry and chemists, where 1/3 of those surveyed had unfavorable view of chemical industry/chemical companies, and the chemical industry was ranked the least favorable among 10 science-related industries. Specific reasons for the negative views were reported to include the environmental impact of chemicals and the harm to health, as well as the view of the industry as one that pollutes the environment and does not communicate with consumers.

Difficulty, and the public's current lack of knowledge of chemistry

Chemistry is hard to learn—as one interview subject exclaimed with frustration, “Why is chemistry so darn difficult?!” (Interview 11) Chemists noted the large body of knowledge, including math skills, required to understand and explain even basic chemical concepts. The need to have knowledge, such as an understanding of how chemical structures work, can pose a challenge when trying to explain chemistry to a non-chemist audience (Hartings and Fahy, 2011).

Many cite the general public's lack of prior knowledge when it comes to chemistry. Communicating chemistry is a challenge when one does not know an audience's pre-existing scheme or misconceptions when talking about concept (Calascibetta et al, 2000; Ucko, 1986; Interviews 2, 3).

A number of chemists, chemistry communicators, and science outreach and education professionals lament the state of formal chemistry education. Many people have little chemistry as part of their formal education (Interview 11). Little chemistry is taught in the elementary grades, and number of educators expressed the need for chemistry to be

introduced earlier in school (LinkedIn). At the secondary level, some we interviewed expressed concern about both the pedagogical approach used to teach chemistry and the curriculum, indicating that it is focused on memorizing esoteric concepts rather than promoting broader understanding and is detached from real-world processes (Calascibetta et al, 2000; Interview 7, 11; LinkedIn). Some also noted the amount of math included in chemistry education at this level, and how that brought an additional set of challenges and difficulties with respect to students' abilities and interest (LinkedIn). At the post-secondary level, professors described how chemistry is viewed as a hurdle in undergraduate years, and something often feared by students interested in medicine and other graduate studies (Interviews 7, 10, 11).

The public's knowledge of chemistry is not the only issue here. A number of people cited the lack of chemistry knowledge of the staff in afterschool programs or on museum floors, as well as that of teachers, especially for elementary grades, as a contributing factor (Interviews 3,5; LinkedIn).

Complexity and the abstract nature of chemistry

Chemistry is complex and abstract, and is difficult to see and therefore understand. Much of chemistry is invisible. Often, a conceptual leap, or even a leap of faith, is required to understand how such small things as atoms can make such large changes in something's properties or behaviors (Brunsell, 2011; Hartings and Fahy, 2011; NRC, 2011; Interview 1; LinkedIn). To paraphrase an interview subject, when you can't see it, it doesn't feel relevant, and therefore it takes more thought and effort to talk with people about it in order to help them build a connection (Interview 8). Similarly, a LinkedIn commenter stated that "the notion that all chemistry happens in a lab somewhere, rather than on your dinner plate, or in the sky, or in your car or your body every day" was "a tough nut to crack."

Although chemistry has an infinite number of applications, chemistry by itself is not perceived as having the same applied aspects of something like biology (Interview 4). One LinkedIn participant offered a helpful summary of how this plays out: "Always, I think that learning and teaching should be about relevance and the ability to apply the information and see the concepts as real and applicable. Even though chemistry affects all aspects of life the examples tend to be a little more abstract. Students often have no idea how some of the high order concepts can be applied to everyday examples."

The LinkedIn discussion surfaced that, in particular, when thinking of children, there needs to be an understanding of how children think and learn. On one hand, children

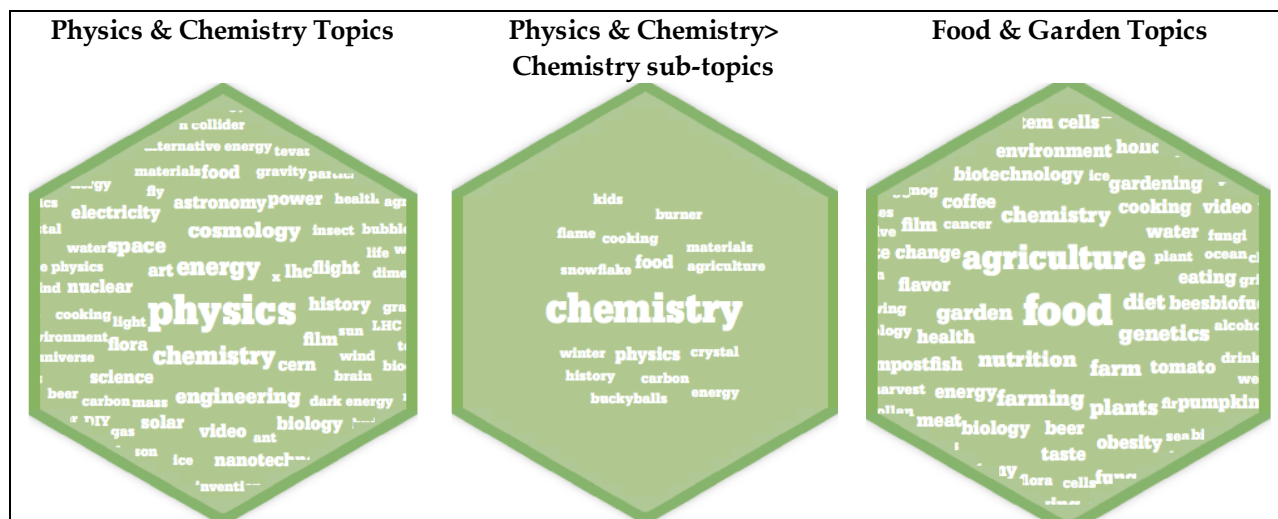
are easy to engage and are natural explorers and scientists; on the other, it is easy for them to develop misconceptions (LinkedIn).

Chemistry's lack of disciplinary unity

Chemistry's central role in science has at the same time led to chemistry being incorporated in a wide range of science domains and endeavors; as much as it is the 'central science' it can also be called 'the in-between science' (Interview 4). Some have characterized this as a "lack of disciplinary unity;" there is no single idea that unites the field, no grand theme or common story about what it is and means (Hartings and Fahy, 2011; NRC, 2011). One LinkedIn commenter described chemistry as "a means to an end."

In addition, there is tremendous overlap of chemistry with other fields and areas of science. Many scientists doing chemistry do not necessarily think of themselves as chemists (NRC, 2011). For example, a 2009 editorial in the journal *Nature Chemistry* addressed the fact that that year's Nobel Prize for Chemistry was awarded to scientists studying the structure and function of the ribosome, something that many consider a topic for biology. That article wrestled with the ideas behind disciplinary distinctions, a recurring theme in discussing what is chemistry in the context of communication of science. The same journal raised this question in 2011, discussing goals and aspirations at the start of the International Year of Chemistry. That editorial cautioned that there is a danger that chemistry becomes so diffuse across different areas that it loses its identity and recognition in its own right.

Chemistry in the media is frequently presented and organized by its application. While this make sense, especially in response to the challenge of the abstract nature of chemistry cited above, it also raises the issue of how audiences find or know that chemistry matters. A clear example of the way chemistry gets embedded in other topics can be seen on the web site for Science Friday, NPR's weekly science radio program. Among the 13 big topics that organize the website's content is "Physics and Chemistry." The text cloud of key words on the webpage shows chemistry as secondary to physics in frequency. Select the chemistry topic, and you see a small number of sub-topics. As evidenced by the key word cloud, chemistry is a major sub-topic in other areas, such as "Food and Garden." However, other areas that logically include chemistry concepts, such as climate change and energy, make no use of the keyword chemistry. See screen shots below.

Figure 1: Topic word clouds for content on Science Friday web site.³

Chemistry is messy

The fact that chemistry experiments and demonstrations are wet, messy, and potentially dangerous is a challenge cited by a number of informal science educators, especially those working in museums and other informal settings. The challenge of including chemistry in science museums is not new. A 1990 ASTC survey of science museums and science centers found that 28% of science museums reported no chemistry activities and less than 30% had chemistry exhibits (Zare, 1996). More recently, Silberman noted that chemistry continues to be one of the least represented disciplines in science museums (2004).

Several sources reiterated the ‘messy and dangerous’ challenge, adding that there are also the issues of cost of materials/consumables and training of staff (Silberman, 2004; Interviews 1, 2, 3, 4, 5, 11). A LinkedIn discussion participant further emphasized the dangerous aspect, offering the example of doing a science program at a library: no one questions bringing a snake or a Tesla coil, but try to bring chemicals (even harmless ones), and you face many hurdles, such as Materials Safety Data Sheets. A few have noted the disappearance of the children’s chemistry set (Zare, 1996; Interview 4), possibly because of these same issues.

³ Screen images taken from www.sciencefriday.com, accessed on May 1, 2013.

Chemistry's 'culture' and lack of interest in or incentive for communication

There is a notion, expressed by some, that chemistry as a field, in particular, has less of a tradition of communication and collaboration with those outside the field than other areas of science (Interviews 8, 9). Chemists “do not actively work on communicating their research in ways that are approachable to non-specialists” (Hartings and Fahy, 2011). As one chemist interviewed for this study noted, it is only recently that chemists were expected to consider outreach or public education as part of their role, and there is still only limited incentive or support to do so (Interview 9). A commenter on LinkedIn noted how the mindset that scientists and students at research institutions be expected, let alone encouraged, to engage in outreach activities is “incredibly rare.” Others note a general sense that chemists are not particularly trained or skilled at communicating with a range of audiences (Interview 1). This issue may not be confined to chemistry, but may be an issue across the science and the academy.

Another criticism that we found in the literature is that chemistry may also suffer from poor communication within its own field, which may both reflect and contribute to this field's culture of communication. Velden and Lagoze (2009) posited that chemistry lags behind other science areas with respect to the adoption of new communication and collaboration technologies (such as open access, pre-print services, and science blogs), and identified a number of contributing issues and factors. These included chemistry's focus on creation, with limited emphasis on development of theory; its large number of small research areas; its dependence on lab-based, rather than digital or computer-based, research; its diversity of research cultures; its proprietary nature and industry incentives for secrecy; and the industry-academy imbalance that resulted, where industry is more a consumer of than contributor to research. What is interesting about these findings is that some of these factors that challenge communication within the field mirror the challenges that have been described in communicating chemistry to the public—chemistry's complexity, the lack of disciplinary unity, and the fact that it's messy, for example.

4. Communicating chemistry going forward

Recommendations for communicating chemistry

Chemistry communication and education in informal settings logically should abide by and benefit from the same principles and frameworks of any good science communication. In other words, good chemistry communication should be the same as good science communication. Good science communication is engaging and relevant, and many of the challenges in communicating chemistry can be considered challenges with making chemistry engaging and relevant. During our research, we sought out

recommendations for effective chemistry communication, outreach, and informal education, which are summarized below. These recommendations align with the ingredients of good science communication already described, and often respond to the identified challenges; while certainly applicable across the sciences, they were offered with chemistry in mind.

Focus on audience: A number of sources indicate that chemistry communication needs to really begin with the audience (Hartings and Fahy, 2011; NRC, 2011). What does the audience know, and what do they want to know? What will appeal to their interests? (Interviews 1, 11; LinkedIn). In the literature, interviews, and discussions, we repeatedly heard the call for a greater attention to audience. There are many kinds of audiences, or ‘publics’ as referred to by Burns, O’Conner, and Stocklmayer (2003). Different audiences have different needs, and all audiences bring existing knowledge, perceptions, and misconceptions to bear on any new experience. The more that chemistry communicators invest in understanding their target audience, the more effective the communication is likely to be. One LinkedIn discussion participant recommended that communicators “conduct research on what key segments of the public already think, understand, and believe; and then create appropriate explanatory metaphors that help people make reasonable inferences. This is a process of science translation -- almost literally finding alternative language, analogies, and images that help.”

Focus on interesting, relevant questions: Chemistry experiences need to be designed around helping the target audience make connections to society (Hartings and Fahy, 2011; NRC, 2011; Interviews 2, 5, 11). In the NRC workshop summary about communicating chemistry in media, producer Stephen Lyons emphasized that chemists need to do a better job of framing their work with big, engaging questions (NRC, 2011). Similarly, others recommended that chemistry communications should start with a question, problem, or phenomenon, and work backwards into the chemistry (Interviews 2, 3, 7, 11; LinkedIn). Activities should not be focused on principles, but be “designed to inspire fun” and include a little “wow” (Silberman, 2004; Interview 5). And, chemistry efforts should focus on questions that the audience thinks are important and for which they have a point of reference (Ucko, 1986; Interviews 5, 6). Many of these same people note that there is such a wide range of examples and issues in chemistry that are cool and exciting, there is something in chemistry for everyone.

Tell good stories, especially about people: What makes chemistry interesting? Compelling stories, including those about people (NRC, 2011). Story-telling, and the need to find and use methods that help people connect and engage with the material, was cited by a number of people as something that chemistry efforts need to improve

and address (Interviews 8, 11). One LinkedIn commenter offered, “Have a story [that] weaves in the chemistry. If it’s not a good story, it doesn’t matter how good the chemistry.” Metaphor is a powerful way to make difficult concepts concrete, and characters keep audiences engaged (Kerby, 2010). Chemistry stories need to include interesting people. An example that was offered was the success of the National Chemistry Week theme, “The Many Faces of Chemistry.” During that year, activities exposed audiences to the diversity of people and professions involved in chemistry, and offered the chance to learn the stories of their work (Interview 5). Another interview subject described doing outreach activities in small towns, where many people had never seen or talked to a chemist and there was value in audiences just learning about chemists as people (Interview 10).

Be thoughtful about outcomes: Chemistry communication efforts need to differentiate between goals and outcomes, and be designed accordingly. There is a difference between the goals of increasing awareness and developing budding scientists. Activities need to be designed with the intended result. How much does the audience/participant need to know? Enough to care? To trust a scientist? To change behavior? To want to learn more? (Interview 1) Having a desired target outcome will inform the design of the experience. Activities designed to interest and entertain are different than those that aim to teach concepts (Interview 7).

Chemistry efforts need to be cautious and attentive with regard to the level of content and detail. Chemistry communication is prone to presenting too many details, and those doing the communicating are not necessarily skilled at knowing when to stop (Interview 3, 8); chemistry communication needs to find the balance between being simple and accessible, and being reductive (Interview 5). One interview participant described the experience of designing good chemistry communication efforts as demanding “the need to let go of a lot of what I think is beautiful or complex about chemistry” in order to make connections that make sense to people, because people need to connect with something other than chemistry as its own subject (Interview 8).

Finally, these different kinds of activities are worth evaluating. As one interview subject shared, “even though many of these people are doing research in chemical education or various disciplines of chemistry, they somehow think outreach is not important enough to include assessment in it” (Interview 7).

Considerations about outcomes, and the appropriate content that will support them, bring us back to the issue of audience. Clearly, all of these elements inform, and rely upon, each other.

Additional considerations

In our conversations with experts and in the online discussion, everyone agreed that communicating chemistry is important and needs to be attended to, and more, expressed a sense of optimism and possibility that there was so much more that could be done to improve chemistry communication, outreach, and learning activities. Building on the recommendations for improving chemistry communication, we identified a number of ideas and issues that seemed to speak to areas for future investigation or consideration.

There are new models and funding sources that encourage scientists and the academy to increase involvement in outreach activities (Interviews 1, 7, 8, 9).

- CCIs are developing a next generation of scientists that are expected to participate in outreach activities. Graduate and undergraduate students in these centers understand that outreach to the community is part of their role, and are being trained in how to best engage with public audiences.
- At the same time, some academic institutions do not necessarily support this work, and in some cases inhibit or dis-incentivize it.
- Who is best positioned and trained to be communicating chemistry? Is it rewarding to researchers, when it may not see it as an intellectual challenge? Are they trained to do it? Should it be a priority?

A number of sources question whether chemistry communication is taking full and best advantage of the incredible array of technology and media, both for creating communications and for dissemination.

- There are a growing number of examples of using video and animation to explain concepts in formal education (particularly by universities). Technology enables us to create more and more valuable visualizations. A lot of ‘demonstrations’ that can’t be done in an exhibit or event space can be done using media. At the same time, there is concern that visual aids need to be done well (Eilks, 2009).
- Chemistry efforts need to pay attention to the role of media and the need for better science literacy in the media. How can chemistry communication efforts best work with the media, especially when there are always new stories about pressing topics such as the environment and energy that are rife with misinformation?
- Who is the audience for science in the media (or for many science communication and outreach efforts)? Most science blogs/journalism are/is being accessed by people who are already interested in science, who tend to be more educated than the general audience. (Flatow, 2013)

- A recent broadcast of the radio program Science Friday, “Preserving Science News in an Online World” (2/1/2013), discussed influences on the public’s perception and understanding as they consume science-related media online. A study published in *Science* magazine found that it was not just the main science content itself, but also the online “life” of content (social media sharing, comments, twitter) that influences readers’ perceptions of the material. For example, negative or rude comments following a science blog post or article have an impact on readers’ responses to the blog itself. This raises the question, how does one shape and use online media environments for most effective science communication?

The informal learning space and associated institutions offer a lot of advantages and affordances. While this is not particular to chemistry as a subject, chemistry efforts need to pay attention to them.

- Informal science has a huge advantage. As one interview subject described, it is driven by interest, and doesn’t include tests (Interview 10). Informal learning experiences can be driven by interest and real-world problems. As one commenter on LinkedIn offered: “We [informal science programs] offer something that no one else offers — opportunities for actual hands-on experiments with no downside for failure to do something wrong.”
- Ucko (2013) asserts that science centers need to recognize the changing landscape of informal science learning, with the growing use of new media and freely available (but unmediated) online sources. In this environment, science museums and centers need to orient themselves around what they uniquely offer and excel at, including learning experiences, public engagement, partnerships, and research and evaluation.

There are interesting new venues, forums, and activities that chemistry may be able to take better advantage of.

- How is/can chemistry be included in the Maker and Maker Faire spaces? (Interviews 3,4,7)
- How can chemistry be incorporated into gaming? (Interview 7)

A number of sources and individuals called for the increased need to invest in research and evaluation to understand what kinds of chemistry communication efforts are successful and effective. At the same time, there is recognition that evaluating these kinds of activities is a major challenge (NRC, 2009; NRC, 2011; Interviews 4, 8, 10).

5. Describing chemistry communication

Overview of the purpose and scope of this description

Over the course of reviewing, researching, and learning about many chemistry communication and outreach activities, we found incredible diversity among efforts: science museums designing exhibits for all ages, university-based chemists engaging in lectures and community events, blogs and online media addressing particular issues and interests, informal STEM programs engaging young people in investigations, nonprofits offering classes about chemistry in our every-day lives.

Recognizing that it is impossible to know of, let alone describe, each and every one of these individual situations, we believe it may be valuable to understand the range of organized activities and efforts that are part of chemistry communication, outreach, and informal education by identifying a number of key categories that describe and catalog the incredible diversity in the field. We believe describing the types of chemistry communication activities, and understanding the ways in which they vary, will help to inform future efforts in developing a framework for supporting chemistry communication in the future. In order to accomplish this, we move from the particular activities to a more general review of the kinds of activities that are both happening and possible.

We considered the challenges and recommendations for good chemistry communication surfaced in the previous section of this report within the more applied context of attributes and characteristics of such experiences. The core recommendations — focus on audience, focus on interesting questions, tell good stories, be thoughtful about outcomes — are essentially a call to be thoughtful in the design of experiences. The categories and descriptors of communication activities we identified support this approach and provide guidance when considering the following questions:

- What is the purpose of the activity?
- Who is the target audience?
- What is, or should be, the venue?
- What content should be included?

These questions are not linear; in many cases, the answers to some of these questions are predetermined, and subsequently inform the response to any unanswered questions.

Below we provide an overview of major categories that reflect the answers to some of these questions, and that help to describe the range of possibilities for activities. Each category includes a table outlining the subcategories and characteristics, followed by a more detailed description of each category, with supporting references and examples. It

should be noted that these categories are not exclusive — many efforts bridge categories or include multiple approaches within a category. These categories do not result in a definitive label or identification of the effort, like a Myers-Briggs personality type. Rather, it allows efforts to be understood in the context of what we know about chemistry communication and science communication efforts writ large.

Purpose/Goal

Dimension	Categories	Sub-categories/descriptions
Purpose/Goal	Education	Develop interest, motivation to learn Understand and use concepts Explore, question, and observe Reflect on science processes Use science language and tools Develop a science identity
	Communication	Awareness of science Enjoyment or other affective responses to science Interest in science Opinions with respect to science Understanding of science

The purpose or goal refers to the overall intention of the effort. Based on the frameworks discussed at the beginning of this report, it is clear that there are varying purposes for communication efforts. While some of the people we heard from via interviews and LinkedIn clearly identified themselves and their work as educational, many were less explicit about the purpose or goal of their work. Therefore, we believe it may be useful to rely on the two main concepts already clearly defined in the literature, education and communication, and use the associated outcomes to get a better understanding of what chemistry outreach efforts can, do, and should accomplish.⁴

- Education: While education may be considered a goal of all chemistry communication efforts, in this case we think it is helpful to distinguish when an

⁴ In reviewing frameworks to define purpose and goals, we found that the CAISE Public Engagement with Science report's *content* focus areas actually reflect and align with the goals of both education and communication. The content focus areas are:

- Understanding of the natural and human-made world: emphasis on phenomena, fact, theory, laws, and concepts.
- The nature of the scientific process or enterprise
- Societal and environmental impacts and implications of science and technology
- Personal, community, and societal values related to applications of science and technology
- Institutional priority or public policy change related to science and technology

effort identifies itself primarily as an education activity. The NRC's strands of informal science learning offer a comprehensive set of learning outcomes that can be achieved through informal education experiences (2009).

- Experience excitement, interest, and motivation to learn about phenomena in the natural and physical world.
 - Come to generate, understand, remember, and use concepts, explanations, arguments, models and facts related to science.
 - Manipulate, test, explore, predict, question, observe, and make sense of the natural and physical world.
 - Reflect on science as a way of knowing; on processes, concepts, and institutions of science; and on their own processes of learning about phenomena.
 - Participate in scientific activities and learning practices with others, using scientific language and tools.
 - Think about themselves as science learners and develop an identity as someone who knows about, uses, and sometimes contributes to science.
- Communication: While we have been using the word communication throughout this report as a comprehensive term encompassing all of the efforts under considering, communication as a goal or purpose here refers back to the definition offered by Burns et al, 2003. They specifically defined communication as producing one of the following responses:
- Awareness of science
 - Enjoyment or other affective responses to science
 - Interest in science
 - Opinions with respect to science
 - Understanding of science

Setting/Format

Dimension	Categories	Sub-categories/descriptions
Setting / Format	Designed space	Science museum Science/nature center Zoo/aquarium
	Media	Video (TV, web-based) Radio (Broadcast, podcast) Print (Journals, online) Blogs Social media and online communities
	Event	Science festival Science café Public lecture/conversation Performance (art and theater)
	Program	Afterschool program Adult education program Citizen science

This is perhaps the most general and quickly identified characteristic of these efforts, answering the question of, “What is it and where is it happening?”

Chemistry communication and outreach includes designed spaces, programs, media, and events (Falk and Dierking, 2010; NRC, 2009; NRC, 2011). Each of these offers a number of further categories or specified formats and settings.

- **Designed space:** Designed spaces include places and environments that are intentionally designed to support science learning (NRC, 2009). These include museums of science and technology, science and nature centers, and zoos and aquariums. Designed spaces tend to provide a range of exhibits and activities, which require little guidance or direction and allow for multiple points of entry (conceptually) to accommodate a wide audience.
- **Media:** Media has grown to be an incredibly broad category that encompasses video, radio, and print communication distributed and available through an ever-growing variety of channels. Once thought of in terms of traditional media formats, such as broadcast television programs like NOVA and science journals, the ubiquity of online access and the array of dissemination channels it enables, like YouTube, blogging, and podcasts, has made media a dominant format for science communication. As noted in the previous section of this report, media offer new opportunities for communication (p. 16), and social media in particular is a space that offers additional possibilities (LinkedIn; Interview 4).
- **Event:** Events include one-time outreach, communication, or learning experiences, in a variety of shapes and sizes. In general, events may be

characterized as being a single experience that brings together experts and an audience. The traditional public lecture, where one or more experts make a presentation to the community, has long been a form of chemistry communication. More recently, the public lecture has been transformed to more informal dialogues or opportunities for chemists to share their knowledge and respond to questions from an audience, and in our research we heard of a variety of such events including Pub Nights and food demonstrations (LinkedIn; Interview 10). Events also include science festivals, which are growing in number around the country. Also in the category of events, we include performances, where chemistry concepts and ideas are communicated through theater, music and art.

- **Program:** Programs have the unique quality of including multiple interactions or experiences, falling on the more formal side of informal science learning. Programs generally fall into two categories: those that serve youth and families, and those that serve adults. Afterschool program in particular have become an opportunity to expand science learning for students. Adult education programs, such as evening classes taken out of personal interest and hobbies, also have become a forum for science learning. We put citizen science initiatives in this category as well, because they often include structured and on-going activities.

Audience

Dimension	Categories	Sub-categories/descriptions
Audience	General public	Attentive public Interested public Issue public
	Children and families	K-8 age youth High school age youth Families
	Targeted demographics	Gender Socio-economic status Underrepresented populations
	Mediators	Educators Journalists Media
	Decision makers	Policy-makers Organization leaders Community influencers

Who is the intended, targeted audience for the effort? The answer to this question dictates many other elements of an effort to communicate about chemistry, and has

been highlighted as a key consideration in the recommendations section of this report (see p. 14).

Audiences are described in many different ways, both within the literature and in our research and review of examples. In some cases, audiences are described by demographics, and in others, by characteristics such as interest and investment. Audience was also described with respect to reaching people in a certain position. In our effort to describe audience, we adapted some of the different publics identified by Burns, O’Conner, and Stocklmayer (2003), while other reflect examples we found in our research.

- **General public:** The general public means that an activity is open to everyone; there is no explicit qualification to participate or group targeted for the audience. A large proportion of efforts describe themselves as open to the general public, but in reality, who is that public? The general public is not one thing, is not all the same, and many communicators can or should attend to the variations. The ‘attentive public’ refers to people who are already informed and invested in science activities, such as students of science elected to participate in a community event. The ‘interested public’ recognizes the people who self-select to participate in activities, even if they are not well-informed about science. And lastly, the ‘issue public’ identifies the segment of the public who participates because of a particular need or concern, such as attending an event that addresses a local environmental or health topic (Hastings and Fahy, 2011).
- **Children and families:** Many programs and events are designed for children and families. In particular, they may target K-8 aged youth, high school students or high school aged youth, and/or families, meaning children of all ages and their parents.
- **Targeted demographics:** We heard of many examples of programs and activities that targeted a particular population—girls, low-income families, and minorities. Many efforts that seek to broaden participation aim to address a specific demographic that is underrepresented in chemistry and/or science (LinkedIn).
- **Mediators:** Mediators are those people responsible for communicating science to others. Mediators include educators (both formal and informal), as well as journalists and other members of the media.
- **Decision-makers:** Decision-makers include policy makers in government, as well as leaders of scientific and educational institutions. They also might include community leaders or influencers—people who are in a position to use what they learn from the activity or communication to make decisions that impact others.

Provider

Dimension	Categories	Sub-categories/descriptions
Provider	Scientist	Academic scientist Industry scientist
	Science communicator	Outreach professional Science journalist Science media-maker Science blogger
	Educators	Museum/science center staff Out-of-school educators K-12 educators

Who is facilitating and offering the chemistry communication effort? This category focuses on the role and identity of the individuals, and in some cases institutions, that are mediating the experience. While “mediators” is included above as a category of audience, there are differences in the kinds of mediators that are providers, and this category may be a distinguishing factor when thinking about how to describe and understand chemistry communication efforts.

- **Scientists:** Scientists include a large group of people who identify doing science and scientific research as their main occupations. Scientists may include both those working in the academy and those working for industry.
- **Science communicators:** Science communicators are people whose primary role is to communicate about science. This includes those working in offices of science outreach (for example, in NSF’s Centers for Chemical Innovation), as well as science journalists, science media-makers, and science bloggers. Science communicators have a varying level of science education and expertise — some are former scientists, and others have had little to no formal science education.
- **Educators:** Educators include those engaged in education in both formal and informal settings. Educators in the informal space include museum facilitators and science center staff. Out-of-school educators include staff who primarily work in afterschool programs or other enrichment programs for youth. K-12 educators are just that — teachers in formal settings. While this study is directed toward informal efforts, there are instances when formal educators are involved in their facilitation.

Chemistry content

What area of chemistry is the subject of or included in the experience? In many cases, this information is not relevant, meaningful, or even made known, to the audience. As we learned when analyzing the challenges chemistry faces, advertising an activity as an

inorganic chemistry education experience may deter audiences. However, from the chemists' perspective, the chemistry content may be an important distinction or consideration. Therefore, it may be useful for those designing the efforts, as well as for those trying to understand the landscape of chemistry communication activities, to situate them within their respective branches of chemistry. These include:

- Organic chemistry
- Inorganic chemistry
- Analytical chemistry
- Physical chemistry
- Biochemistry

Context for content

Dimension	Categories	Sub-categories/descriptions
Context for content	Chemistry (explicit)	Basic chemistry Biochemistry Materials Nanoscience
	Everyday chemistry (implicit)	Food and cooking Health and medicine Gardening and agriculture Products (i.e., cosmetics, cleaners)
	The environment	Current events Climate change Natural resources and energy Atmosphere and water systems
	Chemistry in other disciplines	Astrophysics Biotechnology Medicine Forensic science

What is the context for the activity or communication? What is the reference point or subject area? How is the chemistry being applied? In our research, we found that while some efforts take place under the banner of chemistry, it is just as likely that chemistry is integrated and presented as part of another science topic or area. While an activity may include a number of chemistry concepts, in this category we are concerned with what the 'public face' of the effort is — how it is described and promoted to participants. This set of categories is not complete or exhaustive, as we are continuously learning about new ways to frame and communicate chemistry. The categories below represent the most frequent areas that have been seen to date.

- Chemistry (explicit): Under the name of chemistry, we include efforts that are *explicitly* identified as being about chemistry, about its core principles and

applications. Communication efforts fall in a number of areas, including biochemistry, materials, and nanoscience, and what we call “basic chemistry.”

- **Everyday chemistry (implicit):** Everyday chemistry is differentiated from the above chemistry category in that these efforts include chemistry in the context of everyday life, embedding chemistry in these topics, investigating how chemistry plays a role in the things we do, see, and use every day. Topics in everyday chemistry include: food and cooking; health and medicine; gardening and agriculture; and everyday products, such as cosmetics or cleaners.
- **Environmental science:** Many chemistry communication efforts address issues of the environment. We saw examples of events responding to current events, such as oil spills, and working to explain concepts such as the carbon cycle. They include efforts that address climate change and global warming, and natural and alternative resources and energy.
- **Chemistry in other disciplines:** Some chemistry communication efforts situate or include chemistry within other science disciplines. This includes activities that refer to the role that chemistry has in areas like astrophysics, biotechnology, medicine, and forensic science.

6. Examples from the field

This landscape study offers recommendations for effective chemistry communication, outreach, and informal education:

- Focus on audience
- Focus on interesting, relevant questions
- Tell good stories, especially about people
- Be thoughtful about outcomes

But what do chemistry communication and outreach efforts really look like, in practice? Over the course of conducting this landscape study, we identified a number of chemistry communication and outreach efforts that exemplified one or more of these ingredients, and that also showcase the diversity of the field. These examples take place in a range of settings—in a museum, online, in an educational program—and address a variety of audiences, goals, and content areas. See the table below for an overview of the examples according to categories used to describe chemistry communication offered in the previous section.

Table 1: Examples of chemistry communication and outreach, by descriptive categories

Example	Periodic Table of Videos	Experiencing Chemistry	Westside Science Club	NISENet Public Forums
Illustrates	<ul style="list-style-type: none"> ✓ Tell good stories ✓ Focus on interesting, relevant questions ✓ Be thoughtful about outcomes 	<ul style="list-style-type: none"> ✓ Focus on audience ✓ Focus on interesting, relevant questions 	<ul style="list-style-type: none"> ✓ Focus on audience ✓ Focus on interesting, relevant questions ✓ Be thoughtful about outcomes 	<ul style="list-style-type: none"> ✓ Focus on interesting, relevant questions ✓ Be thoughtful about outcomes
Purpose/ Goal	Communication	Education	Education	Communication
Setting/ Format	Media: Video	Designed space: Science museum	Program: Afterschool	Event: Public forum
Audience	General public	General public	Children, ages 8-13 (low income, under-represented)	General public
Provider	Scientists, Science journalist/ media-maker	Museum/ science center staff	Out-of-school educators, Scientists	Scientists, Museum/ science center staff
Chemistry/ Context for content	Physical chemistry	Content varies	Content varies	Nanoscience, nanotechnology

The examples also illustrate the role that chemists can and do play in such activities, and the value of partnerships between scientists, educators, and communication experts. We do not offer these examples as the definitive or even most successful models for communicating chemistry, but rather share these examples with the intention of providing a concrete reference for how some of these issues can be addressed.

Periodic Table of Videos

The Periodic Table of Videos (<http://www.periodicvideos.com/>), created in England but presented everywhere via the world wide web, is a collection of videos that explore the elements in the periodic table. The project was developed by Brady Haran, a BBC-trained video journalist. Haran spent a year filming scientists at work the University of Nottingham, and was inspired by his time working with chemistry researchers. Working closely with Professor Martyn Poliakoff, an original set of 118 videos were quickly created, and over the past few years they have continued to create additional videos, updating some elements, expanding into videos about molecules, and creating topical interest videos that often focus on chemistry and current events. Most recent

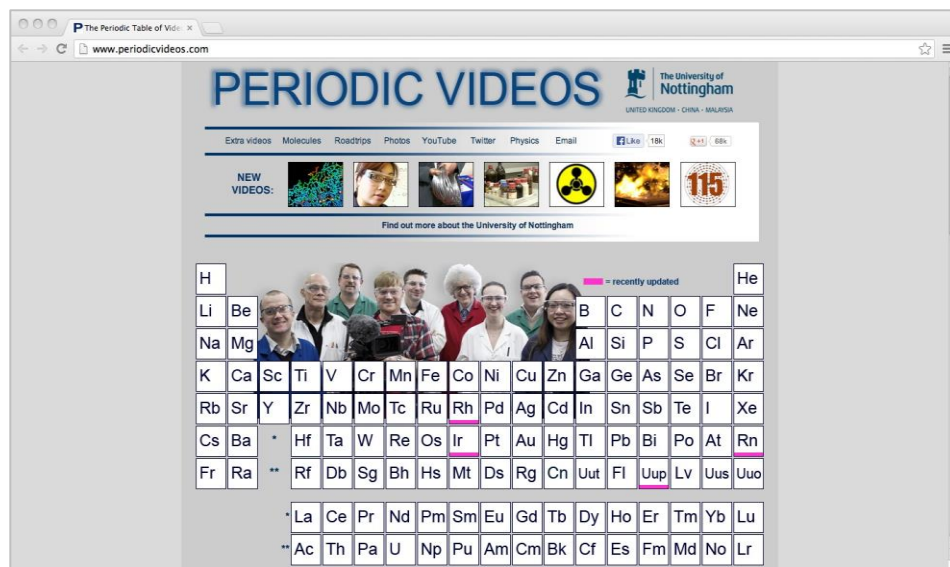
examples of these “current event” videos include one on the recent Nobel Prize in Chemistry, and one on chemical weapons and sarin gas.

PTOV is an example of using media to make chemistry come to life – showing both the chemistry as well as the chemists in action. The short videos – 5-10 minutes in length – are not scripted, and have a personal, in-the-moment feel; the chemists, including Poliakoff (aka “The Professor”) and 8 others, become familiar characters in a series of adventures about the elements. Videos often feature experiments or demonstrations showing chemical reactions, and the chemistry is made tangible through close-ups in the lab as well as frequent analogies and references to every-day materials and phenomena. Chemists often respond to **interesting, relevant questions** over the course of the demonstrations. The [helium video](#) includes explanation of why your voice sounds high when you breathe it in, and in the [fluorine video](#), the chemist answers the question of how fluorine can be so reactive and yet used in toothpaste as fluoride. Some videos focus exclusively on a question posed by a viewer, such as, “[What is the most dangerous chemical you’ve ever handled?](#)” Current event videos address relevant questions that arise from the news.

Some videos, despite their simplicity, **tell good stories**, in addition to asking interesting questions. For example, “[High Altitude Water Boiling](#)” follows Haran trekking in the Himalayas to Mt. Everest Base Camp. At stops along the way, he measures the decreasing temperature at which water boiled. [A subsequent video](#) picks up the story of the trek, and brings it back to the lab to explain why the boiling point is lower at high elevation. [Another video](#) shares the story of the Professor’s lab, as he shares what it means to pack and move to a new one.

While the authors of the Periodic Table of Videos (PTOV) have not declared a particular set of goals for their work, we think that the project exemplified communication goals such as awareness, enjoyment, interest, and understanding of science, specifically chemistry. The **audience** for the PTOV is everyone and anyone with internet access, and with that in mind, the creators strive to explain abstract concepts in an accessible manner. Haran and Poliakoff have heard that their viewers include everyone from young children to Nobel laureates (Haran, 2011b). According to their analysis of IP addresses of viewers, the audience comes from over 200 countries and territories, with the highest viewership North America, the UK, and the EU countries (Haran, 2011a).

Figure 2. Period Table of Videos home page.



PTOV offers an example of using social media to expanding communication reach. In addition to its own web site, PTOV has a [YouTube channel](#). YouTube is both a popular destination for finding videos on the web and also enables viewers to comment on an individual video. It also provides statistics on viewers and usage. As of November 2013, the PTOV YouTube channel had over 340,000 subscribers. The most popular video, “[Gold Bullion Vault](#),” had over 2,600,000 views. The most popular element video, on hydrogen, had over 540,000 views. PTOV also now has a [Twitter account](#), with over 15,000 followers. Tweets include links to videos and photos, solicitations for questions for the chemists, and the occasional chemistry jokes and puns.

In a commentary published in *Nature Chemistry* in 2011, Haran and Poliakoff discuss the challenge of **being thoughtful about outcomes** and measuring the impact or effectiveness of their chemistry communication efforts. Assessing something like the PTOV – that exists in the online sphere – is a complicated endeavor, as meaningful measures are hard to identify, let alone execute. Simply tracking viewers is not all that informative. As Haran and Poliakoff share, all views are not created equal, as “one ‘view’ cannot distinguish between a high school teacher showing the video to an entire class or one individual watching the same video numerous times” (Haran, 2011a). Further, the online world is fluid, and a video can get embedded in a popular news site or blog, or featured in social media and made ‘viral,’ suddenly skewing viewership and leading to more questions than answers in trying to understand what a video’s impact might be. Haran and Poliakoff offer that there is a qualitative difference that might be explored in where and how videos are shared. The example they give is that having one

of their videos shared on a science teaching blog is more meaningful, and more relevant to understanding impact, than when a video is picked up by an automated search.

Individual user comments, posted in response to individual videos, may offer the most useful information about how viewers are responding to the videos and what they take away from them. These comments offer a qualitative peek into the videos' impact. Types of comments Haran and Poliakoff describe receiving include: scientific questions, and sometimes responses to questions from other viewers; affect, or how the video made the viewer feel; interest, such as an interest in learning more or pursuing chemistry; and usage, or comments on how the viewer used the video to study or shared with a class. While outcomes for such a diffuse communication activity are hard to measure, the people behind this work are thinking about how to understand the impact and effectiveness of this kind of communication, and offer some early insights into how this kind of work can be thoughtfully evaluated.

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Oregon Museum of Science and Industry Chemistry Lab

The Oregon Museum of Science and Industry (OMSI) offers an experience that is unusual for a science museum: the Chemistry Lab (<https://www.oms.edu/chemunits>) is a hands-on wet lab, where visitors have the opportunity to try their hands at actual chemistry experiments. As far as staff knows, the Chem Lab is the first hands-on wet lab of its kind at a science museum. Visitors who walk into the Chem Lab get to put on goggles and try their hand at any of six different experiments prepared for the day. Ten themed sets of experiments rotate through the lab on a weekly basis.

The Chem Lab offers an engaging and exciting set of activities to its visitors, and provides an example of how a **focus on audience** can shape those activities. While the audience for the museum is the general public, Chem Lab educator Elizabeth Dannen explained in an interview that the target audience is children in the upper elementary and middle school grades, as well as families with young children. The lab does not require children to sit through a lot of exposition, but lets them get their hands dirty, so to speak, as quickly as possible. A sign accompanying experiments offers enough background information to inform the visitor of what it is about, and then provides the 6 to 10 steps of instruction for conducting the experiment. Instructions also include processing questions, such as “What happened?” or “What color is it?” These lab instructions are written at a 5th grade level, although younger children are often able to read them on their own as well. Lab staff shared that they have had 3 year olds doing experiments with their parents reading the instructions.

Visitors come with all backgrounds, skills levels, and interests. The Chem Lab further **considers its audience** by **asking interesting, relevant questions** that might attract and engage such diverse groups. The “Crime Scene Chemistry” theme includes experiments that answer questions such as how blood type is determined, how forensic scientists analyze invisible blood at crime scenes, and how investigators identify mysterious substances using chemistry. Less obviously interesting themes, like “Industrial Chemistry” are made relevant through experiments that ask what makes the color in fireworks, and what does water have to do with launching the space shuttle? The Chem Lab makes a point to describe the experiment providing reference points that most audiences would know.

Many people wander into the Chem Lab without any particular interest or goal; others come in particularly to do chemistry. The Chem Lab enables visitors who want to work independently to do so, and also provides further information and support for visitors who want it, as there are staff and volunteers available. When describing the lab, one staff person commented that the staff and volunteers often gauge the visitors’ level of

knowledge and are very helpful and vital in making the experience more relevant. They will often engage with visitors and assist when visitors want to try experimenting with the experiment—that is, making changes to the steps of the experiment to see what happens. The back of the signs for each experiment include additional information for those that want more, such as detailed chemistry content regarding the molecules and reactions, as well as real-world applications of the phenomenon in the experiment. For example, an experiment about chemical reactions using luminol notes that this is something you also see in fireflies and glow sticks.

As a science educator interviewed for this report acknowledged, the Chem Lab comes with built-in appeal—for many kids, the opportunity to do hands-on experiments is a new and exciting experience. Beyond retiring some out-of-date experiments and getting volunteer and visitor feedback on new experiments, the Lab's efforts to evaluate or **understand outcomes** have been minimal. They do track the number of people who come through the lab, which ranges from 140-180 on a quiet weekday, to 400-600 on a weekend. The most visitors the Lab has had on a single day is over 1,000. Dannen shared that she fields a lot of phone calls about people coming specifically to visit the Chem Lab, "so it's clear that people are drawn to it and recognize our setup as a unique experience... Some home school families even make weekly visits to our lab and incorporate it as part of their science curriculum" (personal communication, July 2, 2013).

The Chem Lab has engaged in a number of partnerships to bring chemistry activities to other areas of the museum, and to bring chemists into the museum. A partnership with the Portland chapter of the American Chemical Society (ACS) has ACS member volunteers coming into the museum during National Chemistry Week (NCW) to facilitate hands-on activities throughout the museum. This year, through an ACS mini-grant, 10 local college students developed hands-on activities related to climate change, which also connected to this year's NCW theme of energy. The students have their activities set up in the Earth Hall.

Two different NSF-funded "broader impact" efforts have led to additional outreach activities. Staff from the Chem Lab are collaborating with the Center for Sustainable Materials Chemistry Center for Chemical Innovation (CCI), based at Oregon State University. With the help of the Chem Lab, researchers from the CCI are developing hands-on activities that relate to their work and have real-life applications. In the future, they will present them at the museum. A blog post from a research on the CCI web site describes the value in working with the OMSI staff to come up with "a creative method of presenting a complex science topic to laymen, or even children" (Knutson, 2013). A Connecting Researchers and Public Audiences (CRPA) project with Portland State

University included a weekend event called “Meet a Scientist.” Researchers, wearing buttons that said “I’m a real scientist!” set up activities related to their work with solar cells and alternative energy around the museum, giving visitors new and additional opportunities to engage in chemistry.

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Westside Science Club

The Westside Science Club (<http://www.vhcorp.org/scienceclub>) is an out-of-school program that engages low-income young people, age 8 to 14, in hands-on science experiences. Founded by Benjamin Dickow, an experienced informal science educator, the Science Club began over five years ago as a way for participants to explore all areas of science; in the past two years, a partnership with the Center for Chemical Innovation in Solar Fuels at CalTech, or CCI Solar, has brought resources, materials, and experts in chemistry to the science club experience. This is an example of how NSF’s “broader impact” goals are realized in the field, and a particularly interesting demonstration of the support and structure chemists require to participate in communication activities.

The Science Club was conceived with a specific **focus on audience**. Dickow, having worked at the California Science Center in Los Angeles, knew that many young people were not able to take advantage of the great programs and resources at great science museums because of transportation and other costs. He liked the idea of a distributed science center, rooted in a community, so he approached Venice Community Housing Corporation, a low-income housing community-based organization about creating a program. Thus began the Westside Science Club, which meets every other Saturday in a community room of one of the housing complexes and brings activities directly to where its audience can reach them. Attendance is usually 12 to 18 kids, shared Dickow in an interview, and most kids come regularly; one 14 year old boy likes to brag that he has never missed a meeting in 5 years.

The Science Club’s audience, the kids who come to participate, share ownership for the club by helping to plan activities, further insuring that the activities meet their needs. Quarterly, a meeting is dedicated to making plans for the activities in the months ahead, and kids talk about what they would be interested in working on. Dickow offers up resources and activities that are available, and field trips are planned. Projects and

activities vary widely, and often include “Maker” activities and simple experiments across the sciences. Science Club activities focus on **interesting, relevant questions** that come from the youth themselves.

Through his work with the Center for Advancement of Informal Science Education (CAISE), Dickow was connected with an NSF program officer who informed him of the supplemental outreach grants NSF was giving to their CCI’s, and in turn connected him with CCI Solar. The partnership with CCI Solar has resulted in scientists, including professors, post-docs, and students, helping to facilitate a number of chemistry activities over the course of the year. One challenge the partnership posed was how to continue to **focus on interesting, relevant questions**, that would appeal to the young people, while also focusing on activities that leveraged the expertise of the CCI Solar scientists and incorporated chemistry.

The CCI’s aim in conducting outreach was to communicate to the public about chemistry, and specifically the science behind the CCI. CCI Solar’s science often does not look like traditional chemistry. When he first began working with the scientists, Dickow recounted a meeting where he asked them what they really wanted the Science Club participants to learn about chemistry. The chemists’ broad goals were that the young people come to understand that 1) everything is chemistry, and 2) chemistry is not scary. Dickow then worked with the scientists to generate a mind map of all of the topics and areas that feed into the work of CCI Solar, and from there, they looked for specific subjects that might serve to get these ideas across and address those goals.

An example of an activity that resulted from this was on electroplating. Stations were set up around the room with different solutions, where the kids could play with turning coins different colors, such as taking a nickel and coating it in bronze. While the scientists explained about electromagnetic bonding, it was also a free-form activity where the participants could play and experiment. Dickow explained how this was one of the first times that the scientists saw high engagement all around the room with an un-directed experience, and he noted that the kids still refer back to that activity. Another activity that was created in direct response to the interest of the participants was about thermal plastics. The kids wanted to learn how to make armor for Batman. This led to an investigation of the special effects industry’s use of thermal plastics, with a culminating activity of making their own breastplates.

In forming the partnership with CCI Solar, Dickow and the Science Club have **been thoughtful about outcomes**, not just for the youth participants but also for the scientists. In an interview, Dickow described the theory of action behind the effort, which is as much about the education of the scientists as the education of the kids. One of their

intended outcomes is to help make the scientists better communicators, with the theory being that if they can communicate well with 8 to 14 year olds, they can also communicate with the general public more effectively. The project is engaged in an evaluation that seeks to understand both the kids' learning as well as the chemists' change in facilitation and communication skills.

To support those outcomes, Dickow has been providing professional development and support to the scientists. Early in the partnership, he led sessions introducing them to the field of and guiding principles behind informal education and science communication. Dickow also made use of materials from [Portal to the Public](#) in these professional development sessions. He worked together with the scientists on the design and planning of activities, helping them learn to pay particular attention to their audience. After activities, they would de-brief and reflect on how the activities went, what worked and what they could do differently.

While it has been valuable to bring scientists to work directly with the young people, it has also been a challenge because there was some uneasiness with new strange adults coming into the young people's established safe, social space. According to Dickow, the scientists had to let go of any traditional ideas about education and what learning looks like, adapt to the informal environment, and build relationships with the kids. Those relationships can pay off though, and Dickow described seeing kids occasionally engaged in long conversations with the scientists about all matters of science and the life of scientists. Further, the kids have gone on field trips to CalTech, and for most it is the first time on a college campus or in a real working laboratory.

It can be a challenge to convince scientists of the value and merit in taking time out of their own work to do these outreach and communication activities. There is little incentive for them to do so. One key to the success of the partnership, according to Dickow, was a post-doc at CCI Solar who became a champion of this work. This post-doc became very engaged in figuring out how to work with the young people, and served as an example to others. He helped to build interest and enthusiasm among others at CCI Solar, who have now become invested in this effort.

NISE Network Public Forums

The Nanoscale Informal Science Education Network (NISE Net, found at <http://www.nisenet.org>) is a national community of researchers and informal science educators dedicated to fostering public awareness, engagement, and understanding of nanoscale science, engineering, and technology. Funded by the NSF, NISE Net started in 2005 as a partnership led by the Museum of Science Boston and including several museums and universities across the country. It invites any individual or organization that is interested in getting involved or accessing resources to become a member on their website. The NISE Net web site is host to a catalog of resources, including guides, materials, and reports, designed to support other informal educators and programs in engaging the public in learning about nanoscience.

The “Public Forum” is one such learning activity. According to the manual on NISE Net’s website, the goal of a forum is “to provide experiences where adults and teenagers from a broad range of backgrounds can engage in discussion, dialogue, and deliberation,” enhancing their understanding of nanoscience and engaging them in discussion about positive and negative impacts of nanotechnologies. Forums also aim to strengthen the public’s and scientists’ acceptance of diverse points of view, increase participants’ confidence in participating in public discourse about nanotechnologies, and attract and engage adult audiences in in-depth learning experiences.

The general design of a forum is 2 hours, which includes expert speakers addressing the topic from different perspective and engaging in some Q&A, followed by small group discussions where experts and audience tackle a range of questions related to the topic. At the end of the forum, small groups report back to the larger group about their discussion. Examples of forum topics that have been designed and documented by NISE Net include “Nanomedicine in Healthcare,” “Risks, Benefits, and Who Decides?” and “Privacy. Civil Liberties. Nanotechnology.”

In designing and generating the Forum model, NISE Net was **thoughtful about outcomes** from inception. The impetus for the public forums was the belief that the public should be engaged in and involved with decision-making about technology and engineering developments that ultimately affect society. The concept built upon the idea that by engaging audiences in dialogue and deliberation, they could explore science concepts and increase science literacy, as well as practice decision-making skills. Further, a central goal was that “participants would engage in dialogue not only on the science itself, but also on its societal and ethical implications” (Bell and Livingston, 2008). These ideas and goals drove and dictated many of the elements of the forum model—bringing together experts and a public audience, and creating a space and

format that allowed for an exchange of ideas and perspectives. Experts are not limited to scientists, but include social scientists, policy-makers, and ethicists for the discussion. For example, one forum held on the issue of nanotechnology, healthcare, and legal issues included a scientist, a lawyer, and an industry representative.

Forums strive to **focus on interesting, relevant questions** by addressing the complicated topics of nanoscience and nanotechnology through their real-world applications and implications, and through framing the forum discussions around questions and problems that participants are likely to have some experience or investment in. As one program manager described in an interview, “the hook is hard, and even harder when it’s something that you can’t see;” therefore, it’s critical that forums address topics that the public understands and cares about. For example, the “Nanomedicine in Healthcare” forum addresses a couple of scenarios that are relevant to many: the use of nanotechnology in topical personal care products, and the use of nanotechnology in diagnosis and treatment of the body. Group discussion questions consider the issues of long-term impact on the body and environment, public disclosure and regulation, expense of such technologies, and consequences of not pursuing such technologies.

Forums offer an illustration of how challenging and complex a **focus on audience** can be. While forums are designed for the general public, in reality, they attract an interested audience. The formative evaluation for one set of forums recommended being particularly thoughtful about outreach and targeting certain audiences. Potential target audiences include those already familiar with and participating in programs at the host institution, and those who work in a field related to the topic (i.e. in healthcare). However, in order to expand the audience and reach those not already familiar, institutions need to partner with diverse community organizations to co-host or co-develop events. In an interview, a program manager who implemented a forum event following NISE Net’s guides and materials described the challenge of attracting and planning for the audience if the event is not built into a venue or program that already has an established audience. While she engaged in outreach through social media and the institutions newsletters, she had lower participation than hoped for, and noted that when she had seen other institutions conduct forums, they had been part of a series of events for their members.

Conducting several forums on the same topic at different institutions, NISE Net did work to be responsive to the audience, making modifications and adjustments from one forum to the next based on audience feedback. For example, one challenge was figuring out a title for the event that would attract and appeal to participants. The formative evaluation of the “Nanomedicine in Healthcare” forums notes several iterations of titles

(for example, one event used the title, “Nanomedicine: Nanotechnology in Health and Healing”).

In addition to being **thoughtful about outcomes** in the initial design of the activity, NISE Net engaged in formative evaluations that helped with the revisions and refinement of the format for activities as well as the discussion questions, and also offered guidance for others who might try to implement their own forum events. Summative evaluations were also conducted to provide data on how forums were able to address and achieve goals. The summative evaluation report of a series of forums on “Nanomedicine in Healthcare” reported that attendees did enhance their understanding of nanotechnology and its potential impact, and in the weeks following, attendees indicated that hearing diverse viewpoints about ethical and societal implications was valuable and that they were motivated by their experience to pay more attention to reports of nanotechnology in the media and discuss it with others.

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Jamie Bell, Ph.D.

CAISE Project Director
Association of Science Technology Centers

Larry Bell

Director, NISE Net
Sr. V.P. for Strategic Initiatives, Museum of Science, Boston

Katharine Covert, Ph.D.

Program Officer, Centers for Chemical Innovation
National Science Foundation

Alphonse DeSena, Ph.D.

Program Officer, Advancing Informal Science Learning
National Science Foundation

Christine Jaworek-Lopes, Ph.D.

NCW Coordinator, New England Section of the ACS
Associate Professor of Chemistry, Emmanuel College

Paul (Wyn) Jennings, Ph.D.

Program Officer, Advancing Informal Science Learning
National Science Foundation

David Johnson, Ph.D.

Education Lead, Center of Sustainable Materials Chemistry
Professor of Chemistry, University of Oregon

Holly Kerby

Executive Director, Fusion Science Theater
Madison Area Technical College

Lisa McElwee-White, Ph.D.

Director, Center for Nanostructured Electronic Materials
Professor of Chemistry, University of Florida

Alex Quinn

Project Director, TV411 What's Cooking?
Education Development Center, Inc.

Meisa Salaita, Ph.D.

Director for Education, Outreach & Diversity, Center for Chemical Evolution
Emory University

David Sittenfeld

Program Manager, Museum of Science, Boston

David Ucko, Ph.D.

President, Museums + more LLC

Martin Weiss, Ph.D.

Science Interpretation, Consultant, New York Hall of Science

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Appendices

Interview guide

We've asked you to participate in this interview because you have been identified as someone who is actively working to help the public understand chemistry. We identified you through [note how referred to interview subject, i.e. NSF project, NAS recommendation].

1. Can you please tell me a little about your professional background and where you work
2. What is your background with regard to communicating science to the public?
 - a. How long have you been doing these kinds of activities?
 - b. What are the most common activities you do to communicate science to the public?
 - c. Where does chemistry fit into your outreach or communication activities?
 - d. Do you think chemistry needs to be approached differently than other science areas? Why or why not?
3. How do you think about communicating chemistry content in the work that you do?
 - a. How do you decide what content is important to include?

- b. How do you decide which strategies you will use? Do those strategies ever differ? If so, how and why?
4. What specific approaches or activities have you found to be most successful?
 - a. Can you think of an example of a particularly exciting and successful effort?
 - b. Have you seen any approaches to communicating science – from another discipline or field – that have impressed you and you’d like to see adapted to chemistry? [If yes, what was impressive? Have you tried to adopt these approaches yourself?]
5. What are the biggest challenges to effectively communicating chemistry concepts?
 - a. Have you done or experienced efforts that were not successful? What do you think may have been the issue?
 - b. Are there any challenges or opportunities that you think are particular to communicating chemistry concepts?
 - c. What kinds of supports would help to address these and other challenges in communicating chemistry?
6. Is there anything else you think we should know?
7. Can you think of any other people we should talk to, or projects we should take a look at, as we continue this study?

LinkedIn discussion prompts

1. How does chemistry fit into your organization’s overall mission, and why? Is chemistry education a key part of what you do? Why or why not?
2. Does communicating chemistry require a different educational approach than other areas of science education? Why or why not?
3. When you work on an exhibit, event, or media piece that involves chemistry knowledge and education, how do you decide what content to include and what strategies to use? What specific approaches or activities have you found to be particularly successful at communicating chemistry knowledge and understanding? What stories of success can you share?
4. Besides yourselves, who do you see doing really good work in communicating chemistry to the public? What are the great examples, past or present, that NAS should know about? Are there approaches or activities you’ve seen used in other

science disciplines — or outside science — that you think could be successful in communicating chemistry? If so, which ones?

5. What do you see as the greatest challenges to communicating chemistry effectively, today and going forward? What do we, as institutions and as a group, need to do to meet these challenges? What do we need other groups (other informal science education institutions, formal education institutions [K-College], government institutions, foundations and other non-profits, corporations) to do to help?