Let's Do Chemistry

A Framework and Strategies to Encourage Positive Attitudes Toward Learning Chemistry in Museums and Informal Settings

By Rae Ostman

NISE
NATIONAL INFORMAL STEM EDUCATION NETWORK

ACS
Chemistry for Life®

EXPLORE SCIENCE

A NISE Network Research-to-Practice Guide

Based on work by the Let's Do Chemistry *project team led by Larry Bell, Mary Kirchhoff, Liz Kollmann, Rae Ostman, and David Sittenfeld* www.nisenet.org

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Explore Science: Let's Do Chemistry is a close collaboration of members of the National Informal STEM Education Network (NISE Network) and the American Chemical Society (ACS). The NISE Network team includes educators, scientists, and researchers from the Museum of Science in Boston; the Science Museum of Minnesota; Arizona State University, the Sciencenter in Ithaca, New York; and the University of Wisconsin-Madison. The ACS team includes chemists, science communicators, and educators from the association. Additional advice, expertise, and oversight are contributed by the ACS Committee on Chemical Safety, the ACS Committee on Community Activities, the Children's Creativity Museum in San Francisco, the Children's Museum of Houston, The Franklin Institute, the Lawrence Hall of Science at the University of California Berkeley, the University of Notre Dame, and the Museum of Life and Science in Durham, North Carolina. It has been a pleasure and a privilege to work with this team, and it is exciting to share our results with the informal education and chemistry education communities.

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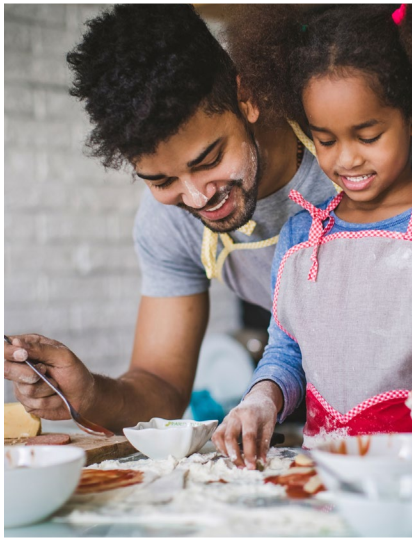
INTRODUCTION

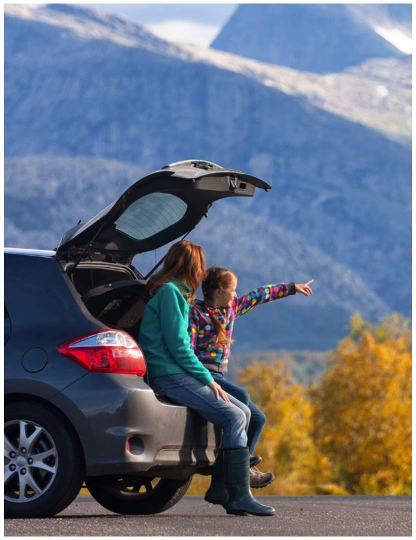
Project overview

Chemistry is everywhere in the world around us. We all use chemistry, and chemicals, every day. When we mix together the ingredients to make batter and put it in the oven to bake, we're using chemicals and chemical reactions to change the batter into cake. When we eat food, our body digests it through a series of chemical reactions, and then uses the nutrients through a different set of reactions. When we drive a car, the energy from the battery and the combustion of fuel are both examples of chemical reactions. And when we do laundry, we use water and a mixture of chemicals in detergent to physically and chemically remove soil from clothes. Many, many things we do every day are examples of chemistry in action!

Chemistry can help us understand how the world works and empower us to create new things. Chemistry is often called the "central science," because it connects the physical sciences, life sciences, and applied sciences such as medicine and engineering.

Despite the importance of chemistry, many people don't realize how it relates to everyday life. Recent reports in the United States and the United Kingdom found that most people have positive attitudes toward science in general, but that they do not feel informed about chemistry specifically or confident in their ability to learn it (National Academies of Sciences, Engineering, and Medicine, 2016a; TNS MNRB, 2015). The UK study found that members of the public often are not familiar with concrete examples of chemistry applications, and so do not see chemistry as personally relevant. Some adults' associations





with chemistry include their experiences in school, where they often found chemistry to be an obscure or difficult subject. The UK report concluded that because most people are emotionally neutral about chemistry, there is great potential to help public audiences develop positive attitudes toward learning and using chemistry (TNS BMRB, 2015).

Explore Science: Let's Do Chemistry takes up this challenge by providing public audiences across the United States the opportunity to meet chemists and do hands-on chemistry activities designed for informal learning environments such as museums. The National Informal STEM Education Network (NISE Network) and the American Chemical Society (ACS) worked together on this project to encourage multiple and diverse public audiences to find chemistry interesting, understand its connection to their lives, and develop a sense of confidence and self-efficacy about learning, using, and talking about chemistry. Throughout this guide, we'll refer to the project as *Let's Do Chemistry,* which is the tagline for the kit of materials and resources the team created.

The NISE Network

The National Informal STEM Education Network (NISE Network) is a community of educators and scientists dedicated to supporting learning about science, technology, engineering, and math (STEM) across the United States. The Network creates resources and coordinates activities on a national and regional level, while Network partners coordinate and implement project activities locally. We achieve our reach and impact through the participation of over 600 partner organizations in Network activities, including museums, universities, and other organizations that provide informal learning opportunities for public audiences. Together, Network partners engage 11 million people each year in high-quality STEM learning.

American Chemical Society

The American Chemical Society (ACS) is the world's largest scientific society, with more than 150,000 members in over 140 countries. ACS is recognized as a leading publisher of authoritative scientific information, with over 50 peer-reviewed journals and comprehensive digital databases of disclosed research in chemistry and related sciences. In its role as a scientific society, ACS serves as a catalyst for innovation, strengthens science education, advances sustainability, and influences public policy. As a professional organization, ACS empowers its members to advocate for chemistry, elevate their career potential, expand their networks, inspire future generations, and improve the scientific understanding of all people.

NISE Network partners engage public audiences in learning about current science, technology, math, and engineering in all 50 states and Puerto Rico.

The American Chemical Society promotes National Chemistry Week and other public educational activities.

Project goals and activities

The goal of *Let's Do Chemistry* is to promote positive attitudes toward learning about chemistry by engaging multiple and diverse public audiences all across the United States in facilitated, hands-on chemistry activities. Specifically, the project is focused on identifying evidence-based design strategies that increase participants' *interest* in chemistry, their perception of its *relevance* to their lives, and their sense of *self-efficacy* (or ability) to learn chemistry.

Major project activities include a research study on public attitudes toward chemistry in the United States; a research study articulating design strategies for encouraging interest, relevance, and self-efficacy and supporting the development of exemplary hands-on activities; and the production of a toolkit of activity materials and professional resources. Through this project, researchers are also collecting data about the impact of the kit materials on both public audiences and participating educators and chemists.

Let's Do Chemistry materials are designed to help museums and chemists collaborate in order to offer National Chemistry Week activities that encourage positive attitudes toward learning chemistry. All the materials developed for the *Let's Do Chemistry* kit are based on evidence about what works to increase museum visitors' interest, relevance, and self-efficacy about learning chemistry. The project team used a research methodology known as *design-based research,* as well as best practices in informal education, to develop these materials. These methods and practices are described in more information later on in the guide.

Physical copies of the *Let's Do Chemistry* kit have been distributed to 250 museums and other organizations that support informal learning in the United States. Digital versions of all the materials are also available for free download from the NISE Network website, at *http://www.nisenet.org/chemistry-kit*. Through local partnerships between NISE Network and ACS members, *Let's Do Chemistry* will have a national impact across the United States.

The *Let's Do Chemistry* kit will be used by NISE Network and ACS partners across the United States. It includes hands-on chemistry activities, staff and volunteer training materials, and other resources.

About this guide

This guide describes some of the project's emerging research findings, explains how they are represented in the *Let's Do Chemistry* kit activities, and suggests ways that educators and chemists can apply the findings. The guide is designed to be a tool for informal educators, chemists familiar with educational outreach, and others that are planning and implementing hands-on programming activities. It is complemented by a variety of practical training tools, which put the ideas contained in this guide—and the activities included in the kit—into practice.

The first chapter, Learning Chemistry in Museums, provides an overview of informal science learning in museums and similar settings. This information is useful context for understanding the project's research and the settings in which its findings will be implemented.

The second chapter, Creating the Framework, explains how the project team simultaneously created and tested the *Let's Do Chemistry* activities and our theoretical framework. This work resulted not only in a set of hands-on activities that are successful at increasing positive attitudes toward chemistry, but also in a set of generalizable activity design strategies that can be used to create or modify other chemistry activities that increase participants' sense of interest, relevance, and self-efficacy. The chapter concludes with a chart summarizing the current version of the framework.

The third chapter, Understanding the Framework, presents the information included in our framework in more detail. It describes how we defined chemistry for public audiences and explains what we mean by interest, relevance, and self-efficacy. These sections are illustrated by training materials that are included in the *Let's Do Chemistry* kit.

Finally, the fourth chapter, Using the Framework, explains how to apply the *Let's Do Chemistry* framework to deliver and develop hands-on chemistry activities. It goes through facilitation and design strategies for hands-on activities that support interest, relevance, and self-efficacy related to chemistry. These ideas are illustrated with examples of activities that are included in the *Let's Do Chemistry* kit. The chapter concludes with a selection of additional resources that educators and chemists can use to apply the project framework to create or adapt other hands-on activities. Most of these resources were developed by ACS and the NISE Network and were chosen because they are well suited to engaging public audiences in informal learning settings, such as museums and National Chemistry Week events.

LEARNING CHEMISTRY IN MUSEUMS

Informal science learning

Science has always been a part of the lives of families and communities, who gain knowledge and experience through activities in their everyday activities. As a cultural practice, science learning takes place within and across both formal and informal learning environments (in school and out of school). Research demonstrates that informal and formal education share a set of common learning outcomes related to science, yet they have complementary and distinct roles to play.

The National Research Council (NRC) Committee on Learning Science in Informal Environments developed an influential "strands of science learning" framework (NRC, 2009) that articulates the kinds of science learning that occurs in both formal and informal learning environments. Learners:

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 process of learning about phenomena;

5. Participate in scientific activities and learning practices with others using scientific language and tools; and

6. Think about themselves as science learners and develop an identity as someone who knows about, uses, and sometimes contributes to science.

Based on a comprehensive analysis of literature on science learning, the NRC Committee determined that informal learning environments such as museums are particularly well suited to promoting interest in and identity development related to science (strands 1 and 6 in the list above). Formal learning environments have the structure and opportunities for sustained engagement to support empirical investigations and the development of deep conceptual and contextual knowledge (strands 2, 3, 4, and 5 in the list above). Together, informal and formal science education supports a lifetime of learning, from initial interest through the development of an identity as a science learner, and, in some cases, pursuit of a career in science (NRC, 2009).

People learn science throughout their lives: at home, at school, outside, and in their community.

Let's Do Chemistry activities are designed to take advantage of the distinct strengths and approaches of informal education. Chemistry learning that takes place in museums and other informal environments can create a foundation to build upon existing science knowledge, discover an interest in the scientific fields of study, develop the motivation to pursue further learning, and grow an identity as a person who learns science and uses it in the personal, professional, and civic aspects of their lives.

Museums provide opportunities for people of all ages and backgrounds to explore and develop positive attitudes toward learning science.

Museums as learning environments

Let's Do Chemistry activities are designed to promote not only chemistry learning, but also positive social experiences. The activities take into account the following motivations and expectations for visiting interactive museums such as science centers and children's museums:

Fun: People visit museums to enjoy themselves in a way that they find worthwhile and meaningful. Science learning is important, but so is having a good time.

Social: People often attend museums in a group, and part of their motivation in visiting a museum is to spend time together. Museum visitors learn best when they do things together. Many groups will be intergenerational, with both adults and children.

Self-directed: There is no set agenda at a museum, and visitors are free to choose what to do and for how long. Brief hands-on activities that can be done in any order and any combination are ideal for a casual visiting group.

Hands-on: Science and children's museums typically encourage interactive learning. With trained facilitators and appropriate safety practices, many aspects of chemistry can be shared through hands-on activities in museum settings.

CREATING THE FRAMEWORK

The *Let's Do Chemistry* team created and tested both general strategies and specific hands-on activities that encourage increased interest, relevance, and self-efficacy about chemistry in museum settings. In this work, we were interested in contributing to the overall body of knowledge about learning science in informal settings; helping educators, chemists, and others use successful strategies in engaging the public in chemistry learning; and creating and sharing broadly a set of resources that would have a positive impact on people's attitudes toward learning chemistry all across the country.

Research goal: to create generalizable knowledge about how to design hands-on chemistry activities that increase participants' sense of interest, relevance, and self-efficacy related to learning chemistry.

Professional practice goal: to create and share a set of tools that communicate and embody the evidence-based strategies identified through project research.

Public learning goal: to create and deliver hands-on activities that engage public audiences in learning about and developing positive attitudes toward chemistry.

These three interconnected goals are reflected both in our research and development process and in the products we have created.

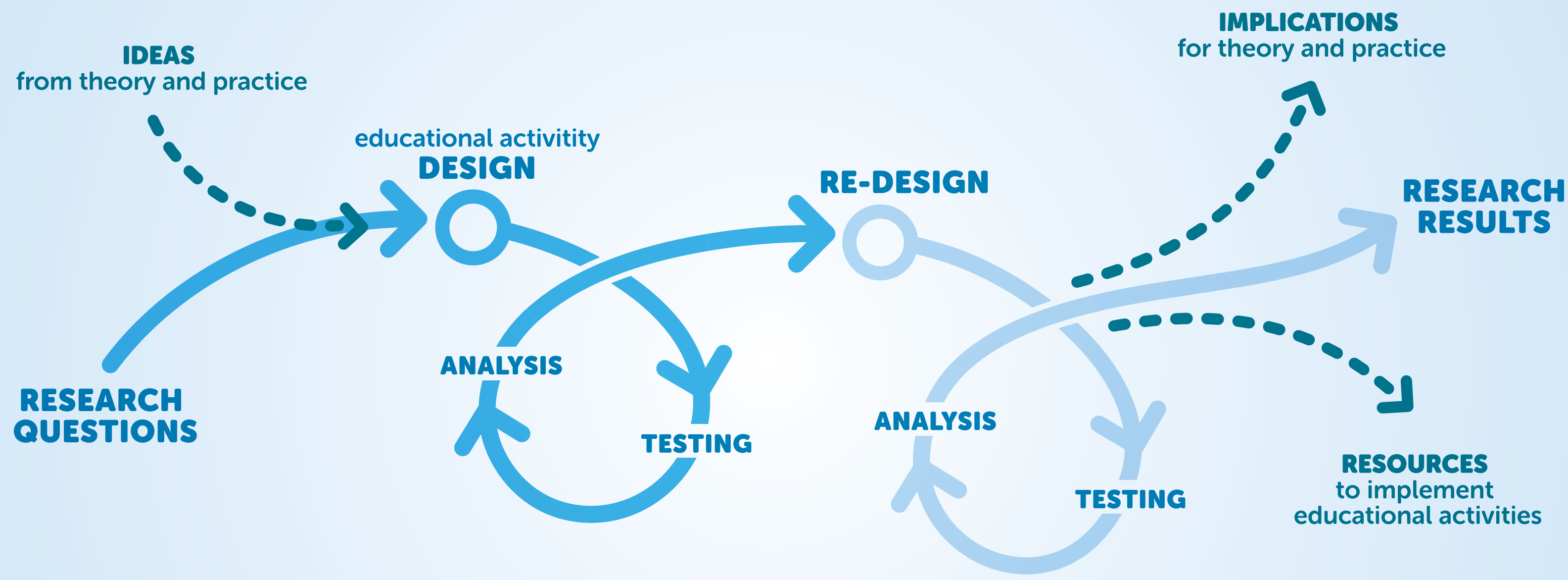
Research and practice

This project is a *research-practice partnership,* which means that researchers and educators work together to investigate questions that are equally interesting and important to everyone (Bevan and Penuel, Eds., 2018; Penuel and Gallagher, 2018). Our research question is: *How should hands-on activities, events, and trainings be designed to increase participants' positive attitudes about interest in, relevance of, and self-efficacy around chemistry?* Specifically, we looked at the ways that facilitation techniques, chemistry content, and activity format and structure affect participants' attitudes about chemistry.

Design-based research to refine the framework

To address our research question, the project team started with an initial theoretical framework, which was based on studies and work within the NISE Network as well as other education literature. The framework identified promising strategies that we felt might lead to increases in participants' interest, relevance, and self-efficacy. To improve the initial framework, and create related chemistry education materials, we used a research methodology called design-based research (DBR) that comes from the learning sciences. DBR combines iterative formative research with design experiments that are based upon learning from prior research and practice. With educators and researchers working side by side, a DBR project can develop and refine educational materials at the same time that it develops and refines a theoretical model. Testing is done in a naturalistic setting such as a museum, rather than a lab or other controlled setting. As a result, DBR contributes to practice and research simultaneously and both the educational products and the research process are tightly integrated and informed by the context of use (Barab, 2014; Collins, Joseph, & Bielaczyc, 2004).

Design-Based Research Process



Design-based research focuses on learning in a real-life setting. Design experiments are based on previous theory and practice. They often go through multiple cycles of design, testing, analysis, and improvement. In the end, the process can result in new theories, practices, and educational materials that can be used by others.

> *"The highlight of design-based research for us has been that it drives rapid iteration. Working on this project has forced us to think creatively about our activities, identify improvements, make changes, and take time to reflect on how visitors respond to them."*
>
> **–Museum educator**

The project team chose to use DBR because we thought it was an appropriate way to test our research questions, and also because we thought it had the potential to build on and enrich existing practices and knowledge developed by the NISE Network and ACS. Through many years of developing and testing hands-on activities on a variety of science topics, the project team had a range of ideas about ways to design and facilitate activities to encourage interest, relevance, and self-efficacy. DBR gave us the opportunity to test those ideas and see if they were valid and generalizable, and to add in new ideas that emerged from the data collected through our collaboration.

As a starting point for our design experiments, the project team and our advisors generated a list of existing chemistry activities, developed by ACS and other sources, and selected a group that seemed well aligned to the initial framework. In our first round of research, we chose five activities, tested them with public audiences, improved them, and tested them again. This iterative testing process allowed us to collect data to improve the activities and inform the framework at the same time. We then did two additional rounds of iterative testing, with a new set of activities each time, for a total of 15 activities. After each round of iterative testing, we used the data we collected to refine the framework. By doing our development and analysis in three rounds, we were able to focus on different design strategies for each round, apply what we had learned in one round to the next, identify gaps, and pose questions that we wanted to address in the future. For example, in our second round of testing we decided to focus on activities that addressed societal issues, since this was a content area that we felt was promising but hadn't tested yet.

After we finished our three rounds of data collection using DBR methods, the team examined the data from all 15 activities together to understand to what degree each activity supported the development of feelings of interest, relevance, and self-efficacy related to chemistry. We also considered why each activity worked the way it did, identifying specific design strategies that appeared to support interest, relevance, and self-efficacy. The team then looked across the activities to identify a smaller group that could be used to create the *Let's Do Chemistry* kit, so that the kit would represent the range of strategies and learning outcomes articulated in the framework and create a foundation for a successful National Chemistry Week event.

At this point, the work split into two integrated strands. One strand of work is continuing to analyze the data collected using DBR to refine the framework. The second strand of work developed the *Let's Do Chemistry* kit using a method called team-based inquiry (Pattison, Cohn, and Kollmann, 2014), as well as our previous experience creating and distributing hands-on activities and similar kits to museums across the US (Ostman, 2016a and 2016b).

The creation of the *Let's Do Chemistry* kit began with the development of a preliminary theoretical framework. This led to an intensive period of design-based research to improve the framework and develop a set of hands-on activities. Finally, the team selected a set of activities that exemplified successful strategies and created training resources to prepare educators and chemists to deliver the activities to public audiences.

Framework

As a result of the team's design-based research, we learned about many strategies to support interest, relevance, and self-efficacy through hands-on chemistry activities. These strategies are now reflected in our revised theoretical framework.

The framework is organized according to strategies related to *facilitation techniques, chemistry content,* and *activity format and structure. Facilitation techniques* include strategies that educators and chemists use while they do the activities with public audiences. These include techniques to invite learners to participate in an activity, support them as they explore the activity, and deepen their understanding of the activity. *Chemistry content* and *activity format and structure* are strategies that are embedded into the design of the activity, including the chemistry ideas and practices it explores, as well as the kinds of things learners do and the materials they use.

So far, the team has completed the data analysis for the content and format strategies but has not yet finished analyzing the data for the facilitation strategies. The framework will be finalized after the activities are implemented at 250 sites across the United States.

Our high-level findings to date include:

- To encourage **interest** in learning chemistry, design strategies related to *chemistry content* and *activity format and structure* are important
- To illustrate the **relevance** of chemistry to everyday life and societal issues, design strategies related to *chemistry content* are important
- To help learners develop feelings of **self-efficacy** related to learning chemistry, design strategies related to *activity format and structure* are important

The current version of the framework is divided into two parts: facilitation techniques and design strategies. The first part lays out the facilitation strategies, which encourage positive attitudes toward chemistry generally. The second part presents the design strategies related to chemistry content and to activity format and structure, which encourage interest, relevance, and self-efficacy specifically. The framework is summarized below in table format; the following chapter presents the information included here in more detail.

Facilitation techniques to encourage positive attitudes toward chemistry

Invite participation →	Support exploration →	Deepen understanding →	Public learning outcomes
Greet participants Start with the basics Model what to do Engage the whole group Have fun!	Let participants do the activity Be flexible and attentive Ask guiding questions Be a good listener Support learners through challenges Offer positive feedback	Ask discussion questions Make connections Share your experience Wrap up	Positive attitudes toward chemistry, including: • Increased *interest* in the field of chemistry • Increased *understanding* of the relevance of chemistry to their lives • Increased feelings of *self-efficacy* about chemistry

Design strategies to encourage interest, relevance, and self-efficacy related to chemistry

Chemistry content →	Activity format and structure →	Public learning outcomes
Chemistry concepts Connections to everyday life Applications and uses of chemistry Connections across other STEM topics	Hands-on and interactive Observation of phenomena Use of tools and materials Experimentation with variables Familiar experiences	Increased *interest* in the field of chemistry
Connections to everyday life Applications and uses of chemistry Chemistry concepts Connections across other STEM topics Connections to societal issues	Familiar experiences Use of tools and materials Observation of phenomena	Increased *understanding* of the relevance of chemistry to their lives
Chemistry concepts Connections to everyday life	Hands-on and interactive Simple to do and easy to understand Use of tools and materials Evoke familiar experiences Observation of phenomena Experimentation with variables	Increased feelings of *self-efficacy* about chemistry

Let's Do Chemistry kit

The *Let's Do Chemistry* kit includes eight brief hands-on activities and one longer interactive activity to engage public audiences in learning about chemistry. It also includes a set of training materials to prepare educators and chemists to deliver the educational activities successfully in order to achieve the project goals. We produced the kit using a collaborative process that took advantage of the expertise of the research team and our emerging research findings, as well as our practical experience with National Chemistry Week and science programming at museums across the country.

The resulting kit of hands-on activities and related resources can be used to engage the public in learning about chemistry, and also serves to articulate the project framework and findings to date. The design strategies we have identified related to chemistry content and activity format and structure are embedded in the final versions of the *Let's Do Chemistry* activities themselves, while the facilitation techniques are activated through their use with public audiences. The following chapters utilize products from the kit to illustrate key points for understanding and using the framework.

"I thought chemistry was science, but it's everywhere!"

–Museum visitor

UNDERSTANDING THE FRAMEWORK

This chapter walks through the *Let's Do Chemistry* framework and explains the information it includes. First, the chapter presents the definition of chemistry that we have been using throughout the project, which reflects both project goals and existing public attitudes toward and understandings of chemistry. Then, it presents our definitions of interest, relevance, and self-efficacy, which incorporate the ideas of educators, chemists, and public participants in our hands-on activities. Both of these sections are illustrated by training materials that are included in the *Let's Do Chemistry* kit.

Defining chemistry

In the *Let's Do Chemistry* activities and training materials, we define chemistry in terms of who does chemistry, what they do, and why they do it. This emphasis on people doing concrete things, rather than on abstract scientific concepts, helps to create a bridge between the chemistry that our participants are doing in the hands-on activities and chemistry as a field of science. Our definition also limits the use of scientific terms, which some participants (such as young children) may not be familiar with.

Chemistry as an everyday activity

The "Atoms to Atoms" game, included as a staff and volunteer training game in the *Let's Do Chemistry* kit, provides a fun way to develop a well-rounded understanding of chemistry and its

DEFINITION OF CHEMISTRY

***Chemists* are scientists who study:**

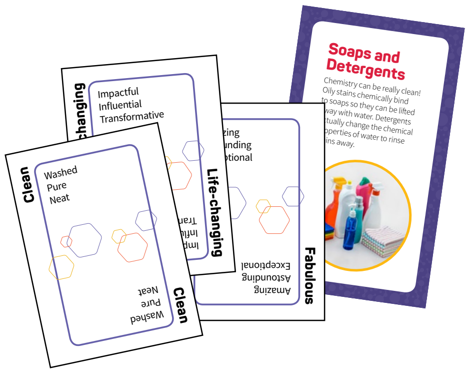
- The elements that make up everything in the world
- The ways different materials behave and change
- How materials interact with each other and combine to make new things

Chemistry can help us understand the world around us, solve problems, and answer questions, such as:

- "What are stars made of?"
- "How do batteries work?"
- "Why is slime stretchy?"
- "How can we make sure our water is safe to drink?"

There are many more questions chemistry can help us answer! You don't have to be a chemist to learn, use, and talk about chemistry.

relationship to everyday life. In this word association game, players use their hand of “word cards” to select words that they think best fit with a given “chemistry-related card.” They then have an opportunity to make the case for their selection, before the judge for that hand chooses a winner and the group moves on to the next chemistry-related card. For example, one participant might think a “Exploring Space” (chemistry-related card) is “Costly” (word card), while another might argue that it is “Important,” and a third might say it’s “Complicated.” A fourth might introduce some humor by declaring that a “Exploring Space” is “Funky.” The resulting conversation gives participants the opportunity to reflect on their values related to applications of chemistry.



Chemistry as a profession

Let’s Do Chemistry activities show that everyone can be a chemist and use chemistry in their everyday lives. Some people can also go on to study chemistry intensively or use chemistry in their careers to solve problems or answer questions. Many chemists do work that is connected to things we might use every day or consider to be important issues facing society. In the *Let’s Do Chemistry* materials, we define chemistry in terms of what chemists study and how people use chemistry.

Eric Breitung is a scientist at the Metropolitan Museum of Art. He tests the dyes, pigments, metals, and modern materials in the museum’s artworks. His research helps conservators preserve objects and bolsters art historians’ understandings of how objects were made and how distant cultures interacted.

LeighAnne Olsen

Eric Breitung is using a portable x-ray fluorescence (XRF) tool to assess the elemental composition of the patina and bronze casting of a 12th century Iranian incense burner.

Americans' attitudes toward chemistry

To help us assess Americans' attitudes toward and understandings of chemistry, the project team conducted an online survey of Americans nationwide. Survey respondents associated a wide variety of fields with chemistry and its potential uses. In particular, a majority of respondents associated chemistry "a good deal" or "very much" with the medical field (81%), energy development (67%), food production (62%), the environment (61%), and industry and manufacturing (61%). These results suggest that Americans are generally aware that chemistry is a wide field that includes many uses and applications (Howell and Scheufele, 2017).

Americans associate chemistry with many fields, including medicine, food production, and energy development.

Learning goals

The primary learning goal for public audiences that participate in *Let's Do Chemistry* activities is to develop positive attitudes toward chemistry as a foundation for lifelong learning. In this section, we explain in more detail what interest, relevance, and self-efficacy entail, and what people might say, do, or feel if they experience these positive attitudes as they engage in *Let's Do Chemistry* activities.

Interest in chemistry

Interest is the feeling of having your attention, concern, or curiosity particularly engaged by something. In our research, we looked for evidence that people were interested in chemistry while they used our activities. We found that interest is related to the chemistry content included in the activity (what the activity is about) as well as the activity format and structure (what people do and the materials they use).

While doing a hands-on chemistry activity, interested learners may:

- try things out
- observe carefully
- experiment with variables
- want to do more chemistry later on

Relevance

Relevance is the pertinence to or connection with the matter at hand. It includes the links that someone makes between a topic and their lives and experiences or broader societal issues (Reich, 2011; Kollmann et al., 2015). In our research, we looked for evidence that learners were making connections to familiar experiences, to everyday life, and to the ways that chemistry is used. Some participants discovered relevance to things they had done elsewhere, and some found relevance to other things they cared about. We found that relatable chemistry content (what the activity is about) is the most important way to establish the relevance of chemistry.

Learners who discover the relevance of chemistry may:

- notice applications and uses of chemistry
- make connections to everyday life
- talk about how chemistry relates to issues that are important to them
- remember familiar experiences

Self-efficacy

Self-efficacy is feeling confident in the ability to learn, talk about, and use chemistry. In our research, we looked for evidence that people felt they were able to talk about and understand specific chemistry activities. We also looked for evidence that people felt they could do more chemistry, later on, as a result of the confidence they developed at the museum. Our research suggests that activity format and structure is especially important to

"[It] makes you wonder what you can mix. I want to go into the kitchen and mix and see what I can get."

–Museum visitor

increasing learners' self-efficacy in chemistry. In particular, activities that support increased feelings of self-efficacy are hands-on and interactive and/or simple to do and easy to understand.

Learners who develop feelings of self-efficacy toward chemistry may:

- understand what to do at an activity
- feel confident as they do the activity
- come up with their own questions or things to try
- figure things out on their own
- think of themselves as someone who can do chemistry

Positive attitudes and hands-on activities

To understand how interest, relevance, and self-efficacy can be encouraged through hands-on chemistry, let's look at the example of the "Gum and Chocolate" training activity included in the *Let's Do Chemistry* kit. In this activity, participants observe the properties of chewing gum, then discover how those properties change when they chew gum together with chocolate. They discover that because chocolate and gum are both oil based, the oil in the chocolate dissolves the gum and creates a sticky mess. The general concept that "like dissolves like" (oily solvents dissolve oil-based things, water dissolves water-based things, and so on) can be applied in many areas of everyday life. For example, sugar dissolves in tea and acetone removes nail polish.

"Gum and Chocolate" is a useful way to introduce the *Let's Do Chemistry* learning goals to educators and chemists, because the chemistry content, activity design and format, and facilitation strategies that

"I wanted to do more, buy the stuff and experiment at home."

–Museum visitor

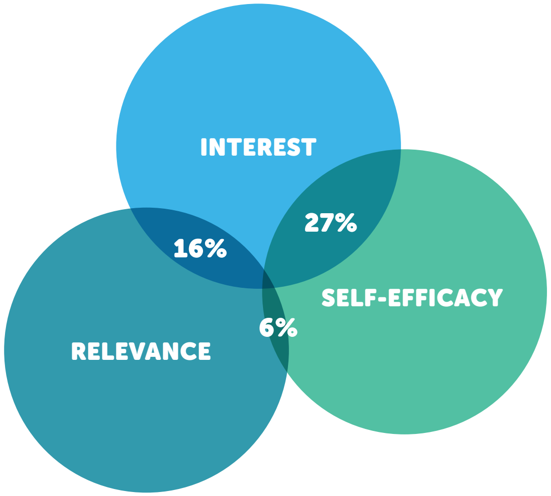
it depends on are straightforward and easy to grasp. The following chart lists the strategies from the framework that our work suggests are associated with this activity, which will be confirmed by ongoing project research.

"Gum and Chocolate" activity

Learning outcomes	Content, design, and facilitation strategies
Learners will increase their feelings of *interest* in chemistry.	Interest is sparked by discovering what happens when you mix gum and chocolate, and then talking about why the gum dissolves: • Hands-on and interactive • Observation of phenomena • Ask guiding questions
Learners will increase their understanding of the *relevance* of chemistry.	Relevance is established by identifying other examples of solubility: • Connections to everyday life • Familiar experiences • Ask discussion questions
Learners will increase their sense of *self-efficacy* related to chemistry.	Self-efficacy is supported by the inherent simplicity of the activity: • Simple to do and easy to understand • Chemistry concepts • Let participants do the activity

Relationship of interest, relevance, and self-efficacy

Our research suggests that as participants form positive attitudes related to chemistry, their increased sense of interest, relevance, and/or self-efficacy may in turn support or reinforce other dimensions of chemistry learning. Among respondents to our nationwide survey, interest, relevance, and self-efficacy are all significantly correlated with each other, not only for chemistry but also for other fields of science. Interest is strongly related to both self-efficacy and relevance, while self-efficacy and relevance have a significant, but lesser, correlation to each other (Howell and Scheufele, 2017). Throughout the remainder of the project, we will conduct additional research on public attitudes to better understand the relationship of interest, relevance, and self-efficacy toward chemistry.



Americans' feelings of relevance and self-efficacy are strongly related to their interest in chemistry and other fields of science. The percentages indicate the degree to which interest, relevance, and self-efficacy overlapped in survey responses, giving a sense of how closely associated those attitudes are.

USING THE FRAMEWORK

This chapter explains how educators and chemists can apply the *Let's Do Chemistry* framework to deliver and design hands-on chemistry activities that help participants develop positive attitudes toward chemistry in informal learning settings such as museums. The chapter is organized around the following ways that the framework can be used:

- **Delivering hands-on chemistry activities** in settings such as museums and National Chemistry Week. This section covers the facilitation strategies that are included in the framework.
- **Training facilitators,** including educators and chemists, to employ the facilitation techniques as they deliver the activities. This section goes over some suggested resources and training activities.
- **Developing chemistry activities** that incorporate our research findings and the strategies in our framework. This section points out ways that three kit activities are designed to encourage interest, relevance, and self-efficacy.
- **Using additional resources** to develop additional activities, beyond those included in the *Let's Do Chemistry* kits. This section includes sources of existing activities that can be adapted, as well as resources related to best practices in hands-on activity development.

Delivering chemistry activities

Let's Do Chemistry activities are designed to be facilitated. This means that we intend for a person (such as a museum educator or volunteer chemist) to provide guidance and ensure safe practices. The facilitator invites people to participate and supports them in strategic ways as they explore the activity and deepen their understanding of it.

Through data collection with participants and discussion among team members, our research has identified a number of key facilitation techniques that encourage positive attitudes about chemistry. At this point, we cannot directly link individual facilitation strategies to specific learning outcomes of interest, relevance, and self-efficacy. It may be that most of these facilitation strategies support the development of positive attitudes in all three areas, while specific content and design strategies are more specifically associated with interest, relevance, and/or self-efficacy.

Many other projects that have focused on informal science learning have highlighted a similar constellation of facilitation strategies as best practices for informal STEM education (e.g., Bevan et al., 2014; Exploratorium Tinkering Studio, 2015; Gutwill, Hido, and Sindort, 2015; Pattison et al., 2016; Pattison et al., 2017). This prior research suggests that the facilitation strategies we identified as encouraging positive attitudes toward learning chemistry are likely to apply to other fields of science as well.

In the *Let's Do Chemistry* framework, we have grouped facilitation strategies according to three general phases of activity delivery: invite participation, support exploration, and deepen understanding. This scheme follows a similar framework developed by the Exploratorium Tinkering Studio (2015). The table that follows shows some of the specific techniques facilitators might use throughout a hands-on chemistry activity. Many of techniques can be used at different points during the activity, but for clarity, they are shown in the table at the stage where they are commonly employed.

Facilitation strategies

Invite participation →

Greet participants
Say "hello," make eye contact, and smile. To start things off, you can ask a question that sparks participants' interest.

Model what to do
To encourage participation or demonstrate safe procedures, you can quickly show learners what to do and then suggest that they try the activity themselves.

Engage the whole group
Participants will learn best if their entire social group takes part. To engage those who are hanging back, ask them a question or suggest something they can do.

Have fun!
Convey a positive attitude about doing chemistry together.

Support exploration →

Let participants do the activity
As much as possible, let participants do the hands-on parts of the activity and let them discover what happens.

Be flexible and attentive
Pay attention to participants' interest, age, and abilities, and modify your facilitation style to create a safe, fulfilling experience for them.

Ask guiding questions
Ask questions to discover what participants know or are interested in. You can also ask questions to help them notice something or try something out.

Be a good listener
Be interested in what participants tell you, and let their curiosity and responses move the interaction forward.

Use simple, clear language
Focus on one main idea at a time—don't feel that you need to tell participants everything at once! Keep the information basic for starters, and be willing to expand on an idea for interested learners.

Offer positive feedback
Observe what participants are doing, and provide positive reinforcement.

Support learners through challenges
Help participants figure out what to try next, rather than telling them what to do. When learners have trouble articulating their thoughts, help them think it through themselves.

Deepen understanding

Ask discussion questions
Ask questions that encourage participants to draw from their own experience, make observations, and test their answers.

Make connections
Help participants observe and think about the activity. Encourage them to make connections to everyday life and societal issues.

Share what you know
Contribute ideas and information from your own experience, maintaining a focus on helping participants develop positive attitudes toward learning chemistry.

Acknowledge what you don't know
If you aren't sure about something, it's ok to say, "I don't know. That's a great question!"

Wrap up
Follow participants' cues, and recognize when they're ready to move on. Thank them for participating, and suggest other activities they might enjoy.

The *Let's Do Chemistry* training materials explicitly refer to these techniques so that facilitators are aware of the delivery strategies that help make each activity successful. In addition, *Let's Do Chemistry* activity materials are structured in a way that roughly corresponds to this sequence, making it easy for facilitators to employ appropriate strategies at the right time.

Training facilitators

Our experience shows that educators, chemists, and museum volunteers can all do a great job delivering hands-on activities in ways that encourage the development of positive attitudes toward learning chemistry. Educators and volunteers who don't have an especially strong background in chemistry can convey their excitement for learning alongside participants and use their skills for creating positive learning experiences. Chemists and volunteers who are comfortable with chemistry can share their expertise and enjoyment of the subject. Partnerships among these professionals are especially powerful: working together, educators and museum volunteers can contribute experience making science engaging and accessible to diverse audiences, while chemists can contribute knowledge and enthusiasm for chemistry.

Role of the facilitator

The most important role of the facilitator of *Let's Do Chemistry* activities is to create a positive learning environment, which helps participants develop positive attitudes toward learning chemistry. In the chart to the right, we contrast the approach this project uses with other ways that people may teach chemistry (or have been taught chemistry).

To encourage positive attitudes, focus on:	And don't worry as much about:
Fostering a fun experience	Getting across a lot of facts
Building confidence	Developing comprehensive knowledge
Sharing excitement	Writing equations
Finding concrete connections	Mastering abstract ideas
Exploring together with someone	Explaining to someone
Offering guidance and suggestions	Showing the right way to do things
Asking questions	Providing answers

The humorous training video *Chem-Attitudes! with Dr. Braxton Hazelby* demonstrates key facilitation skills, such as encouraging exploration and asking open-ended questions, that help participants develop positive attitudes toward learning chemistry. The video is included in the *Let's Do Chemistry* kit.

Training strategies

The *Let's Do Chemistry* kits are designed to help ensure that educators and chemists will be successful in facilitating hands-on chemistry activities. Whether they are educators, chemists, or other volunteers, we recommend that facilitators participate in a brief training session prior to doing *Let's Do Chemistry* activities with public audiences. The kits include a full range of flexible training materials that our project partners can use to bring facilitators up to speed on specific hands-on activities and general strategies to support positive attitudes towards learning chemistry. These materials were developed in collaboration with educators and chemists, and tested with a variety of facilitators from different backgrounds. This work suggests that *Let's Do Chemistry* trainings should:

- **Explain participant learning goals** for the activities, especially interest, relevance, and self-efficacy
- **Understand the role of the facilitator** in supporting participant learning
- **Build a common understanding of chemistry** that can be shared with participants
- **Identify and practice key facilitation techniques** for hands-on chemistry activities
- **Demonstrate and utilize safe practices** for hands-on chemistry

Developing chemistry activities

As described above, the activities included in the *Let's Do Chemistry* kit incorporate evidence-based design strategies to encourage positive attitudes about chemistry. Like the facilitation strategies shared above, these strategies are also generalizable, and can be applied to other hands-on activities. Educators and chemists can use the framework's strategies to create new activities or modify existing hands-on chemistry activities so that they support interest, relevance, and self-efficacy.

Here, we go through design strategies related to chemistry content and to activity format and structure, which our research shows support increased feelings of interest, relevance, and self-efficacy. It's important to note that the *Let's Do Chemistry* activities utilize multiple strategies that support positive attitudes, and that many of these strategies can support more than one learning outcome (interest, relevance, and/or self-efficacy). For the sake of clarity, however, the first part of this section will discuss interest, relevance, and self-efficacy in turn, illustrated by the way one hands-on chemistry activity supports that particular dimension of learning. At the end of the section, there is a table that summarizes all the learning outcomes supported by each activity that is included in the kit.

The *Let's Do Chemistry* kits include a variety of tools to train facilitators. For example, the improv exercises included in the kits can help educators and chemists develop skills such as being a good listener.

INTEREST is supported by ***chemistry content*** and ***activity format and structure***

Our research shows that design strategies related to *chemistry content* and *activity format and structure* promote increased interest in the field of chemistry. In particular, we found that exploration of basic chemistry concepts and connections to everyday life are especially successful content strategies. Opportunities for hands-on interaction and observation of real phenomena stand out among strategies related to activity format and structure. The table below also includes additional design strategies that contributed to feelings of interest.

Design strategies for interest

Chemistry content →	Activity format and structure →	Public learning outcome
Chemistry concepts Connections to everyday life Applications and uses of chemistry Connections across other STEM topics	Hands-on and interactive Observation of phenomena Use of tools and materials Experimentation with variables Familiar experiences	Increased *interest* in the field of chemistry

EXAMPLE: "CHEMISTRY IS COLORFUL"

In the Chemistry Is Colorful activity, participants explore a chemical process known as *paper chromatography*. First, they create a colorful pattern on filter paper, using water to carry the pigment from water-based markers across the paper. Then, they play a matching game that explains how chemists can use the process of chromatography to separate mixtures and identify materials. The activity's content and design utilize a number of strategies for increasing interest that are generalizable to other hands-on chemistry activities, including:

- Creating the chromatograms is **hands-on and interactive** and allows the **use of tools and materials**
- Playing the matching game encourages close **observation of phenomena**

"Chemistry Is Colorful" is successful at increasing participants' *interest* in chemistry.

RELEVANCE is supported by chemistry content

Our research findings indicate that design strategies related to *chemistry content* are especially important to increasing participants' appreciation of the relevance of chemistry. Two key content strategies for increasing feelings of relevance are sharing the applications and uses of chemistry and helping participants make connections to everyday life. The table below also includes additional design strategies that contributed to understandings of relevance.

Design strategies for relevance

Chemistry content →	Activity format and structure →	Public learning outcome
Connections to everyday life Applications and uses of chemistry Chemistry concepts Connections across other STEM topics Connections to societal issues	Familiar experiences Use of tools and materials Observation of phenomena	Increased understanding of the *relevance* of chemistry to their lives

EXAMPLE: "WHAT'S IN THE WATER?"

The activity "What's in the Water?" utilizes a number of content and design strategies for increasing participants' feelings of relevance. The activity introduces participants to several chemical tests that identify invisible properties of water. First, participants learn to use a pH strip to measure acidity or alkalinity; a refractometer to measure salinity; and a thermometer to measure temperature. Then, they have a chance to experiment with additional water samples, some of which might be from a local body of water or aquarium. The activity's content and design use a number of strategies for increasing relevance that are generalizable to other hands-on chemistry activities, including:

- Testing water samples **evokes familiar experiences** and allows participants to make **connections to everyday life**
- Learning why people test water **makes connections to societal issues** that can be addressed using chemistry

"What's in the Water?" is successful at increasing participants' understanding of the *relevance* of chemistry to their lives.

SELF-EFFICACY is supported by *activity format and structure*

Design strategies related to *activity format and structure* are especially effective at increasing participants' sense of self-efficacy related to chemistry. Specific design strategies include supporting hands-on interaction, providing opportunities to experiment with variables, and designing activities to be simple to do and easy to understand. The table below also includes additional design strategies that contributed to feelings of self-efficacy.

Design strategies for self-efficacy

Chemistry content →	Activity format and structure →	Public learning outcome
Chemistry concepts Connections to everyday life Experimentation with variables	Hands-on and interactive Simple to do and easy to understand Use of tools and materials Evoke familiar experiences Observation of phenomena	Increased feelings of *self-efficacy* about chemistry

EXAMPLE: "NATURE OF DYE"

The activity "Nature of Dye" is especially successful at creating feelings of self-efficacy through these and other strategies. In this activity, participants use a mortar and pestle to crush cochineal insects and use them to make dye. The activity is structured to allow participants to make and test predictions, and continue experimenting to discover the properties of the dye. The activity's chemistry content and its format and structure include a number of generalizable strategies for increasing self-efficacy, including:

- Making dye is a **hands-on and interactive** way to feel confident learning about basic **chemistry concepts** such as pH
- Systematically making and testing predictions creates opportunities for **experimenting with variables**

"Nature of Dye" is successful at increasing participants' feelings of *self-efficacy* related to learning chemistry.

Let's Do Chemistry activity outcomes

While we focused on just one dimension of learning in the examples included above (interest, relevance, or self-efficacy), our research shows that many of the *Let's Do Chemistry* activities support more than one dimension. The table to the right summarizes the learning outcomes for each of the public engagement activities included in the kit. The color-coding and percentages refer to the proportions of visitor groups who reported an increase in interest, relevance, and self-efficacy during the DBR process. Overall, the activities included in the kit performed well over all three dimensions, although each activity has particular strengths.

Learning outcomes by activity

	Interest	Relevance	Self-efficacy
What's in the Water?	Medium	High	Medium-High
Sublimation Bubbles	Medium-High	Medium	Medium
Rocket Reactions	Medium-High	Medium-High	High
Molecules in Motion	Medium-High	Medium	Medium-High
Nature of Dye	Medium-High	Medium-High	High
Cleaning Oil Spills with Chemistry	Medium-High	Medium	Medium
Chemistry Makes Scents	Medium-High	High	High
Chemistry Is Colorful	High	Medium-High	High
Build a Battery	Medium	Medium-High	High

Proportions of visitor groups who reported increased interest, relevance, and/or self-efficacy

High (86–100%) Medium-High (71–85%) Medium (51–71%)

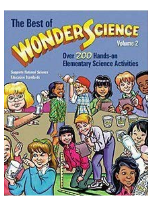
The supporting materials for each *Let's Do Chemistry* activity specify its learning goals, and highlight key strategies for achieving those learning outcomes. These materials—along with all of the kit contents—can be accessed at http://www.nisenet.org/chemistry-kit.

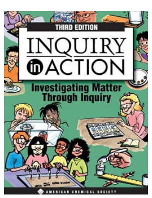
Additional resources

There are many additional resources that can support educators and chemists in adapting or developing hands-on chemistry activities using the strategies identified in the framework. Here, we share a selection of tools that are readily available, and explain how they may be helpful in using the framework to develop or modify hands-on chemistry activities to promote positive attitudes. Most of these materials are available online and can be downloaded for no charge.

Chemistry activities

The American Chemical Society has created a variety of resources to support chemistry education in different educational settings. ACS educational resources have the advantage of being rigorously developed by chemistry education experts, and can be trusted to work, to achieve their learning objectives, and to represent safe chemistry practices. Many of these activities are appropriate for informal learning environments such as museums, and make a great starting point for creating programming that is designed to promote interest, relevance, and self-efficacy related to learning chemistry.



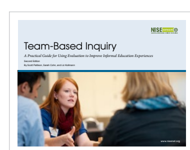


In particular, the *Let's Do Chemistry* team recommends the *Best of WonderScience* series for brief hands-on chemistry activities and *Inquiry in Action: Investigating Matter Through Inquiry* for longer interactive chemistry programs (Kessler and Bennett, 1997; American Chemical Society, American Institute of Physics, and American Mathematical Society, 2001; Kessler and Galvan, 2007). Many additional resources are also available from the education tab of the ACS website: https://www.acs.org/content/acs/en/education.html.

Activity development

The NISE Network has created a variety of resources related to hands-on activity development (or adaptation), which are available for free download and use. *NISE Network Program Development: A Guide to Creating Effective Learning Experiences for Public Audiences* provides a comprehensive overview of the development practices the Network uses to develop and evaluate public programs, including hands-on activities (Ostman, 2016b). This iterative process includes review by educators and STEM experts, testing with target audiences, and feedback from Network partners. The guide also contains a variety of tools the NISE Net program development team has used through the years to do this work.

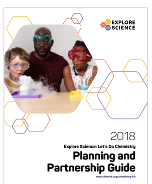
A companion NISE Network resource, *Universal Design Guidelines for Public Programs in Science Museums,* describes ways to create and implement hands-on activities so that they are inclusive of a wide range of museum visitors and provide access for as many people as possible (Museum of Science, 2010). The Network's universal design framework for programs includes three main concepts: repeat and reinforce main ideas, offer multiple entry points and multiple ways of engagement, and provide physical and sensory access to all aspects of the activity.

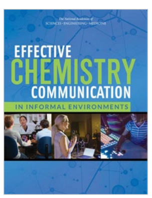


The Network utilizes a variety of methods to evaluate our educational materials against their learning goals, including a process known as team-based inquiry. As described in *Team-Based Inquiry: A Practical Guide for Using Evaluation to Improve Informal Education Experiences,* the TBI process involves an ongoing cycle of inquiry: question, investigate, reflect, and improve (Pattison, Cohn, and Kollmann, 2014). In addition to the written guide, the NISE Network has created a suite of other resources, including tools and training videos, to help others learn and use team-based inquiry.

It is important to note that while the *Let's Do Chemistry* team used design-based research methodology to create our framework, other practices can be used to apply it. In general, the NISE Network recommends an iterative process that includes testing with participants (public participants) and review by educators and chemists (professional participants), and a systematic process for gathering evidence to confirm whether or not a product is meeting its learning objectives.

Event and partnership planning





The *Explore Science: Let's Do Chemistry Planning and Partnership Guide* provides guidance for implementing successful chemistry events such as National Chemistry Week programming. It also offers tips for creating partnerships between museums and scientists (Sciencenter, 2018). Two volumes from the National Academies of Sciences, Engineering, and Medicine *(Effective Chemistry Communication in Informal Environments* and *Communicating Chemistry: A Framework for Sharing Science)* share evidence-based practices for chemistry communication and engagement, and suggest ways that chemists and chemistry-related professionals can partner with science centers and similar organizations to develop and implement engaging chemistry experiences for children and for adults (2016a and 2016b).

Safe chemistry practices

Learning and using safe practices is an integral part of learning chemistry. Safety should be part of all stages of planning and implementing hands-on chemistry activities in informal settings.

Let's Do Chemistry activities have been designed to be safe for use in informal settings with family audiences, and have been reviewed by experts in both chemistry safety and museum safety standards. Each activity includes essential safety information, and the *Explore Science: Let's Do Chemistry Safety Guide* covers topics including chemical safety guidelines, protocols, and precautions; planning a safe chemistry event; and specific protocols for *Let's Do Chemistry* activities (Museum of Science, 2018). The *Let's Do Chemistry* activities follow the ACS safety framework known as RAMP: **R**ecognize the hazards; **A**nalyze the risks from the hazards; **M**inimize the risks from the hazards; and **P**repare for emergencies.

If you are developing or using additional activities (beyond those included in the *Let's Do Chemistry* kit), ACS provides a variety of additional resources related to safe chemistry practices, which may be useful. These tools include information on safe practices in different educational settings, as well as information on health and environmental concerns, and are available for free download from the ACS website.

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