JOURNAL OF CHEMICAL EDUCATION

pubs.acs.org/jchemeduc Article

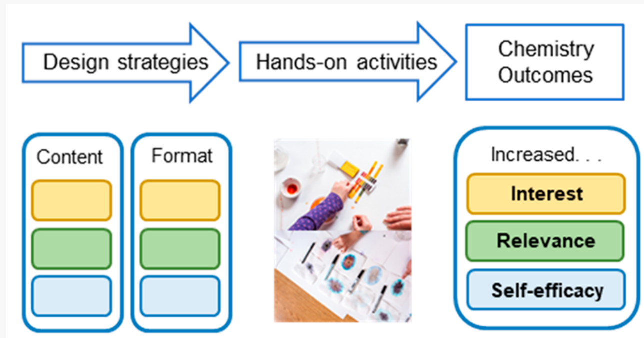
Design Strategies for Hands-On Activities to Increase Interest, Relevance, and Self-Efficacy in Chemistry

Allison Anderson, Elizabeth Kunz Kollmann,* Marta Beyer, Owen Weitzman, Marjorie Bequette, Gretchen Haupt, and Hever Velázquez

Cite This: https://doi.org/10.1021/acs.jchemed.1c00193 Read Online

ACCESS | Metrics & More | Article Recommendations | Supporting Information

ABSTRACT: Chemistry is a vital and highly relevant field of science that is under-represented in science centers and museums. Amidst concerns that the public is ambivalent about the chemistry field, the *Explore Science: Let's Do Chemistry* project sought to understand how to design hands-on activities that could increase the feelings of interest, relevance, and self-efficacy around chemistry. Using design-based research, the team tested and refined a variety of activities while simultaneously creating a framework for future use about content and format strategies that increase interest, relevance, and self-efficacy. Science museum visitors tested these activities and were interviewed afterward to learn whether or not they had experienced any changes in their attitudes toward chemistry and what about the activity contributed to these feelings. Data indicated that the types of content embedded in an activity influence increased feelings that chemistry is relevant and interesting, while the format used in an activity contributes to increased interest and self-efficacy around chemistry. The design framework created from these findings can be used by other chemistry educators to develop additional chemistry outreach activities that support increased interest, relevance, or self-efficacy in participants.



KEYWORDS: *General Public, Elementary/Middle School Science, Chemical Education Research, Public Understanding/Outreach, Hands-On Learning/Manipulatives, Inquiry-Based/Discovery Learning, Enrichment/Review Materials, Professional Development*

FEATURE: Chemical Education Research

■ INTRODUCTION

Literature Review

Chemistry is one of the core sciences that people encounter as a part of their everyday lives. Whether they recognize it or not, chemistry is occurring within our bodies when we breathe, eat, or exercise. It is also a part of the world around us, from natural processes like photosynthesis to human-created materials such as plastic, or technologies such as energy and transportation. The ubiquity of chemistry means that it is important that the public has an understanding of it to be able to make decisions as a part of their everyday lives.[1,2] Therefore, it is critical that the public be exposed to this science discipline, yet the 2018 National Science and Engineering Indicators showed that many students are not exposed to very much chemistry as a part of their formal education, and that nearly a quarter of U.S. students do not take chemistry classes in high school.[3] However, there are other places beyond school where chemistry could potentially be encountered, as studies show that people spend up to 95% of their time outside of formal education environments.[4] People engage with and can learn science outside of school though museums, after-school programs, libraries, and television and other media, among other informal learning opportunities.[4] It has been shown that environments such as these can be particularly good at impacting public interest and excitement about science, as well as helping them build their identity as science learners.[5] Nonetheless, even in these environments, chemistry is typically under-represented. As of 1996, fewer than 30% of science museums reported that they had an exhibition about chemistry.[6] More recent landscape reviews show that chemistry is still less commonly presented in informal education environments than other science topics such as biology or physics.[7−9]

While it is clear that more exposure to chemistry is important for the public, mere exposure is not enough.

Received: February 26, 2021

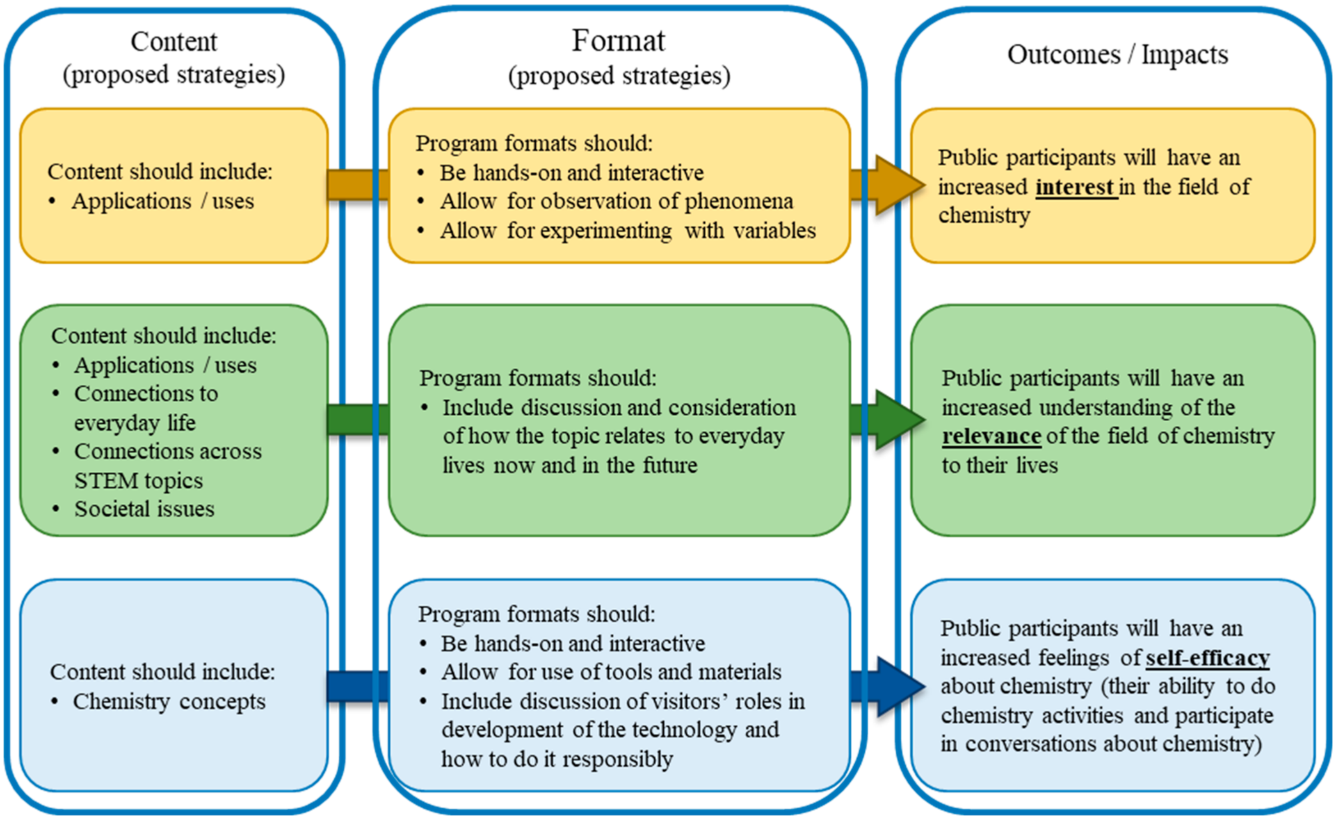


Figure 1. Initial project framework, outlining the content and format design strategies for chemistry activities that might lead to increased interest, relevance, or self-efficacy around chemistry topics.

These experiences need to be thoughtfully designed to account for the public's current attitudes toward chemistry, as has been outlined in the 2016 National Academies of Sciences, Engineering, and Medicine (NASEM) guide.[10] Many scientists and educators are concerned by what they see as growing "chemophobia" among members of the public or at least an indication that the public feels negatively toward chemistry.[6,11,12] However, a study from the Royal Society of Chemistry (RSC) found that the issue was not so much that the public felt negatively about chemistry, but that they did not have very many feelings about chemistry at all.[13]

The RSC suggested three main areas to focus on when trying to improve the public's perceptions of chemistry. The first area is the public's interest in chemistry. Hidi and Renninger describe interest as the "psychological state of engaging or the predisposition to reengage with particular classes of objects, events, or ideas over time" (ref 14, p 112). The RSC report found that nearly 50% of people do not feel interested or engaged in the topic of chemistry.[13] Another area that the RSC report suggests needs to be emphasized is the relevance of chemistry to people's lives. Relevance is the connection a person makes between a topic and their lives and experiences or broader societal issues.[15,16] In this case, the report found that 45% of people either do not know or disagree that it is important to know about chemistry in their daily lives.[13] A final area that is essential to address is self-efficacy: a person's confidence, or expectancy for success, in a particular content domain such as their ability to understand, talk about, or participate in that area.[17] The RSC report found that 52% of people do not feel confident in their abilities to talk about chemistry.[13]

Findings and recommendations from the RSC report suggest that it may be possible to positively impact public attitudes toward chemistry, specifically through increasing their interest in chemistry, their understanding of the relevance of chemistry in their lives, and their feelings of self-efficacy in relation to chemistry.[13] Beyond the RSC report, the NASEM report *Effective Chemistry Communication in Informal Environments* calls for not only taking this kind of research into account when designing outreach but also conducting further research to understand how to best design these kinds of informal experiences.[18] The NASEM report suggests that in order to improve chemistry communication for the public it is important for more science communication research to be conducted, including about public perceptions and understanding of chemistry.[18] Additionally, the report calls for the use of evidence-based practices in the development of chemistry outreach activities. The *Explore Science: Let's Do Chemistry* project did just this by conducting a design-based research study to create both activities and a theoretical framework about the content and design of hands-on chemistry activities that can lead to increases in these visitor attitudes (interest, relevance, and self-efficacy) towards chemistry.

Project Background and Research Questions

Chemists, educators, and researchers from the American Chemical Society; Museum of Science, Boston (MOS); and Science Museum of Minnesota (SMM), among others, teamed up though an NSF-funded project called *ChemAttitudes: Using Design-Based Research to Develop and Disseminate Strategies and Materials to Support Chemistry Interest, Relevance, and Self-Efficacy* (NSF DRL-1612482). Also known as *Explore Science:*

https://doi.org/10.1021/acs.jchemed.1c00193
J. Chem. Educ. XXXX, XXX, XXX−XXX

Let's Do Chemistry, this project created a kit of hands-on chemistry activities that embody the project's research findings. Throughout this article, the shorter tagline, *Let's Do Chemistry*, will be used for materials and resources created as part of the kit and the overall project. The team chose to produce activities for museums and other informal education settings to address the current lack of chemistry within many science museums.

The project team decided to use design-based research (DBR) methods to conduct this study. DBR recognizes the limitations of laboratory experiments to address the needs of real-world education settings.[19−21] To counteract this limitation, DBR encourages the study of education deliverables in their natural contexts and utilizes "formative research to test and refine educational designs based on theoretical principles derived from prior research" (ref 19, p 18). In these studies, educators and researchers work together, and data are collected that allow for the simultaneous refinement of both the educational deliverables and a theoretical framework that guides the design of those deliverables. The goal of DBR is "developing evidence-based claims... that result in knowledge about how people learn" (ref 22, p 1).

DBR was an ideal method for the *Let's Do Chemistry* project for a number of reasons. First off, the project involved educators at MOS and SMM working with researchers, also from those sites, to create, study, and refine the hands-on chemistry activities. Second, there was prior research upon which this project could build. This prior research was gathered from informal education literature and the work of project team members related to engaging the public in nanotechnology through the Nanoscale Informal Science Education Network.[23,24] The research team was able to take the evidence from this prior research and create an initial theoretical framework describing the content and format strategies that should be included in hands-on activities to achieve the desired educational goals of increased interest in, understanding of the relevance of, and feelings of self-efficacy toward chemistry. Educators at SMM and MOS then took this starting framework to guide their development of the *Let's Do Chemistry* activities. Once these educational experiences were created, they were tested in the real-life context of the museums. On the basis of learnings from these tests, both the hands-on chemistry activities and theoretical framework were refined through a cyclical process until the team felt the activities were optimized. The research questions guiding the DBR work were the following:

- Can hands-on chemistry activities positively impact visitors' attitudes toward chemistry?
- What content and format strategies included in hands-on activities support visitors' positive attitudes toward chemistry?

Theoretical Framework

The starting framework for this project consisted of content and format design strategies that could be intentionally included in hands-on activities to produce a positive change in attitudes around chemistry. See Figure 1 for the initial theoretical framework. The individual strategies that the team thought could be used to impact each individual attitudinal goal were based on prior work and literature as described in the following paragraphs.

Prior work led the *Let's Do Chemistry* team to believe that interest in chemistry could be boosted if the content of an activity included information about applications and uses of chemistry. The team defined this as including information about human-made products or technologies developed using chemicals or chemistry.[16] The format strategies that the team thought could enhance visitor interest in chemistry included being hands-on and interactive, allowing for observation of chemistry phenomena, and allowing for experimentation with variables.[14,16,25]

Similar to interest, the team thought that understanding of the relevance of chemistry could be increased if the content included information about applications and uses.[15,16,26,27] However, on the basis of prior work, it was thought that other content areas could also boost relevance, such as information to help participants make connections to everyday life like cooking, work, or school,[27,28] or connections to societal issues like climate change or access to safe food sources.[15,26−29] A final content area that the team thought could increase understanding of relevance was information about connections to other science, technology, engineering, and math (STEM) topics such as biology, health, or space science.[27,28] Prior work led the *Let's Do Chemistry* team to feel that the activity format could increase participants' understanding of relevance if it included a discussion of how chemistry relates to individuals' everyday lives now and in the future.[25,27,30]

Finally, on the basis of prior studies and previous work, the team felt that activities aimed at increasing participants' self-efficacy should include content about chemistry concepts. The team defined chemistry concepts as basic theories, terms, or ideas that explain the mechanism behind a chemistry concept or phenomena visitors are learning about.[29,31,32] The format strategy of being hands-on and interactive, or allowing people to participate and not passively watch an activity, was thought to potentially increase self-efficacy.[16,18] Other format strategies that the project team felt could support feelings of self-efficacy included allowing for the use of tools and materials and discussion about the public's role in technology development.[25]

On the basis of this initial framework, the project team created and tested 15 activities that embodied the various strategies in an attempt to increase participant interest, relevance, and/or self-efficacy. In addition, the activities covered a variety of chemistry related topics. For example, as part of one activity, visitors used markers of primary and secondary colors, filters, and water to explore chromatography. In another activity, visitors experimented with the effect of acids and bases on a dye created by crushing cochineal bugs. In a third activity, visitors explored different ways to test water quality such as through understanding its pH, salinity, and temperature. A short description of each activity included in this research is available in the Supporting Information for this article. Once the activities were finalized at the conclusion of the DBR process, a subset of activities (nine for public audiences and two for training educators) were packaged into a kit that was distributed to 250 sites across the U.S. for use during the 2018 National Chemistry Week and beyond. The expectation was that visitors would use these activities in their groups with an educator facilitating the experience. Visitors could use the activities as long as they wanted, but each experience was likely to last from 5 to 15 min. Detailed information about the final activities and additional resources included in the kit can be found at www.nisenet.org/chemistry-kit.

https://doi.org/10.1021/acs.jchemed.1c00193
J. Chem. Educ. XXXX, XXX, XXX−XXX

■ METHODS

Data collection occurred at MOS and SMM. Protocols were reviewed by the MOS institutional review board (FWA 00010051; IRB 00005416) and approved for data collection with human subjects (protocol 2016.08). At both MOS and SMM, study participants were recruited from among individuals who were attending the museums on the days when data collection occurred. These subjects will be referred to as "visitors" throughout this article. Similar to other DBR studies that have gathered data over evolving projects, data for this research came from visitors' responses during an iterative development phase, which was when the 15 activities were being considered for inclusion in the final kit.[15] Visitors typically spent 10−15 min participating in one of the hands-on chemistry activities and then were invited to participate in a 10−15 min interview afterward.

Museum visitors used the facilitated activities by themselves or as part of a group, either as multigenerational groups, adult-only groups, or children-only groups with parent/guardian permission. Because the activities were created for visitors eight years of age or older, data collectors aimed for participation from people in this age range. In total, 274 paired interviews and observations were collected through the study. Researchers tried to get at least one group member to answer all of the close- and open-ended interview questions. However, multiple group members sometimes provided additional responses for the open-ended questions, all of which were included in the analyses.

The team collected demographic information from 246 of these groups to better understand who chose to participate in the study and to provide context for the results. Most visitors who used the activities were part of multigenerational groups (60%), with the remaining responses coming from adult-only groups (26%) or children-only groups (13%). Ultimately, visitors were split evenly between adults and children, and more than half of all visitors identified as female (57%). Some visitors had no prior chemistry experience (46% children and 10% adults) while others had taken chemistry in high school (42%), had taken chemistry in college (21%), or had a job that involved chemistry (7%). In terms of self-identified race and ethnicity, the vast majority (84%) of visitors said that someone in their group was white or Caucasian. Otherwise, they shared that they or someone in their group identified as Asian (9%), Hispanic or Latino (7%), multiracial (6%), or Black or African American (5%).

To meet project needs, the research team created an interview instrument that yielded relevant information for formative activity development as well as for the project's research questions around how to support attitudes toward chemistry. Specifically, visitors were asked several close-ended questions about whether they had experienced any changes in their feelings of interest in chemistry, their understanding and perception of its relevance, and their feelings of self-efficacy with respect to the subject after doing the activity. The exact wording to these questions were:

"Compared to when you walked into the museum today:

- How **interested** are you in chemistry after this activity?
- How **relevant** do you feel chemistry is to your life?
- How **confident** are you in:
    - Your **understanding** of the chemistry concepts in this activity?
    - **Talking** to others about the chemistry concepts in that activity?
    - Your **ability to do** a similar activity on your own?"

Visitors responded to these questions on a five point scale ranging from "much LESS [interested/relevant/confident]" to "a lot MORE [interested/relevant/confident]" with a neutral option to say they experienced "no change". To understand what contributed to their feelings, visitors were then asked the open-ended follow-up question: "What about the activity made you feel this way?" The purpose of this open-ended format was to capture immediate and top-of-mind feelings about why visitors felt they had experienced positive change, no change, or negative change and to understand how the activity contributed to their feelings of interest, relevance, and self-efficacy. Other questions in the interview provided additional formative feedback to help make improvements to the activities, especially if visitors indicated no change or negative changes in attitude. Participation was voluntary, meaning that visitors could chose to skip questions or stop at any time, which caused the sample size to fluctuate as shown in Table 1.

Table 1. Sample Size by Question

Attitude	Number of Visitor Groups (Rating)[a]	Number of Visitor Groups (Explanation)[b]
Interest	264	207[c]
Relevance	256	186[c]
Self-efficacy	250	176[c]

[a]Compared to when you walked into the museum today how [interested/relevant/confident]... [b]What about the activity made you feel this way? [c]No response and "I don't know" removed for analysis

Once the data were collected, the team used a mixed methods approach to look for trends across the quantitative and qualitative data that could help inform both activity development and the research framework. The main findings discussed in this article come from visitors who reported that they experienced a positive change in interest, relevance, and/or self-efficacy and their explanations in response to the question, "What about the activity made them feel this way?" In order to analyze these responses, the research team developed a codebook that was based on the content and format strategies outlined in the original framework. In addition, researchers looked for new and emerging themes that explained aspects of the activity design that contributed to increases in the three chemistry attitudes that had not been in the original framework.

The creation of the codebook was an intensive process, during which the research team considered ways to adjust or enhance the definitions of the various content and format strategies and discussed places where there was confusion. This process involved research team members at both MOS and SMM performing inter-rater reliability tests (IRR) with Dedoose software for the content and format parent codes as well as the subcodes within each of these categories. The team assessed agreement using the pooled Cohen's κ, considering the team to be in "good agreement" within a range of 0.65−0.80.[33−37]

As part of this process, the research team created one master codebook that could be applied across all activities and all visitor responses; full definitions can be found in this article's Supporting Information. The "content" parent code included any data in which visitors attributed the content of their conversations, the activity, or their thoughts as reasons for improved feelings around interest, relevance, and/or self-efficacy. The "format" parent code was applied to data that referred to what the visitors were doing during the activity, or how they were interacting with it as reasons why they increased their interest, relevance, and/or self-efficacy toward chemistry. Because visitors sometimes had nuanced responses that referenced multiple strategies, some responses were coded as both "content" and "format". Thus, percentages within the findings do not add to 100%. After the codebook was finalized, the team analyzed data from all 15 activities in Dedoose. This included coding all responses and assessing whether or not the themes aligned with the original framework.[36] From this analysis, the team found ways that the project's starting theoretical framework was confirmed or should be adjusted.[37] This paper shares the research findings behind the final theoretical framework for the *Let's Do Chemistry* project. No differences in ratings were found in terms of visitors' ages (comparing adults to children) or gender (comparing female to male). Therefore, data were analyzed and are shared together.

■ FINDINGS

The aim of this research was to better understand what content and format strategies for hands-on chemistry activities support growth in interest, relevance, and/or self-efficacy. To answer this question, the *Let's Do Chemistry* team first asked visitors the extent to which the activity they used supported a change in attitudes toward chemistry. Then, visitors were asked to explain what about the activity they used supported these feelings. The findings from these lines of inquiry are described in the following sections.

Changes in Visitors' Attitudes toward Chemistry Due to the Hands-On Activities

Most visitors reported that they felt more interested in chemistry after participating in one of the *Let's Do Chemistry* hands-on activities. When asked, 76% of visitors (n = 264) shared that they were "a little more" or "much more" interested in chemistry after taking part in one of the activities, while 23% of visitors indicated "no change" in their interest level, and 1% felt "less" interest in chemistry. Findings showed that visitors' previous interest in chemistry, whether due to their profession, field of study, or general curiosity, sometimes meant that their interest did not change or decreased. Other visitors commented that, while they were interested in the activity, their overall interest in the topic had not changed. See Figure 2.

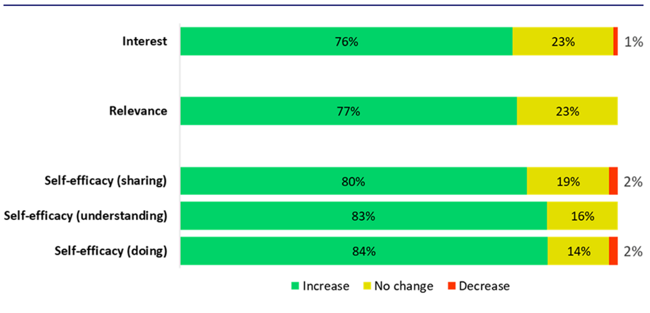


Figure 2. Percentage of visitors indicating an increase, no change, or decrease in attitudes about chemistry after using one of the activities: interest (n = 264 visitor groups), relevance (n = 256 visitor groups), or self-efficacy (n = 250 visitor groups).

Similar to results for interest, most visitors felt that chemistry was more relevant to them after participating in one of the hands-on activities. When asked "compared to when you walked into the museum today, how relevant do you feel chemistry is to your life", 77% of visitors (n = 256) reported they felt that chemistry was "a little more" or "much more" relevant to their lives after using the activity, while the remaining 23% reported "no change" in how relevant chemistry felt to them (Figure 2). When explaining why they had experienced "no change", visitors typically said that they already felt chemistry was relevant either to their own personal lives or more generally to everyone's daily lives. Other visitors commented on how the activity was not personally relevant to them.

Results show that almost all visitors increased their feelings of self-efficacy with regard to chemistry after using one of the hands-on activities. When asked "Compared to when you walked into the museum today", 96% of visitors (n = 250) reported they felt "a little more" or "much more" confident for at least one of the three elements of self-efficacy studied. In looking at each element of self-efficacy separately, 83% of visitors shared they were "more" confident in understanding chemistry concepts, with 16% saying they experienced "no change". In terms of confidence in talking to others about chemistry concepts, 80% of visitors reported being "more" confident while 19% experienced "no change", and 2% felt they were "less" confident in discussing with others. Finally, when asked about how confident they were doing a similar activity, 84% of visitors were "more" confident, 14% reported "no change", and 2% felt they were "less" confident in undertaking something comparable (Figure 2). Most visitors who did not increase their confidence were unable to explain why. Like relevance and interest, many visitors already had confidence in their abilities to do, talk about, or understand chemistry or had positive feedback for the activity. However, some visitors felt they had either insufficient knowledge going into the activity or coming out of the activity to feel more confident.

Content and Format Strategies That Supported Visitors' Increased Attitudes toward Chemistry

To understand the strategies that support increases in visitors' interest, relevance, or self-efficacy toward chemistry, researchers asked visitors what about the hands-on activity they felt led to these positive changes. As indicated in the Methods, researchers started with initial codes for these open-ended questions based on previous work about the content and format strategies expected to lead to increases in interest, relevance, or self-efficacy. In the graphs below, these "proposed strategies", the blue bars, refer to those design elements initially included in the theoretical framework. Additionally, researchers looked for "emergent strategies" in visitors' responses that were not a part of the initial framework. These emergent strategies are the green bars in the graphs.

Design Strategies That Support Interest

Data showed that visitors mentioned both content and format related design strategies as important for their increased feelings of interest in chemistry. Out of the 207 visitors who reported that the activity they used increased their interest in chemistry, 61% mentioned format strategies and 42% mentioned content strategies, thus indicating that both content and format are important to increasing interest as part of hands-on chemistry activities.

https://doi.org/10.1021/acs.jchemed.1c00193
J. Chem. Educ. XXXX, XXX, XXX−XXX

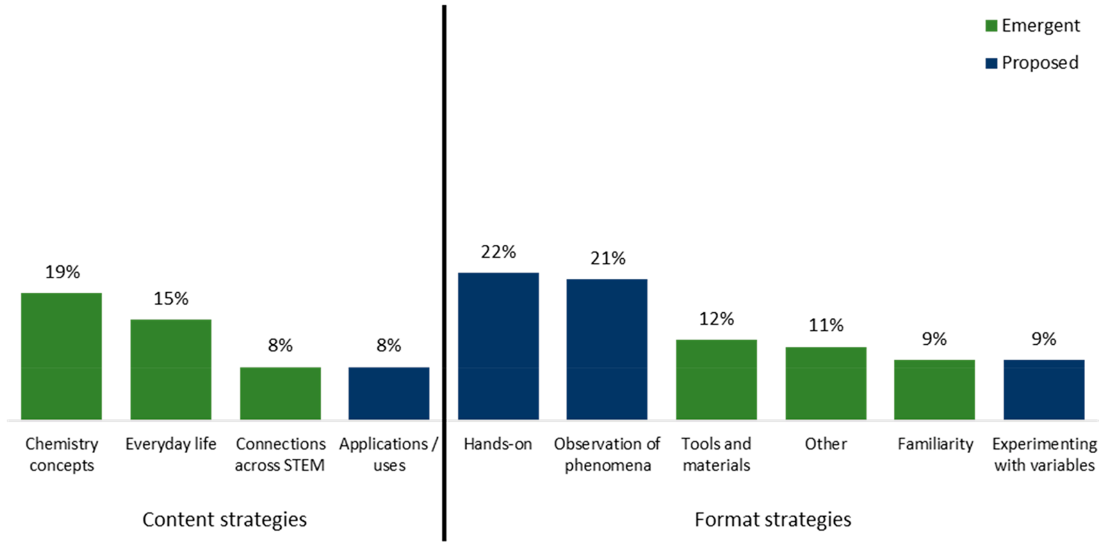


Figure 3. Percentage of visitors who attributed the content or format design strategy to why they had increased interest in chemistry after using one of the activities. n = 207 visitor groups.

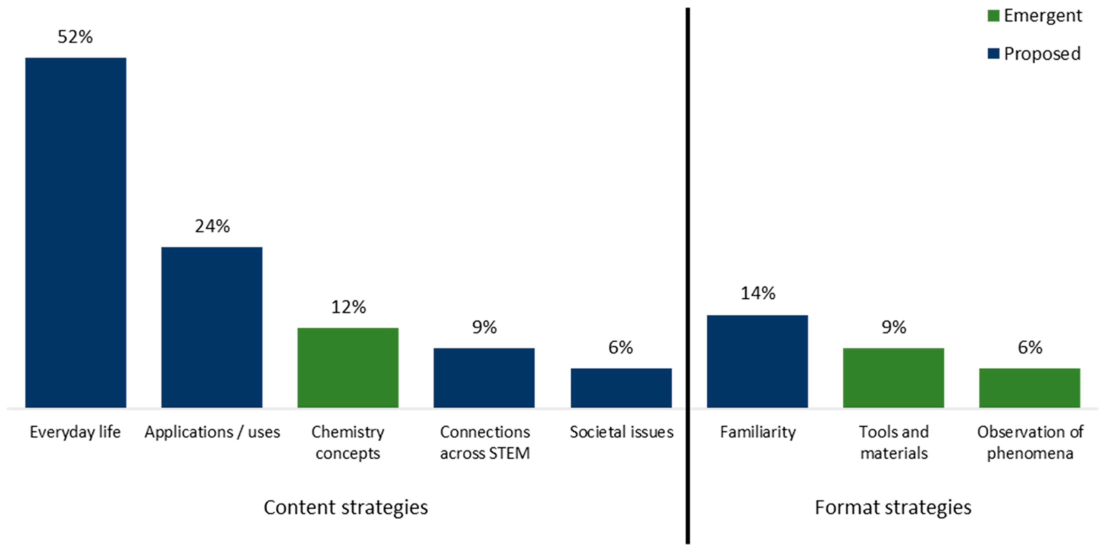


Figure 4. Percentage of visitors who attributed the content or format design strategy to why they had increased feelings that chemistry was relevant after using one of the activities. n = 186 visitor groups.

The two format strategies that visitors most often mentioned as leading to increased feelings of interest were the hands-on nature of the activity (22%) and the ability to observe phenomena (21%), which were both strategies that had been included in the project's initial framework. For example, one child, in sharing that their interest increased because the activity was hands-on, said the facilitator "wasn't just showing us, we actually got to do it". Another child explained that the observation of phenomena, or "being able to see different things make a reaction", contributed to their increased interest. For some visitors, the format of experimenting with variables (9%), as initially suggested in the framework, was helpful for leading to increased interest as well.

However, the data suggested several emergent format strategies that also seemed to support visitors' interest in chemistry. Visitors noted tools and materials (12%) used during the activity as a format strategy that supported their interest. Here, visitors talked about tools and materials that were either typically associated with chemistry, such as pipets, as well as those that were familiar to them from nonscience activities, such as a mortar and pestle used for cooking. Visitors also mentioned how formats that recreated familiar experiences (9%), such as experiments they had previously done in school or opportunities to use recognizable materials, contributed to their feelings of increased chemistry interest. Although some visitors mentioned aspects of the activity format that were coded as "other" (11%), no patterns emerged from these responses. These results may indicate that there are other components of an activity's format that contribute to interest, but they are not as common across visitors. See Figure 3.

Beyond format strategies, the data showed the importance of content strategies for increasing visitors' interest in chemistry. While 8% of visitors confirmed that references to applications or uses of the chemistry topics presented in an activity could support interest, there were other types of content not in the initial framework that seemed to be more effective at influencing this attitude. For example, 19% of visitors felt that hearing about chemistry concepts during the activities,

https://doi.org/10.1021/acs.jchemed.1c00193
J. Chem. Educ. XXXX, XXX, XXX−XXX

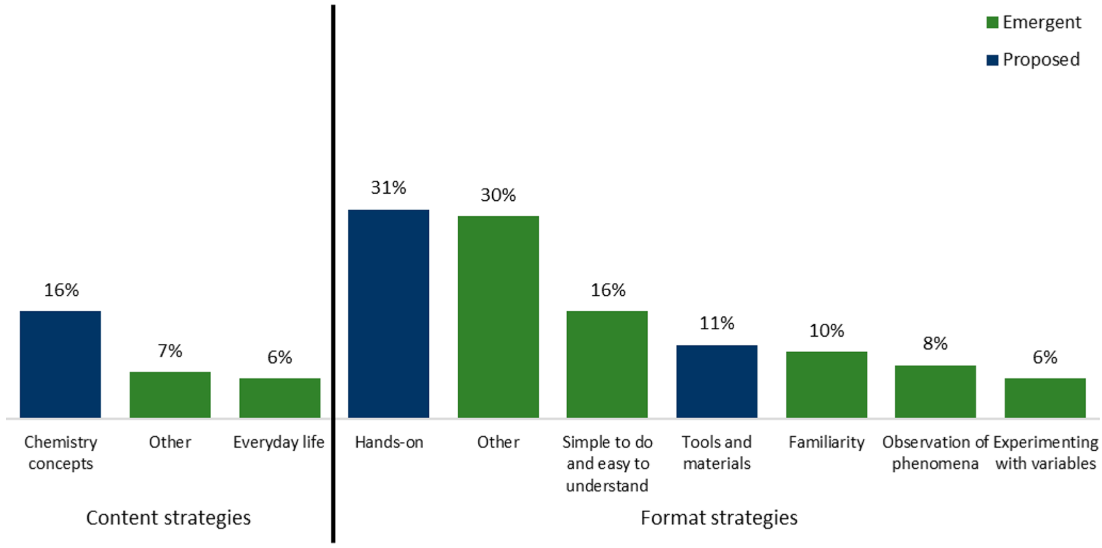


Figure 5. Percentage of visitors who attributed the content or format design strategy to why they had increased feelings of self-efficacy around chemistry topics after using one of the activities. n = 176 visitor groups.

either basic terminology or more complex aspects of how or why something was occurring, helped them feel more interested in chemistry. In an activity exploring cochineal dye, one child described that they were more interested in chemistry because they learned "if the substance is acidic or basic that it can change the color". Likewise, 15% of visitors explained that information connected with their everyday lives helped them feel more interested. Another child using the cochineal dye activity said they were more interested "because it relates to everyday life, because we use dyes in lots of things we use". Finally, 8% of visitors found it helpful to include connections to other STEM topics.

Design Strategies That Support Relevance

Unlike the results for interest, where visitors' responses mentioned that both content and format strategies increased their interest, visitors predominantly noted content when describing what about the activity helped them feel chemistry was more relevant. For this question, out of 186 visitors who reported that the activity made chemistry feel more relevant, 77% mentioned content related strategies while only 27% talked about format related strategies.

From the beginning, the project team had thought that making connections to visitors' lives would be a key strategy for supporting the sense that chemistry is relevant to them, and over half of visitors (52%) attributed content which allowed them to make connections to their day-to-day lives as being a reason why chemistry felt more personally relevant (see Figure 4). An adult who felt this way shared that chemistry was more applicable because the facilitator "talked about plants and nature which are in our everyday. So good to know." Other anticipated strategies that were useful for helping visitors see chemistry as more relevant included sharing content related to applications or uses of the various topics being covered (24%), making connections to other STEM subjects (9%), and creating connections to broader societal issues (6%). After using an activity about cochineal dye and describing how the activity's focus on applications had helped them see the relevance of chemistry, one adult said, "The food and cosmetics [mentioned], I relate to those things." Only one content strategy emerged in the data that had not been anticipated by the project team. Some visitors credited chemistry concepts embedded in the activities as useful for increasing their understanding of chemistry's relevance (12%). Chemistry concepts that visitors mentioned as being helpful ranged from better understanding basic definitions to grasping how or why something happened.

Overall, visitors were less likely to say that format strategies helped them feel chemistry was relevant to their lives. However, some visitors (14%) felt that when familiar formats were used, these helped them see how chemistry was more connected to them. For example, visitors shared that they recognized similar actions or activity setups from prior life experiences, with one visitor explaining that an activity about oil spills reminded them of "science kit projects like Mentos and Diet Coke". Initially, the project team thought that including discussions and consideration of how the topic relates to people's everyday lives now and in the future might support relevance. While this particular strategy was not included in any activities, visitors said that integrating familiar design strategies such as similar actions or activity setups from life experiences helped them increase their understanding of relevance. This finding suggests that providing the opportunity for visitors to recognize what they are doing or using in the activity and how that connects to their own lives could be key. As shown in Figure 4, the two other format strategies that helped visitors increase their feelings of relevance included using tools and materials (9%), largely those from their everyday life rather than those that were more traditionally associated with chemistry, and having opportunities to observe phenomena (6%). These format strategies were not a part of the initial framework but emerged from the data.

Design Strategies That Support Self-Efficacy

Out of 176 visitors who indicated they were more confident understanding, sharing, or doing chemistry, 77% attributed format strategies to their increased feeling of confidence, and 30% mentioned content strategies. These results are the opposite of what was seen for supporting relevance, where visitors instead noted the importance of content strategies. These findings are also distinct from those related to interest,

https://doi.org/10.1021/acs.jchemed.1c00193
J. Chem. Educ. XXXX, XXX, XXX−XXX

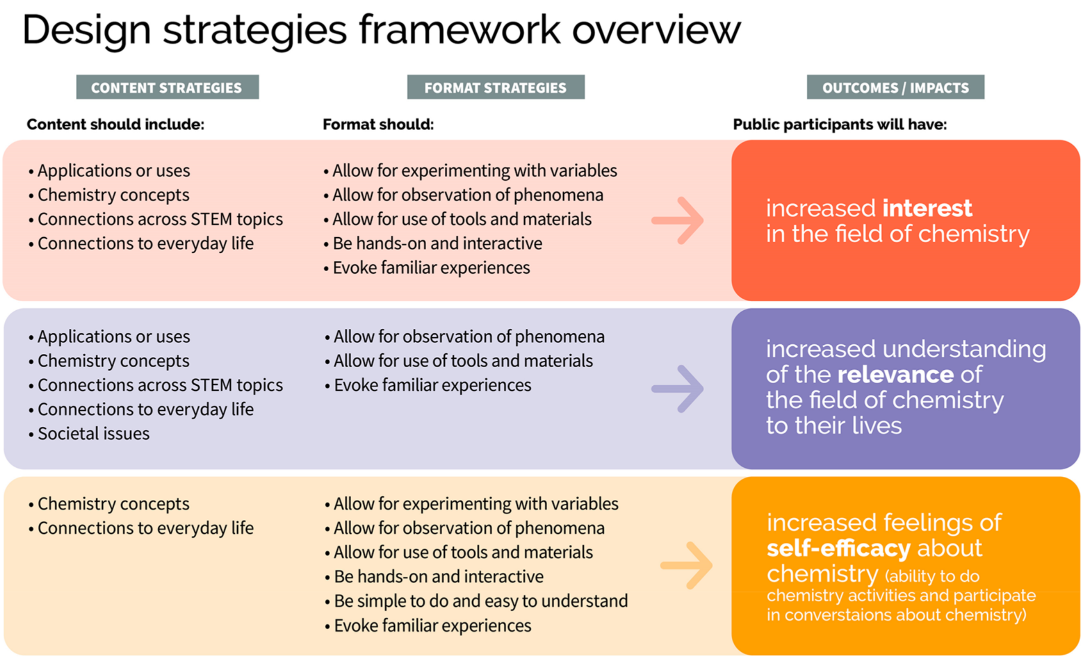


Figure 6. Final design strategies framework, which outlines the content and format design strategies that were shown through the research could lead to increased interest, relevance, or self-efficacy around chemistry topics. Graphic design by Emily Maletz for the NISE Network.

where there was close to an equal balance in the percent of visitors who mentioned content or format strategies.

For self-efficacy, the initial framework suggested that incorporating hands-on opportunities would be important to contributing to visitors' feelings of confidence. As seen in Figure 5, data from this study reinforced this idea, with 31% of responses indicating that a hands-on component was helpful for visitors' self-efficacy. As one adult explained, they were more confident because "I did it myself, so it clicked really well." Additionally, it was confirmed by 11% of visitors that tools and materials helped increase their self-efficacy. However, all of the other format strategies that were important for supporting visitors' confidence were unexpected.

A large emergent category that was important for visitor feelings of self-efficacy was initially coded as "other" (30%). Upon further inspection, within the "other" category it was found that having a format with explanations or visuals or the opportunity to interact with an educator were common themes. Beyond these elements, visitors' responses in the "other" category were inconsistent, suggesting that there are potentially many formats that can contribute to feelings of self-efficacy depending on the visitor and what they bring to the experience. Beyond these "other" responses, one key emergent format strategy that visitors noted as helpful for increasing their sense of confidence toward chemistry was taking part in activities that felt simple to do and easy to understand (16%). Visitors expressed that easy to follow, unintimidating activities which had a low threshold or barrier for successful participation or comprehension of the material were beneficial for helping them feel that the activity and content were something they were able to do or understand. One adult, when talking about how this sense of simplicity was helpful, noted that the activity "was presented in an easy to understand manner. The language, how it was set up. Easy to follow. Not too fast." Visitors also said that activities with formats familiar to something from their prior life experiences helped their confidence (10%), in addition to activities that allowed for observing phenomena (8%) or experimenting with variables (6%).

Fewer visitors mentioned content strategies when talking about activity aspects that supported feelings of self-efficacy. Those that did primarily talked about chemistry concepts (16%), including basic chemistry information or more in-depth explanations of how or why something happened. One adult felt that the activity they tried had a "good basis of the knowledge and explanation of what you needed material wise, what was going on, and why [the] battery is working". Responses from visitors that fell in the "other" category described different types of content that had helped their self-efficacy, with most visitors saying that learning something new was important to their increased feelings of self-efficacy (7%). As one adult said, their confidence increased because the activity "just gave me knowledge I didn't have previously". Some visitors (6%) also mentioned that hearing about content related to their daily life made them feel more confident.

Final Design Strategies Framework

Findings described above from the *Let's Do Chemistry* research were used to update the initial project framework. The final framework includes design strategies shown to increase interest, relevance, and self-efficacy in visitors, see Figure 6. Some of the strategies that were originally thought to support a specific attitude were also shown to influence others. For example, the project team originally thought that allowing for observation of phenomena might be important only for increasing interest in chemistry, but visitor responses indicated that this format strategy could support all three attitudes. Other strategies were absent from the initial framework but emerged from visitor responses. For instance, the team learned that a hands-on activity should be simple to do and easy to understand in order to increase feelings of self-efficacy. Finally, some strategies that were initially considered to be important were mentioned so infrequently or not at all by visitors that they were ultimately cut from the framework.

https://doi.org/10.1021/acs.jchemed.1c00193
J. Chem. Educ. XXXX, XXX, XXX−XXX

STUDY LIMITATIONS

Design-based research studies take place within the context they are designed for, thus providing both opportunities and limitations. Because of this study's contextual setting within museums, there was a high degree of complexity that, unlike experimental studies, could not necessarily be controlled. For example, as is common in museum settings where the needs of diverse audiences have to be met, each *Let's Do Chemistry* activity incorporated multiple content and/or format strategies. This complexity in the design of the activities meant that it was impossible to isolate different content or format strategies and test them individually. However, by using qualitative methods that asked visitors to describe what about an individual activity increased their interest, understanding of relevance, or feelings of self-efficacy about chemistry, the team was able to understand the specific strategies that seemed to be most important for a broad audience. Moreover, by looking at data across all of the different activities, the research team was able to create a broader theoretical framework for the field.

As noted in the Introduction, DBR relies, to a large degree, on qualitative data. In the case of *Let's Do Chemistry*, open-ended questions asked visitors what about the activity led to an increase in chemistry attitudes. The research team used these data, instead of questions with predefined lists of activity strategies, to determine the criteria that influenced increases in visitors' attitudes toward chemistry. These data allowed the team to look for strategies already in the theoretical framework as well as uncover strategies that were missing. However, asking for responses in this way meant that visitors did not necessarily provide understanding of all of the different design strategies that might have supported interest, relevance, and self-efficacy, only ones that were top of mind. Therefore, it is possible that some strategies are missing from the final framework although the researchers feel confident that the most important strategies are represented.

Another limitation of the *Let's Do Chemistry* study was that, despite the number of activities tested and the diversity of design criteria included, two strategies in the original framework ("discussion around visitors' roles in the development of technology" and "discussion about how topics in the activity relate to visitors' lives in the future") were never incorporated into any of the activities. The *Let's Do Chemistry* team consulted the framework during the development process and made a concerted effort to include all of the strategies from the initial framework in the 15 activities being tested. However, these two criteria did not end up being appropriate for the activities created and were never included. Therefore, this study cannot comment on whether these strategies are able to support increases in chemistry interest, relevance, and self-efficacy. Because there was no evidence from the study, these strategies were removed from the project's final theoretical framework. However, the researchers feel that these two approaches should be studied as part of another project to understand whether they support increases in chemistry interest, relevance, and/or self-efficacy.

IMPLICATIONS

As described in the Introduction, the NASEM report, *Effective Chemistry Communication in Informal Environments*, recommends that researchers conduct studies to understand public perceptions and understanding of chemistry and use these findings to develop chemistry outreach activities.[17] Findings from the RSC report indicated that the public does not have many feelings about chemistry, and that they also are not confident in their abilities to do and talk about chemistry.[13] On the basis of this literature, the *Let's Do Chemistry* team determined that it would be important to develop outreach activities that increase public interest in and understanding of the relevance of chemistry as well as increase feelings of self-efficacy as a way to positively impact their attitudes toward chemistry. Overall, the research reported in this paper shows that these three attitudes can be shifted, at least in the moment, after doing a hands-on activity with a facilitator. After using one of the activities, over 75% of visitors reported that they felt chemistry was more interesting, felt chemistry was more relevant, and/or were more confident in the presented topic. However, the *Let's Do Chemistry* project team wanted to do more than just create activities that lead to increases in these outcomes. The team also wanted to learn about the design strategies included in the activities that support these attitudes. This desire aligns with guidance from the NASEM practical guide: *Communicating Chemistry: A Framework for Sharing Science: A Practical Evidence-Based Guide*.[10]

One recommendation of the NASEM guide is for science communicators preparing to do chemistry outreach to think about what would be interesting and relevant to their audiences.[10] The *Let's Do Chemistry* research study findings offer specific, evidence-based content and format strategies that can be used to thoughtfully design or modify hands-on activities to impact these areas. Broadly, findings from the *Let's Do Chemistry* project show that, in cases when communicators are hoping to increase public interest in chemistry, it is important to consider both the activity format and the chemistry content that is included in activities. More specifically, activity formats should allow for participants to do something hands-on and interactive as well as provide opportunities for them to observe phenomena. Chemistry content should include chemistry concepts and connections to everyday life. In order to enhance participants' understanding of the relevance of chemistry to their lives, communicators should pay special attention to the kinds of content included in an activity. Particularly, it is important to include content connections to everyday life, as well as describe applications and uses of chemistry. By intentionally relying on these design strategies when creating or modifying hands-on activities, research from this project shows that communicators may make chemistry feel more interesting or relevant for visitors.

The NASEM practical guide and report do not emphasize self-efficacy as a potential goal or outcome for participants. However, chemistry communicators should consider how they can increase participants' confidence in learning about, understanding, or talking to others about the chemistry topics presented, as recommended by the RSC.[13] Findings from the *Let's Do Chemistry* project indicate that it is important for communicators to give special consideration to the format of an activity to increase self-efficacy. Activities should be hands-on and interactive as well as simple to do and easy to understand to support this participant outcome.

Whether targeting interest, relevance, or self-efficacy, the theoretical framework developed by the *Let's Do Chemistry* project can support the creation of effective chemistry experiences by chemistry communicators. While some strategies were found to be more effective for particular outcomes, others were shown to positively impact all three attitudes. Thus, the framework from this project can inform the

https://doi.org/10.1021/acs.jchemed.1c00193
J. Chem. Educ. XXXX, XXX, XXX−XXX

activity design for various identified goals. Because the *Let's Do Chemistry* research looked at the content and format strategies for increasing museum visitors' interest, relevance, and/or self-efficacy across a range of ages and experience levels, it is likely that these findings can be effectively applied to similar hands-on activities in other informal education settings.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.1c00193.

Design strategies analysis definitions (PDF, DOCX)
Let's Do Chemistry activity descriptions (PDF, DOCX)

■ AUTHOR INFORMATION

Corresponding Author

Elizabeth Kunz Kollmann − *Museum of Science, Boston, Boston, Massachusetts 02114, United States;* orcid.org/0000-0002-2205-6844; Email: ekollmann@mos.org

Authors

Allison Anderson − *Museum of Science, Boston, Boston, Massachusetts 02114, United States;* orcid.org/0000-0001-8784-6305
Marta Beyer − *Museum of Science, Boston, Boston, Massachusetts 02114, United States*
Owen Weitzman − *Museum of Science, Boston, Boston, Massachusetts 02114, United States*
Marjorie Bequette − *Science Museum of Minnesota, St. Paul, Minnesota 55102, United States*
Gretchen Haupt − *Science Museum of Minnesota, St. Paul, Minnesota 55102, United States*
Hever Velázquez − *Science Museum of Minnesota, St. Paul, Minnesota 55102, United States*

Complete contact information is available at:
https://pubs.acs.org/10.1021/acs.jchemed.1c00193

Notes

This article is based on work supported by the National Science Foundation under Grant DRL-1612482. Any opinions, findings, and conclusions or recommendations expressed in this presentation are those of the authors and do not necessarily reflect the views of the Foundation.
The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

As a collaboration between the National Informal STEM Education Network, the American Chemical Society, and the Museum of Science, Boston, many people contributed to this research project. The authors would particularly like to thank the project PIs (Larry Bell, Mary Kirchhoff, Rae Ostman, and David Sittenfeld), activity developers (Thor Carlson, Angela Damery, Susan Heilman, Emily Hostetler, KC Miller, Jill Neblett, and Becky Smick), and former members of the research team (Nikki Lewis, Sarah Pfeifle, and Kaleen Tison Povis).

■ REFERENCES

(1) Technological Literacy Committee. *Technically Speaking: Why All Americans Need to Know More about Technology*; The National Academies Press: Washington, DC, 2002.
(2) Kelly, G. Discourse in science classrooms. In *Handbook of Research on Science Education*; Abell, S. K., Lederman, N. G.; Eds.; Lawrence Erlbaum Associates: Mahwah, NJ, 2007.
(3) National Science Board. *Science and Engineering Indicators 2018*; NSB-2018-1; National Science Foundation: Alexandria, VA, 2018.
(4) Falk, J. H.; Dierking, L. D. The 95% solution. *Am. Sci.* **2010**, *98* (6), 486−493.
(5) *Learning Science in Informal Environments: People, Places, and Pursuits*; Bell, P., Lewenstein, B., Shouse, A. W., Feder, M. A., Eds.; The National Academies Press: Washington, DC, 2009.
(6) Zare, R. N. Where's the chemistry in science museums? *J. Chem. Educ.* **1996**, *73* (9), A198−A199.
(7) National Research Council. *Chemistry in Primetime and Online: Communicating Chemistry in Informal Environments*; National Academies Press: Washington, DC, 2011.
(8) Silberman, R. G.; Trautmann, C.; Merkel, S. Chemistry at a science museum. *J. Chem. Educ.* **2004**, *81* (1), 51−53.
(9) Grunwald Associates and Education Development Center. *Communicating Chemistry Landscape Study*; National Research Council, 2013.
(10) National Academies of Sciences, Engineering, and Medicine. *Communicating Chemistry: A Framework for Sharing Science: A Practical Evidence-Based Guide*; National Academies Press: Washington, DC, 2016.
(11) Entine, J. *Scared to Death: How Chemophobia Threatens Public Health*; American Council on Science and Health: New York, 2011.
(12) National Science Board. *Science and Engineering Indicators—2002*; National Science Foundation: Arlington, VA, 2002.
(13) TNS BMRB. *Public Attitudes to Chemistry: Research Report*; Royal Society of Chemistry: London, 2015.
(14) Hidi, S.; Renninger, K. A. The four-phase model of interest development. *Educ. Psychol.* **2006**, *41* (2), 111−127.
(15) Kollmann, E. K.; Svarovsky, G.; Iacovelli, S.; Sandford, M. *NISE Net Research on How Visitors Find and Discuss Relevance in the Nano Exhibition*; NISE Network: Boston, 2015.
(16) Reich, C. Making the unfamiliar interesting and relevant for museum visitors. In *Review of NISE Network Evaluation Findings: Years 1−5*; NISE Network: Boston, 2011; pp 118−139.
(17) National Academies of Sciences, Engineering, and Medicine. *Effective Chemistry Communication in Informal Environments*; The National Academies Press: Washington, DC, 2016.
(18) Cahill, C.; Lussenhop, C. *Effects of Feedback from a Virtual Tutor on Computer Programming Self-Efficacy*; Museum of Science: Boston, 2012.
(19) Collins, A.; Joseph, D.; Bielaczyc, K. Design research: Theoretical and methodological issues. *J. Learn Sci.* **2004**, *13* (1), 15−42.
(20) O'Donnell, A. M. A commentary on design research. *Educ. Psychol.* **2004**, *39* (4), 255−260.
(21) Sandoval, W. A.; Bell, P. (2004). Design-based research methods for studying learning in context: Introduction. *Educ. Psychol.* **2004**, *39* (4), 199−201.
(22) Barab, S.; Squire, K. Design-based research: Putting a stake in the ground. *J. Learn. Sci.* **2004**, *13* (1), 1−14.
(23) *Evaluating the NISE Network: Reflections from the Evaluation Workgroup*; Kollmann, E. K., Beyer, M., Eds.; NISE Network: Boston, MA, 2016.
(24) Ostman, R. *NISE Network Program Development: A Guide to Creating Effective Learning Experiences for Public Audiences*; NISE Network: Saint Paul, MN, 2016.
(25) Ellenbogen, K.; Livingston, T.; Ostman, R.; Bell, L.; Garcia-Luis, V.; Johnson, M.; et al. *Nanoscale Science Informal Learning Experiences: NISE Network Learning Framework*; NISE Network: Saint Paul, MN, 2012.
(26) Cam, A.; Geban, O. Effectiveness of case-based learning instruction on epistemological beliefs and attitudes toward chemistry. *J. Sci. Educ. Technol.* **2011**, *20* (1), 26−32.
(27) Keller, J. M. Development and use of the ARCS model of instructional design. *J. Instr. Dev.* **1987**, *10* (3), 2−10.

(28) NISE Network. *2015 NanoDays Planning Guide*; Sciencenter: Ithaca, NY, 2014.
(29) Potvin, P.; Hasni, A. Interest, motivation, and attitude towards science and technology at K-12 levels: A systematic review of 12 years of educational research. *Stud. Sci. Educ.* **2014**, *50* (1), 85−129.
(30) Hattie, J.; Timperley, H. The power of feedback. *Rev. Educ. Res.* **2007**, *77* (1), 81−112.
(31) Svarovsky, G.; Goss, J.; Ostgaard, G.; Reyes, N.; Cahill, C.; Auster, R.; et al. *Summative Study of the Nano Mini-exhibition*; NISE Network: Saint Paul, MN, 2013.
(32) Svarovsky, G.; Tranby, Z.; Cardiel, C.; Auster, R.; Bequette, M. *Summative Study of the NanoDays 2014 Events*; NISE Network: Notre Dame, IN, 2014.
(33) Cohen, J. A coefficient of agreement for nominal scales. *Educ. Psychol. Meas.* **1960**, *20* (1), 37−46.
(34) de Vries, H.; Elliott, M. N.; Kanouse, D. E.; Teleki, S. S. Using pooled kappa to summarize interrater agreement across many items. *Field Methods* **2008**, *20* (3), 272−282.
(35) Landis, J. R.; Koch, G. G. The measurement of observer agreement for categorical data. *Biometrics* **1977**, *33* (1), 159−74.
(36) Patton, M. Q. *Qualitative Research and Evaluation Methods*; Sage Publications: Thousand Oaks, CA, 2002.
(37) Design strategies that were mentioned by 5% or fewer visitors were not included in the final framework.

https://doi.org/10.1021/acs.jchemed.1c00193
J. Chem. Educ. XXXX, XXX, XXX−XXX