Let’s Do Chemistry

Design Strategies and Facilitation Techniques 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 | Revised Version

Based on work by the Let’s Do Chemistry *project team led by Larry Bell, Mary Kirchhoff, Elizabeth Kunz 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 Museum of Life and Science in Durham, North Carolina, and the University of Notre Dame. 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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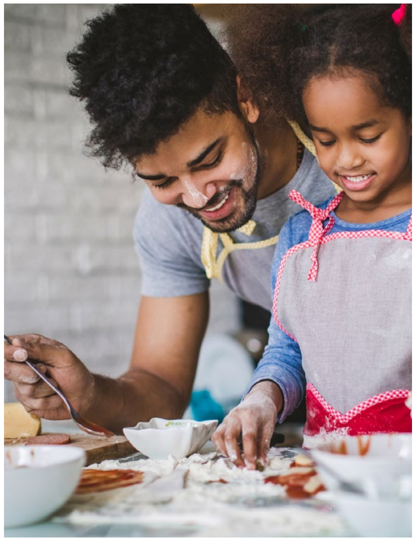
INTRODUCTION

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 they do not feel informed about chemistry specifically or confident in their ability to learn it (NASEM 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 relevance to their lives, and develop a sense of confidence and self-efficacy about learning, using, and talking about chemistry. Throughout this guide, we 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, scientists, and other professionals dedicated to supporting learning about science, technology, engineering, and math (STEM) across the United States. Network project teams and leadership create resources and coordinate activities on a national and regional level, while Network partners implement project activities locally. We achieve our reach and impact through the participation of over 700 partner organizations in Network activities—including museums, universities, and other organizations that provide informal learning opportunities for public audiences. Together, NISE Network partners engage 15 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 60 peer-reviewed journals and curated 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 several US territories.

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

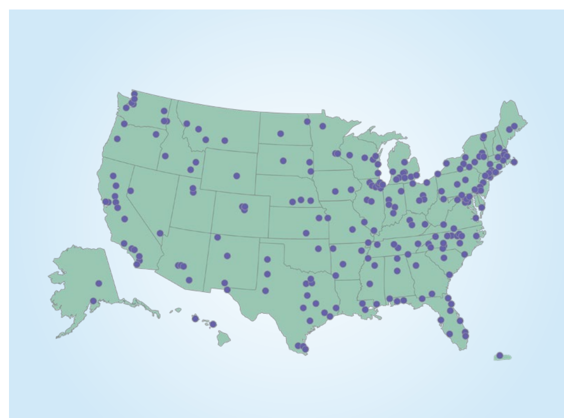
Project goals and activities

The goal of *Let's Do Chemistry* is to promote positive attitudes toward learning chemistry through participation 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 articulating design strategies and facilitation techniques for encouraging interest, relevance, and self-efficacy and supporting the development of exemplary hands-on activities; the production of a toolkit of activity materials and professional resources; and a research study on public attitudes toward chemistry in the United States. Through this project, researchers also collected 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 to support National Chemistry Week and similar programs through 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 detail later on in the guide.

In 2018, physical copies of the *Let's Do Chemistry* kit were distributed to 250 museums, chemistry public outreach programs, and other informal learning organizations in the United States. Digital versions of all the materials are 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* has had a national impact across the country.



The *Let's Do Chemistry* kit is 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 research findings, explains how they are represented in the *Let's Do Chemistry* kit activities, and suggests ways that educators and chemists can apply them. The guide is intended to be a resource for informal educators, chemists familiar with educational outreach, and others who are planning and implementing hands-on programming activities.

The first two chapters provide background information that contextualizes the project and describes our research and development work. Learning Chemistry in Museums provides an overview of informal science learning in museums and similar settings and describes the definition of chemistry that we used for the *Let's Do Chemistry* activities and training materials. 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 in the *Let's Do Chemistry* kit of hands-on activities that increase positive attitudes toward chemistry, as well as a framework identifying the activity design strategies and facilitation techniques that make the activities successful.

The final three chapters dig into our research findings and explain how to implement them. Understanding the Framework describes what we mean by interest, relevance, and self-efficacy and how they relate to participant behaviors as they participate in hands-on chemistry activities. Using the Framework to Design Activities discusses how chemists and educators can apply the framework to create or modify chemistry activities that increase participants' sense of interest, relevance, and self-efficacy. Finally, Using the Framework to Facilitate Activities explains how to share chemistry with participants in ways that support their engagement and learning.

Each chapter includes a section that summarizes our research findings and suggests some of their implications for practice. The guide also identifies 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. The guide concludes with References Cited.

"These kits are bringing our community together. I reached out to scientists, entertainers, businesses, universities, students, librarians, teachers, and more. The event brought people from all walks of life together to teach and learn at our museum, allowing us to serve our community in a unique way."

– Museum educator

LEARNING CHEMISTRY IN MUSEUMS

This chapter contextualizes our project within the field of informal science learning. It also provides a practical definition of chemistry that we used for the *Let's Do Chemistry* activities and training materials. Finally, it offers a summary of key points from prior research and our own work and suggests some of the ways these findings can be used.

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 lives. 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 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 occur 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.

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

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 offer 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 support 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).

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 for people 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 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 and talk about things together. Many groups will be intergenerational, with both adults and children.

Self-directed: There is no set agenda at a museum—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.

> *"Chemistry is more than just test tubes and beakers."*
>
> **– Museum volunteer**

Chemistry for museum visitors

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.

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.

> *"My favorite thing about the event at the science center was seeing adults just as interested as the children in the activities. I saw grandparents just as engaged as their grandkids!"*
>
> **– Museum director**

Raychelle Burks is an analytical chemist at American University. She builds tools to identify illegal drugs, explosives, and chemical and biological weapons. Her team pairs color-changing sensors with cell phones to create portable, easy-to-use detection devices.

Courtesy of IF/THEN® Collection, ifthencollection.org

Raychelle Burks uses her experience working in a crime lab to find illegal chemicals. She describes her job as "part chemist, part engineer, and 100% fun!"

Americans’ understanding of chemistry

To help us assess Americans’ familiarity with chemistry, the project team conducted an online survey of adults across the United States. 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.

Definition of Chemistry

Chemists are scientists that 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.

APPLYING WHAT WE LEARNED

The table below summarizes some key findings from prior work and this project. It also includes some of the ways that chemists, educators, and others might apply our findings as they share hands-on chemistry activities with members of the public in museums, National Chemistry Week events, and other informal settings.

LEARNING CHEMISTRY IN MUSEUMS

What we found	How you can use it
Most people have neutral feelings toward chemistry. This is different from other fields of science, where people tend to have positive feelings.	Recognize that for many people, a first step toward learning chemistry will be developing positive feelings toward it. This doesn't mean convincing them that chemistry is "good," but rather making them feel good about learning chemistry.
Informal learning settings such as museums and National Chemistry Week are especially well suited to helping people develop positive attitudes toward science.	Focus on helping people develop positive attitudes, such as interest, relevance, and self-efficacy, as they do hands-on chemistry activities. This goal will take advantage of the special strengths of informal settings and complement the other opportunities they have to learn about and use chemistry throughout their lives.
Most people have a limited understanding of what chemistry is. Americans are generally aware that chemistry is a wide field with many different applications.	When interacting with the public, use concrete definitions of chemistry that focus on who chemists are, what they do, and what they learn or make through their work. Try to avoid abstract definitions of chemistry that rely on scientific terms (such as "matter"). Find opportunities to connect chemistry to everyday life and fields of work that people may be more familiar with, such as cooking, food production, medicine, and energy.

CREATING THE FRAMEWORK

This chapter describes the process we used to do our research and develop the *Let's Do Chemistry* activities. The chapter concludes with a summary of important considerations and findings and their implications.

Purpose of the framework

The *Let's Do Chemistry* team created and tested both general approaches and specific hands-on activities that encourage interest, relevance, and self-efficacy for 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.

The project's three interconnected goals are reflected both in our research and development process and in the products we have created:

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.

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). Throughout the project, the team explored this research question: *How should hands-on activities be designed to increase participants' positive attitudes about interest in, relevance of, and self-efficacy around chemistry?* Specifically, we looked at the ways that activity design strategies and facilitation techniques affect participants' attitudes about chemistry.

Design-based research to refine the framework

To address our research question, the project team started with a theoretical framework, which was based on studies and work within the NISE Network as well as other education literature. The framework identified promising, evidence-based 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).

"Chemistry doesn't have to be intimidating. It can be fun, hands-on, safe, and accessible for all learners."

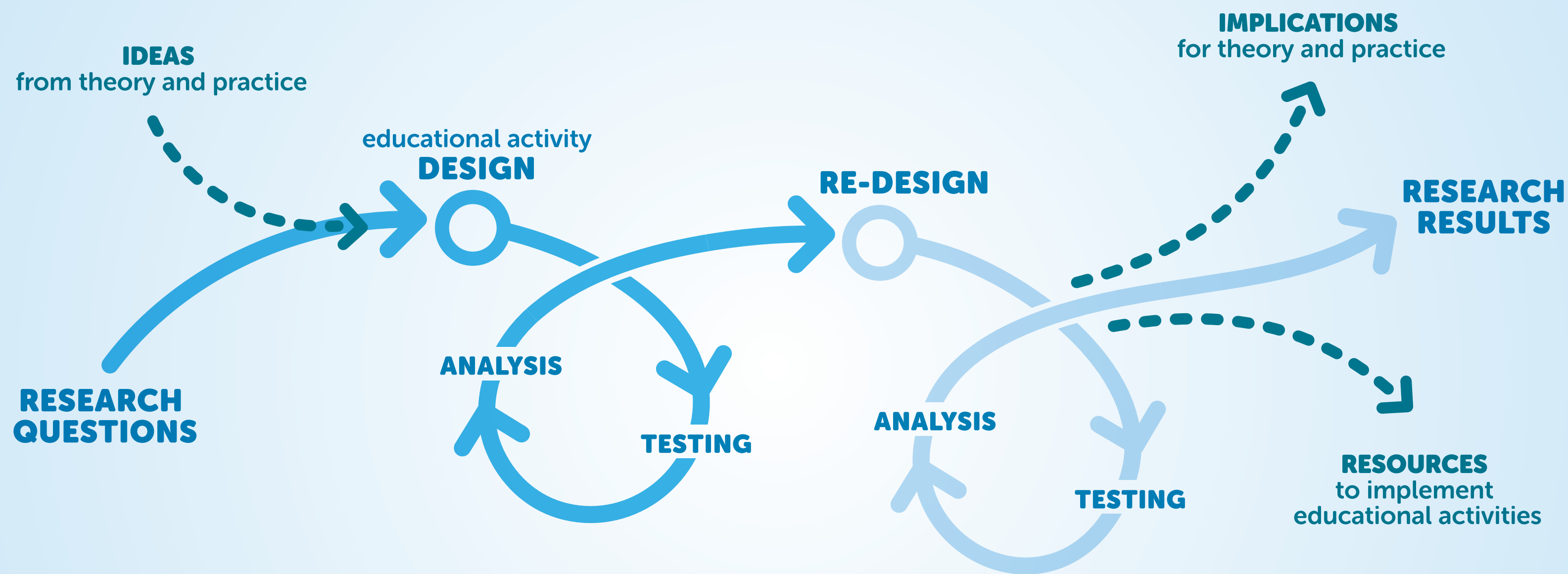
– Museum educator

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.

Design-Based Research Process



Design-based research studies learning in a real-life setting. Design experiments are based on previous theory and practice, as well as the requirements of the educational setting. 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. (Diagram adapted from Fraefel, 2014, Fig. 1.)

> *"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 with 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 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.

Alex Madonik is a retired chemist who worked on life sciences and biotechnology products. He helped develop tests to diagnose viral infections such as human immunodeficiency virus infection (HIV) and hepatitis C. Rapid, sensitive tests for viruses are more important than ever for public health.

Courtesy Alex Madonik

Today, Alex Madonik teaches chemistry in community college and volunteers in classrooms and science festivals. He helps students discover the many roles that chemistry plays in our daily lives.

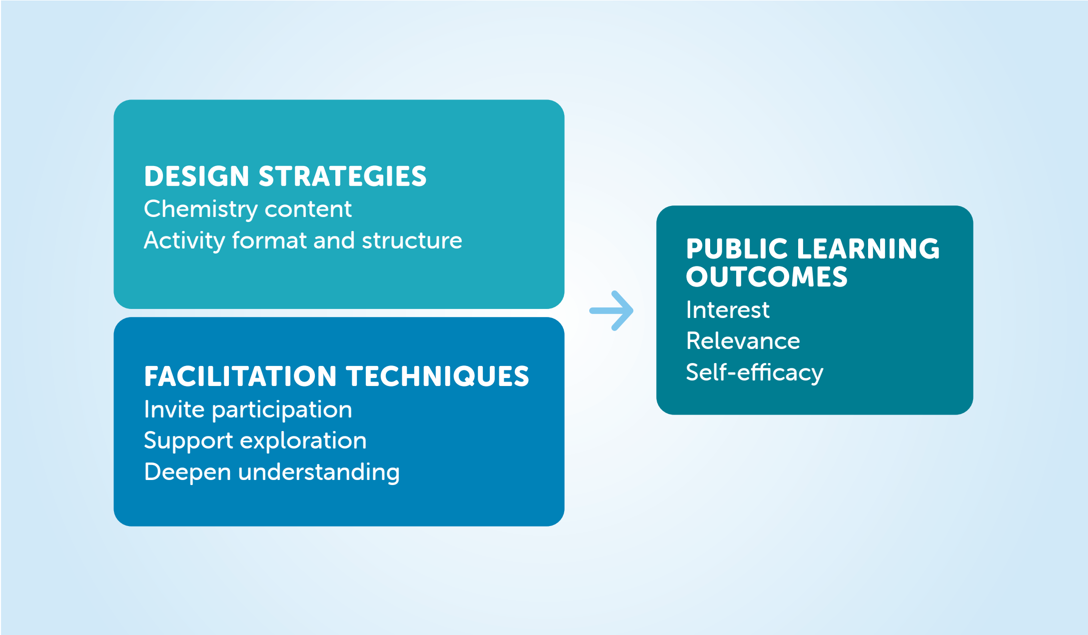
the same time. We then did two additional rounds of iterative testing, with a new set of activities each time, for a total of 15 activities. After each round of iterative testing, we used the data we collected to refine the framework. By doing our development and analysis in three rounds, we were able 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 continued to analyze the data collected using DBR to refine the framework. The second strand of work finalized the activities included in the *Let's Do Chemistry* kit using a method called team-based inquiry for continued testing with museum visitors (Pattison, Cohn, and Kollmann, 2014), and also drew on our previous experience creating and distributing hands-on activities and similar kits to museums across the US (Ostman, 2016a and 2016b).

Framework for hands-on chemistry learning

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



The framework includes *design strategies* that are embedded into the design of the activities and *facilitation techniques* that chemists and educators use when they do the activities with members of the public. Design strategies include the chemistry ideas and practices that the activities explore, as well as the kinds of things learners do and the materials they use during the activities. Our research findings show that individual design strategies encourage specific outcomes related to interest, relevance, and self-efficacy. Facilitation techniques include inviting learners to participate, supporting them as they explore the activities, and deepening their understanding. In contrast to design strategies, facilitation techniques encourage positive attitudes toward chemistry more generally.

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 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.

These activities and related resources can be used to engage the public in learning about chemistry, and also serves to articulate the project framework and research findings. The design strategies we have identified as 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**

APPLYING WHAT WE LEARNED

The table below presents some key considerations and findings from our design-based research process. It also offers suggestions for chemists, educators, and other professionals who develop or deliver hands-on chemistry activities for public audiences.

CREATING THE FRAMEWORK

What we found	How you can use it
Many different people contributed to this study, and everyone's perspective was important. This includes chemists, educators, researchers of learning, and members of the public.	If possible, include a diverse group of people as you create and do hands-on chemistry activities, including chemists and educators. Remember that members of the public also have important ideas and points of view to share with you.
The way an activity is designed influences what people learn from it. Elements of activity design include chemistry content and its format or structure.	Whether you're creating a new hands-on chemistry activity or modifying an existing one, there may be opportunities to improve its design so that it does a better job of supporting positive attitudes toward learning chemistry.
The way an activity is facilitated also influences what people learn from it. Facilitators use many techniques to invite people to participate, guide their exploration, and enhance their understanding.	There are a variety of techniques that educators and chemists can use as they do chemistry activities with the public. Just as an activity's design can be optimized to support learning, so can an activity's facilitation. As you refine an activity's content and structure, you can also experiment with the way you deliver it.

UNDERSTANDING THE FRAMEWORK

This chapter presents the learning goals for *Let's Do Chemistry* activities, as well as our final framework. It begins with an explanation of how we defined interest, relevance, and self-efficacy. Next, it describes the design strategies that are part of the framework, including chemistry content and activity format and structure. Then, the chapter presents the facilitation techniques that are part of the framework, including techniques to invite participation, support exploration, and deepen understanding. Finally, the chapter ends with a summary of key findings and implications for practice.

Learning goals

As described in the previous chapter, our research shows that Americans are aware that chemistry is widely used, but that they are mostly ambivalent about it. For this reason, 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 chapter, 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. We also define the design strategies and facilitation techniques that help support positive attitudes toward learning chemistry among activity participants, according to our research.

"We did the dye activity with a family where the father worked in pharmaceuticals. They made connections with the type of work that he did. He was very proud to have a way to share that with his family."

– Planetarium manager

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 were engaged in our activities, and also for evidence that they were interested in re-engaging with chemistry in the future.

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

- try things out
- observe carefully
- experiment with variables
- want to do more at the museum or later on

Relevance of chemistry

Relevance means being pertinent or connected with the matter at hand. It is the connection 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.

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 about chemistry

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 do 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.

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

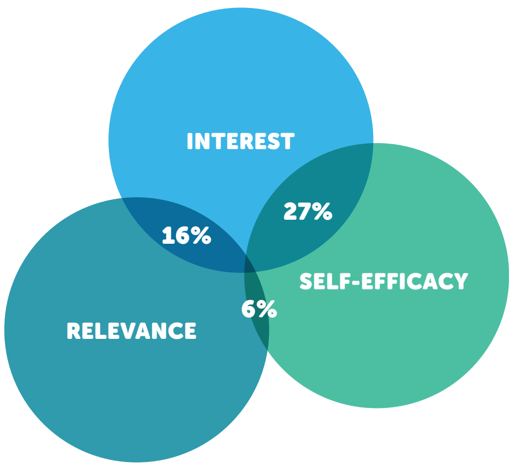
- understand what to do
- feel confident as they do the activity
- come up with their own questions or things to try
- figure things out on their own
- think of themselves as someone who can do chemistry

"The third-grade class requested the Sublimation Bubbles activity again and again. They figured out that moving or talking made the bubble pop faster; if they were quiet and still the bubble would last a little longer. When the bubble popped they would laugh, cheer, and clap."

– University outreach coordinator

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 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). This finding is consistent with our design-based research findings, which show that most learners report more than one of these learning outcomes.



Americans' interest in chemistry is strongly correlated with their understanding of its relevance to their lives and their feelings of self-efficacy in chemistry and other fields of science.

Helen Tran is a chemist at the University of Toronto. She considers herself a "molecular architect" who designs flexible polymers. The new materials she creates might allow us to make electronics that are stretchable and recyclable.

Courtesy of IF/THEN® Collection, ifthencollection.org

Helen Tran builds chemicals molecule by molecule, allowing her to develop materials with new properties. One of her current challenges is figuring out how to make biodegradable plastics.

Design strategies

In our research, we examined two different types of design strategies: chemistry content and activity format and structure. Strategies related to chemistry content look at what the activity is about, while strategies related to activity format and structure look at how learners interact with the content, the facilitator, and others in their group.

Chemistry content

The content of hands-on chemistry activities includes the topics, information, and scientific concepts that learners discuss, think about, and hear about during an activity. Our data showed that learners felt that the content of an activity was especially important to increasing their interest in chemistry and their understanding of its relevance. In our research, we found five types of content that helped participants develop interest, find relevance, and/or increase their feelings of self-efficacy toward chemistry:

- **Connections to everyday life** are explicit links between the chemistry concepts in the activity and learners' own lives or personal experiences. For example, participants may recognize that chemical reactions play a key role in food they like to cook. These connections support interest, relevance, and self-efficacy.
- **Chemistry concepts** include information about fundamental terms or ideas of chemistry. Often, chemistry concepts are key learning objectives of hands-on chemistry activities and are essential to understanding what is happening and why. Chemistry concepts support all of the learning outcomes we studied: interest, relevance, and self-efficacy.
- **Applications and uses of chemistry** include information about products or technologies that people create using chemicals or chemistry. Describing applications of chemistry in technologies such as cars or mobile phones can spark participants' interest and help them find relevance in chemistry.
- **Connections across STEM topics** are links between chemistry and another STEM field. Examples include the role of chemistry in medicine or agricultural science. Connections to other disciplines of STEM support learners' interest and feelings of relevance related to chemistry.
- **Connections to societal issues** explore the role of chemistry in identifying, causing, or solving problems. For example, chemistry can be used to detect imbalances in natural bodies of water and to maintain water quality in swimming pools and fish tanks. Learning about connections to societal issues can help participants find relevance in chemistry.

"I was helping a little guy put the battery together. I gave him the pieces in order and assisted when he needed it. When it lit up, he jumped up and down and exclaimed, 'I did that!' He pulled his parent over and explained to them how he had made the light work."

– Museum educator

Activity format and structure

The format and structure of hands-on chemistry activities includes what visitors are doing and how they are using or interacting with the activity materials. Our data showed that learners felt that activity format and structure were most important to increasing their interest in chemistry and feelings of self-efficacy related to chemistry. We found six activity characteristics that helped participants develop positive attitudes toward learning about chemistry: hands-on interaction; use of tools and materials; recollection of familiar experiences; observation of phenomena; experimentation with variables; and simplicity of procedure and content.

- **Familiar experiences** use objects, materials, or procedures that participants recognize from their everyday lives or prior experiences. For example, a child might have colored with markers and an adult might have prepared a box of macaroni and cheese. Familiarity is associated with all three of the learning outcomes we studied (interest, relevance, and self-efficacy).
- **Observation of phenomena** happens when learners use their senses to directly experience a phenomenon (such as seeing a color change, hearing a gas expand, or smelling a scent). This strategy supports interest, relevance, and self-efficacy.
- **Tools and materials** allow learners to use and manipulate physical objects and supplies as they do an activity. These materials might be scientific (such as pipettes or pH strips) or familiar (such as salt and water). This strategy supports all three learning outcomes: interest, relevance, and self-efficacy.
- **Hands-on interaction** means that learners primarily do the activity themselves (with support from the facilitator). This strategy supports learners' interest and feelings of self-efficacy.
- **Easy to do and understand** means that learners feel confident about what to do and how to do it and they feel comfortable with the chemistry. This does not necessarily imply that the activity or content itself is simple, but rather that the activity is designed in a way that helps participants view it as doable and understandable. This strategy is associated with learners developing feelings of self-efficacy related to learning chemistry.
- **Experimentation with variables** allows participants to investigate systematically. For example, they might decide which products or samples to test using chemistry. We found that experimentation supports learners' interest and feelings of self-efficacy related to chemistry.

"I had a memorable experience leading 'Build a Battery.' The family that I was working with stayed for over 30 minutes working together as a family. The activity was designed in a way that allowed them to follow their own lines of inquiry with very little facilitation from myself!"

– Museum educator

Arlyne Simon is a biomedical engineer at Intel, as well as a children's book author, inventor, and entrepreneur with a passion for healthcare. She has invented a blood test that detects when cancer patients reject a bone marrow transplant, trained clinical lab technologists in Kenya, and helped build supercomputers. Today, she is helping to design medical imaging equipment.

Courtesy of IF/THEN® Collection, ifthencollection.org

Facilitation techniques

Facilitators use a variety of techniques as they guide participants through hands-on chemistry activities. We identified facilitator moves that support positive attitudes toward learning chemistry and grouped them into three categories—*invite participation*, *support exploration*, and *deepen understanding*—based on an existing facilitation framework (Exploratorium, 2015a and 2015b). Techniques to invite participation initiate engagement and encourage participation throughout the activity. Techniques to support exploration maintain engagement and help participants move through the activity. Finally, techniques to deepen understanding encourage meaning-making. These facilitation moves can happen at any time during an activity, and occur in any order.

Our data suggest that facilitation techniques support positive attitudes (interest, relevance, and self-efficacy) generally, rather than being connected to specific outcomes. However, we did uncover a few interesting patterns. Asking participants to talk about relevant prior experiences and knowledge—a technique for *inviting participation*—appears to be related to increased feelings of relevance and self-efficacy. Techniques to *support exploration* and *deepen understanding* can increase participants' self-efficacy. And techniques to *deepen understanding* can increase participants' sense of the relevance of chemistry, especially providing additional information.

> *"So many adults comment, 'That's the first time I have really understood chemistry.' There's such rich value in learning along with their children!"*
>
> **– Museum educator**

Invite participation
To invite participation in hands-on chemistry activities, facilitators can:

- **Provide an introduction to the activity** by sharing what it's about and suggesting where to start
- **Introduce and model the use of tools** by demonstrating or explaining how they work
- **Build rapport with participants** by getting to know them and chatting as they go about the activity
- **Learn about participants' prior experiences** with chemistry and their understanding of relevant concepts by listening and asking questions
- **Encourage all group members to participate** by suggesting something they could do or asking them a question
- **Assist in transitions** from one part of an activity to another
- **Allow participants to decide how long to stay** at an activity, by providing opportunities to continue or wrap up

Support exploration
To support exploration in hands-on chemistry activities, facilitators can:

- **Offer positive feedback and encouragement** to let participants know they're on the right track
- **Share basic information and vocabulary** when they are needed and relevant
- **Give step-by-step instructions or assistance** when needed
- **Ask participants to make observations and predictions** at key moments in the activity
- **Encourage experimentation and persistence** by asking questions and making suggestions

Deepen understanding
To deepen understanding in hands-on chemistry activities, facilitators can:

- **Describe how or why something is happening** by providing additional information
- **Help participants make connections** beyond the activity
- **Encourage participants to apply what they learned** during the activity
- **Ask participants to give explanations** in their own words

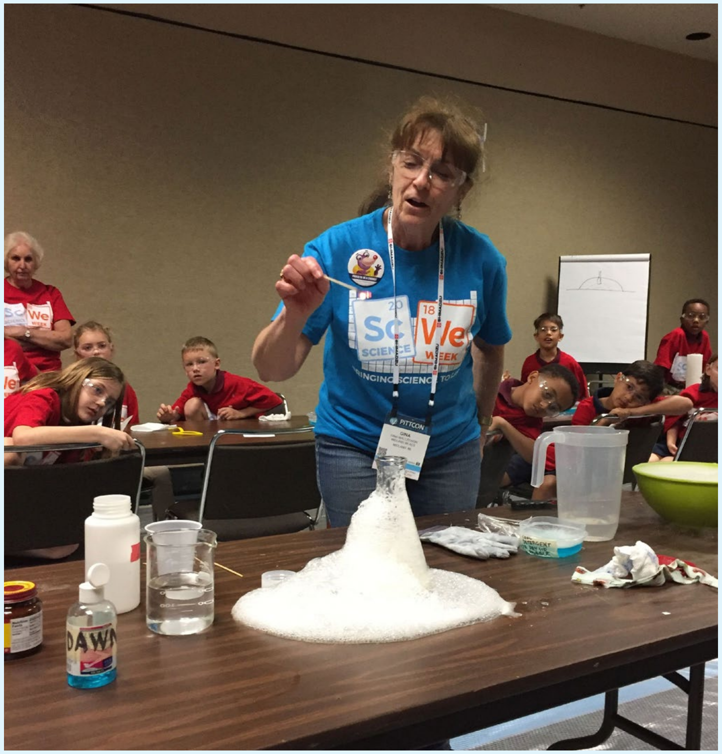
Positive attitudes and hands-on activities

To understand how these design strategies and facilitation techniques work together to support interest, relevance, and self-efficacy through hands-on chemistry, we can look at the example of the "Gum and Chocolate" training activity included in the *Let's Do Chemistry* kit (adapted from Montes-González et al., 2010). 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" (oil dissolves 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 it depends on are straightforward and easy to grasp. (This activity can also be done with public audiences, with appropriate safety precautions.) The following chart lists examples of strategies from the framework that are associated with this activity.

Museum volunteers and chemistry students trying the "Gum and Chocolate" activity, which helps them become familiar with the learning goals for *Let's Do Chemistry* activities.

Gina Malczewski is a biochemist who worked for Dow Corning Corporation. She tested the safety of ingredients used in pharmaceutical products. She also worked on the silicone tubing that is used to manufacture drugs and medications, because it is easy to sterilize and doesn't contaminate the products.



Courtesy Gina Malczewski

Gina Malczewski is now retired and volunteers her time sharing chemistry with others. She helps families experience the value and fun of science firsthand and encourages students to consider careers in science.

“Gum and Chocolate” Activity

What learners do at the activity	Examples of related design strategies and facilitation techniques	Learning goals
Learners participate in the activity by: • Chewing the gum and examining the result • Chewing the gum and chocolate together and examining the result	Facilitation techniques: • Invite participation: Provide an introduction • Invite participation: Assist in transitions • Support exploration: Give step-by-step instructions Design strategies: • Format: Easy to do and understand • Format: Observation of phenomena	Learners increase their feelings of *interest* in chemistry. Learners increase their *understanding* of the relevance of chemistry. Learners increase their sense of *self-efficacy* related to chemistry.
Learners discover what happens when you mix gum and chocolate: • The chocolate dissolves the gum • Solubility is an important concept in chemistry	Facilitation techniques: • Support exploration: Share basic information and vocabulary • Deepen understanding: Describe why or how something is happening Design strategies: • Format: Hands-on interaction • Content: Chemistry concepts	
Learners identify other examples of solubility: • Stirring sugar into tea or coffee • Using nail polish remover	Facilitation techniques: • Deepen understanding: Help make connections beyond the activity Design strategies • Format: Familiar experiences • Content: Connections to everyday life	

Let's Do Chemistry activities

Our research shows that many of the *Let's Do Chemistry* activities support more than one of our participant learning goals. 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. Overall, the activities included in the *Let's Do Chemistry* kit were successful in supporting all three learning goals, although each activity has particular strengths.

The supporting materials for each *Let's Do Chemistry* activity specifies its learning goals, and highlights 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*. (The documentation for each activity cites the source material we adapted.)

Learning Outcomes by Activity

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

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

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

APPLYING WHAT WE LEARNED

Based on our research, we can offer the following tips for sharing hands-on chemistry activities with members of the public in museums and other informal settings.

UNDERSTANDING THE FRAMEWORK

What we found	How you can use it
Interest is the feeling of having your attention, concern, or curiosity particularly engaged by something.	To figure out if participants find an activity interesting, consider whether or not they: try things on their own, observe what is happening, experiment with variables, and/or want to do more.
Relevance is the connection that someone makes between a topic and their lives and experiences or broader societal issues.	To figure out if participants find an activity relevant, consider whether or not they: notice applications and uses of chemistry, make connections to everyday life, talk about how chemistry relates to issues that are important to them, and/or remember familiar experiences.
Self-efficacy is feeling confident in the ability to learn, talk about, and use chemistry.	To figure out if an activity is helping participants develop feelings of self-efficacy, consider if they seem to: understand what to do, feel confident as they do the activity, come up with their own questions or things to try, figure things out on their own, and/or describe themselves as someone who can do chemistry.
Interest, relevance, and self-efficacy are related to each other. Most of the learners we studied reported more than one learning outcome.	As much as possible, focus on supporting positive attitudes generally, since interest, relevance, and self-efficacy are likely to work together and reinforce each other.
Interest, relevance, and self-efficacy are also related to other dimensions of chemistry learning.	Keep in mind that developing positive attitudes will also help participants learn concepts, practices, and other dimensions of chemistry. Positive attitudes are key to all chemistry learning!

USING THE FRAMEWORK TO DESIGN ACTIVITIES

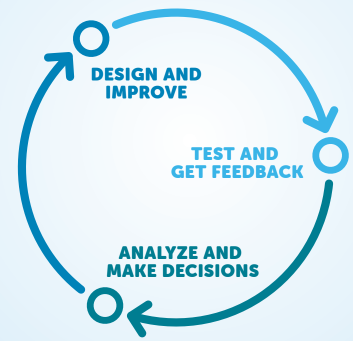
This chapter explains how to apply the *Let's Do Chemistry* framework to create hands-on chemistry activities that help participants develop positive attitudes toward chemistry in informal learning settings such as museums. Educators and chemists can use the framework's design strategies to create new activities or modify existing chemistry activities so that they support participants' interest, sense of relevance, and feelings of self-efficacy in chemistry.

The chapter first provides a brief overview of best practices for developing hands-on activities. Next, the chapter goes through interest, relevance, and self-efficacy in turn. Each of these learning outcomes is defined, and one hands-on chemistry activity is used to illustrate the strategies that support that particular dimension of learning. The chapter concludes with a list of selected resources that are relevant to developing additional activities, beyond those included in the *Let's Do Chemistry* kits.

Developing chemistry activities

To develop the *Let's Do Chemistry* activities, our team used an iterative development process that included design, testing, and analysis (as described earlier in the chapter *Creating the Framework*). We created and tested multiple versions of the activities, improving them each time. The simplified diagram to the right captures the key steps of this ongoing process.

Iterative Development Process



As part of the development process for *Let's Do Chemistry*, people with many different types of expertise and perspectives contributed to the activities, including:

- **Educators and chemists with expertise in public engagement,** who helped ensure the activities would support learning objectives and be feasible to do in the context of informal learning environments;
- **Chemists with the subject matter expertise,** who reviewed the activity content for accuracy and the protocols for safety;
- **Researchers and evaluators** who studied what and how people learned as they did the activities; and
- **Museum visitors**, who tried draft versions of the activities and provided feedback to improve the activities and information to shape the framework.

We highly recommend getting feedback from a broad group of people as you adapt or develop chemistry activities, ideally through a systematic process of testing, getting feedback, and improving the activity. NISE Network has resources that provide more information on activity development and testing. It is not always feasible or necessary to use a rigorous design-based research approach or other lengthy iterative development process to adapt or develop activities, but advice from those who will implement and learn from the activities is important to ensuring their success. The resources at the end of this chapter can provide a grounding in evidence-based practices to adapt existing activities or create new activities.

Safe chemistry practices

Safety should be part of all stages of planning and implementing hands-on chemistry activities in informal settings. The American Chemical Society uses the **RAMP** risk management process to ensure safety.

RAMP Risk Management Process

RECOGNIZE the hazards → **ASSESS** the risks → **MINIMIZE** the risks → **PREPARE** for emergencies

Design strategies

Our research examined the relationship of the activity design strategies with learning outcomes. We found that some strategies supported all three outcomes (interest, relevance, and self-efficacy), while others supported one or two. This information is summarized in the table to the right.

Relationship of Design Strategies to Learning Outcomes

Design strategy	Interest	Relevance	Self-efficacy
CHEMISTRY CONTENT			
Connections to everyday life	Medium	High	Low
Chemistry concepts	Medium	Medium	Medium
Applications and uses of chemistry	Low	High	Very low or not observed
Connections across STEM topics	Low	Low	Very low or not observed
Connections to societal issues	Very low or not observed	Low	Very low or not observed
ACTIVITY FORMAT AND STRUCTURE			
Familiar experiences	Low	Medium	Low
Observation of phenomena	High	Low	Low
Tools and materials	Medium	Low	Medium
Hands-on interaction	High	Very low or not observed	High
Easy to do and understand	Very low or not observed	Very low or not observed	Medium
Experimentation with variables	Low	Very low or not observed	Low

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

High (over 21%)
Low (6%–10%)
Medium (11%–20%)
Very low or not observed (5% or less)

Examining the findings by learning outcome

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

We found that **interest** is supported by a number of activity design strategies, including strategies related to chemistry content (what the activity is about) and strategies related to activity format and structure (what people do and the materials they use). Among the groups we studied, hands-on interaction and opportunities to observe chemistry-related phenomena were particularly helpful in sparking interest in chemistry.

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

EXAMPLE: "CHEMISTRY IS COLORFUL"

In the activity "Chemistry Is Colorful," 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 utilizes a number of design strategies for increasing interest that are generalizable to other hands-on chemistry activities:

- Creating the chromatograms uses familiar tools and materials
- Playing the matching game encourages close observation of a chemistry phenomenon
- Learning why the colors spread explores chemistry concepts that relate to everyday life

RELEVANCE is supported by *chemistry content*

Our data showed that relatable chemistry content is the most important way to establish the **relevance** of chemistry. In particular, learning about the applications and uses of chemistry and making connections to everyday life helped learners feel that chemistry was relevant to them.

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

EXAMPLE: "WHAT'S IN THE WATER?"

The activity "What's in the Water?" 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 applicable to other hands-on chemistry activities:

- Testing water samples allows participants to make connections to everyday life and may recall familiar experiences
- Understanding the test results helps participants comprehend chemistry concepts such as temperature and salinity
- Experimenting with water lets participants consider the local impact of chemistry

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

Our research suggests that strategies related to activity format and structure are especially important to increasing learners' feelings of **self-efficacy** related to chemistry. In particular, designing activities to be hands-on and interactive is likely to help learners develop feelings of self-efficacy related to chemistry.

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

EXAMPLE: "NATURE OF DYE"

In the activity "Nature of Dye," learners 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. They also learn about different natural and synthetic dyes used in a variety of products.

The activity utilizes a number of design strategies for increasing self-efficacy that are generalizable to other hands-on chemistry activities:

- Making dye from natural materials is a hands-on, interactive process that uses a variety of tools and materials
- As they experiment with different colors of dye, participants learn about chemistry concepts such as pH
- The activity is easy to do and understand, helping participants build confidence in learning chemistry

Examining the findings by strategy

So far, we have looked at the design strategies that support each of the three learning outcomes that interested us in this study (interest, relevance, and self-efficacy). Now we will consider which design strategies appear to have the greatest impact on supporting positive attitudes toward chemistry. Four strategies are associated with high percentages (greater than 21%) of visitor groups that reported positive learning outcomes:

- *Application and use of chemistry* is associated with relevance
- *Connections to everyday life* is associated with relevance
- *Hands-on interaction* is associated with interest and self-efficacy
- *Observation of phenomena* is associated with interest

These four design strategies may be useful as a “go-to” group of strategies to use when creating new activities or adapting existing activities for use in informal learning settings. Especially in the early stages of activity development, it may be helpful to focus on these strategies as a way to support positive attitudes.

Our findings also showed that different strategies reinforce each other, so the full complement of strategies will be useful as activity selection and development progress. In addition, it is important to keep in mind that different strategies are suited for use with different activities.

Nancy Ortiz is a development lab manager at Quaker Houghton. Her team of chemists create custom-made oils for steel mills, which are used to lubricate the rollers that press hot slabs of steel into thinner sheets. It is important that these sheets be free of surface defects when they are used to construct buildings, vehicles, or appliances. In the past, Ortiz has also formulated engine oils for NASCAR and worked on biorenewable engine oils.

Courtesy Nancy Ortiz

Nancy Ortiz works with each steel mill to understand its manufacturing process and the desired final product. Then, she designs a lubricant that will withstand the process and create the finish the mill wants.

APPLYING WHAT WE LEARNED

The table below summarizes some key practices for developing hands-on chemistry activities, as well as findings from our research. It also provides suggestions for ways to implement these practices and findings.

USING THE FRAMEWORK TO DESIGN ACTIVITIES

What we found	How you can use it
Best practices for activity development include using an iterative, systematic process that includes knowing your goals, testing a prototype or draft version of the activity, gathering feedback, and then improving your design.	If possible, test your activity at least once and improve it before you consider it "done." You might make changes to the chemistry content, the things participants do, or the materials they use so that it is easier to deliver, works better for participants, and meets your goals. Some of the people you might include in this testing process are chemists or educators to facilitate the activity, members of the public to use the activity, and researchers/evaluators who specialize in learning to study the activity.
Safe practices are essential when sharing chemistry with the public.	Consider safety from the very beginning. In order to share an activity with the public, you must be able to do it safely and in compliance with the policies of your venue.
Interest, relevance, and self-efficacy are related to each other. Most of the learners we studied reported more than one learning outcome.	As much as possible, focus on supporting positive attitudes generally, since interest, relevance, and self-efficacy are likely to work together and reinforce each other.
Interest is related to all aspects of activity design, including chemistry content (what the activity is about) and activity format and structure (what people do and the materials they use).	To make an activity more interesting, try tweaking the chemistry concepts you present and the methods and materials you use to engage people in hands-on learning.
Relevance is related to chemistry content.	To make an activity more relevant to participants, look for opportunities to connect chemistry content to familiar experiences, everyday life, and the ways that chemistry is used.

Self-efficacy is related to activity format and structure.	To make an activity more successful at supporting self-efficacy, find ways to make it hands-on and interactive, allow participants to use tools and materials, make sure it is easy to figure out what to do, and help participants find a connection between what they are doing and the chemistry content.
Design strategies work in combination to support positive attitudes toward learning chemistry. Most strategies support more than one learning outcome (interest, relevance, and/or self-efficacy), and all learning outcomes were related to more than one design strategy.	When you're developing hands-on chemistry activities, think about using multiple strategies. These may relate to chemistry content or activity format and structure. It is likely that in their final form, your activities will use many strategies in combination. For example, to make an activity hands-on and interactive, you can provide tools and materials for participants to use.
The following strategies from our framework had the strongest associations with our learning goals: • Hands-on interaction (interest, self-efficacy) • Observation of phenomena (interest) • Application and use of chemistry (relevance) • Connections to everyday life (relevance)	There is no single, simple formula to follow in order to develop a successful chemistry activity. However, if you're not sure where to start when creating a new activity or adapting an existing one, these strategies are likely to be helpful.
Interest, relevance, and self-efficacy are also related to other dimensions of chemistry learning.	Keep in mind that developing positive attitudes will also help participants learn concepts, practices, and other dimensions of chemistry. Positive attitudes are key to all chemistry learning!

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.

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.

Chemistry activities

The American Chemical Society has created a variety of resources to support chemistry education in different educational settings. ACS education and outreach 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.

ACS Chemistry for Life®

In particular, the *Let's Do Chemistry* team recommends several online collections of hands-on activities available at:

www.acs.org/kids
www. acs.org/education
www. acs.org/outreach

USING THE FRAMEWORK TO FACILITATE ACTIVITIES

This chapter explains how educators and chemists can apply the *Let's Do Chemistry* framework to facilitate hands-on chemistry activities in ways that help participants develop positive attitudes toward chemistry. The chapter covers delivering hands-on chemistry activities in informal learning settings such as museums or during National Chemistry Week, as well as ways to train facilitators, including educators and chemists, to employ the framework's facilitation techniques. The chapter concludes with additional resources and suggested training activities.

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, chemist, or volunteer) 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, we identified a number of key facilitation techniques that encourage positive attitudes about chemistry. Most of these techniques support the development of positive attitudes generally, rather than being 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 refining our framework of facilitation techniques, we adapted an existing scheme developed by the Exploratorium Tinkering Studio (2015).

"The facilitators quickly mastered asking questions that made young visitors think about chemistry and how it touches their lives."

– Retired chemistry teacher

Framework of facilitation techniques

In the *Let's Do Chemistry* framework, techniques that facilitators use to support learners' interest in chemistry, understanding of its relevance, and feelings of self-efficacy are categorized into three groups. These are techniques to invite participation, support exploration, and deepen understanding. The following table shows some of the specific techniques facilitators might use throughout a hands-on chemistry activity.

Framework of Facilitation Techniques

INVITE PARTICIPATION

- Provide an introduction to the activity
- Introduce and model the use of tools
- Build rapport with participants
- Learn about participants' prior experiences
- Encourage all group members to participate
- Assist in transitions from one part of an activity to another
- Allow participants to decide how long they stay

SUPPORT EXPLORATION

- Offer positive feedback and encouragement
- Share basic information and vocabulary
- Give step-by-step instructions
- Ask participants to make observations and predictions
- Encourage experimentation and trying again

DEEPEN UNDERSTANDING

- Describe why or how something is happening
- Help participants make connections beyond the activity
- Encourage participants to apply what they learned
- Ask participants to give explanations

Learning outcomes:

- Increased **interest** in the field of chemistry
- Increased understanding of the **relevance** of chemistry to their lives
- Increased feelings of **self-efficacy** about chemistry

Use of the techniques with *Let's Do Chemistry* activities

By videotaping experienced facilitators and analyzing their moves as they did hands-on chemistry activities with museum visitors, we were able to study what kinds of techniques facilitators used at different times. Our data showed that skilled facilitators tailor their approach as they work with different groups of participants. Through the course of an activity, they shift back and forth among moves that invite participation, support exploration, and deepen understanding throughout an interaction.

Facilitation moves to invite participation often took place at the beginning of an interaction, but also continued throughout to keep all members of a group engaged and on track. Similarly, moves to support exploration and deepen understanding also occurred at multiple points throughout an interaction, often before and after each other. The graphic below shows when and how often facilitators used different techniques.

Facilitators use many techniques to support engagement and learning with "Rocket Reactions."

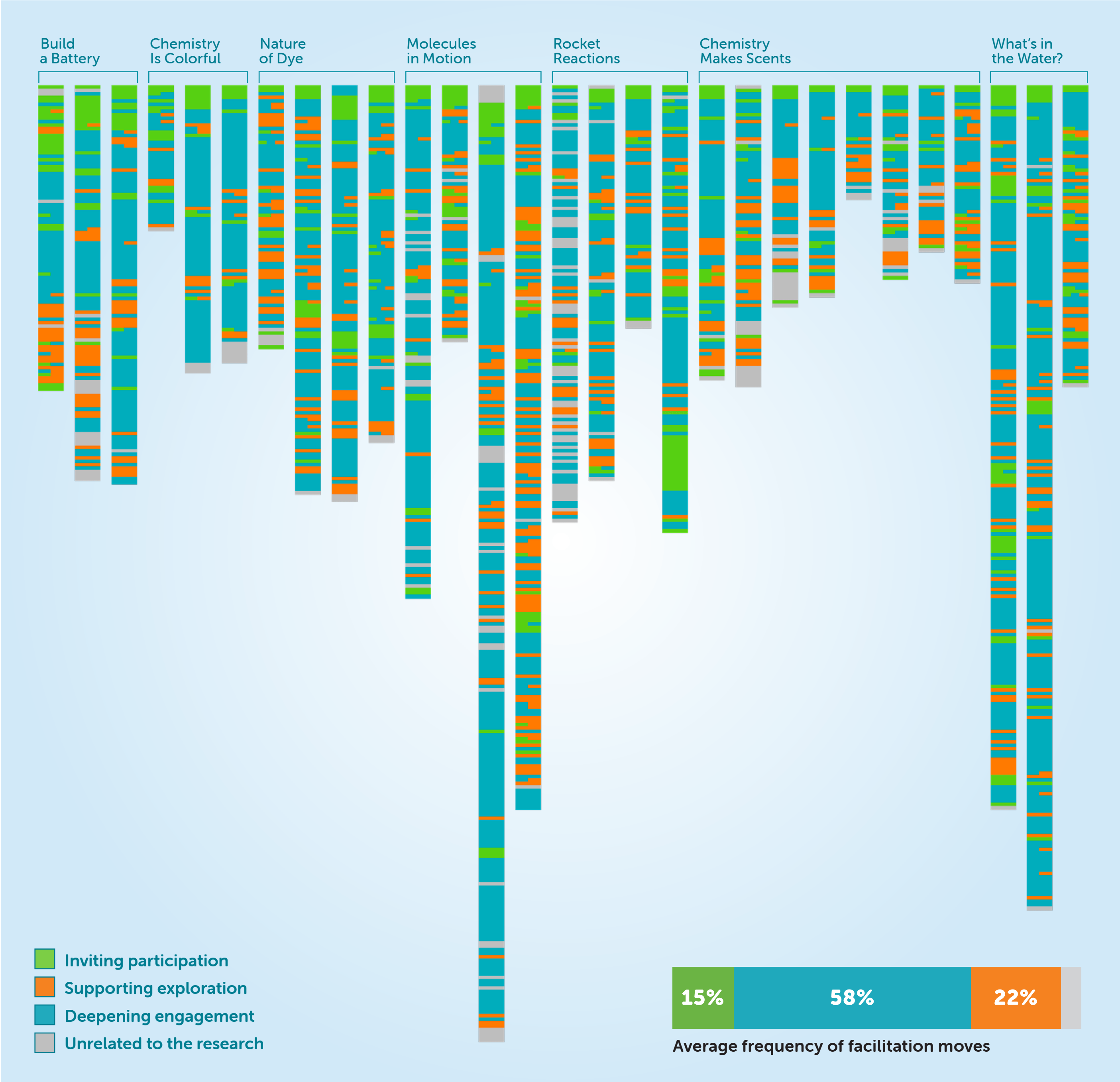
EXAMPLE: "ROCKET REACTIONS"

The activity "Rocket Reactions" uses a chemical reaction that propels a small plastic tube up in the air. First, participants place citric acid and baking soda in a tube. They predict what will happen when they add water and cap the tube, then observe the results. After their first "rocket launch," they experiment with different proportions of chemicals to see what works best.

Facilitators use a number of techniques to guide learners, such as:

- Prompting participants to recall prior experiences by asking if anyone has ever used the chemicals in the activity
- Encouraging experimentation by asking participants to make a prediction or decide what might work better
- Helping participants deepen their understanding by asking them to describe what they see or explain what they think is happening

Distribution of Facilitation Moves During an Activity



Each vertical bar represents one videotaped interaction, and each stripe within a bar represents a technique the facilitator used during the interaction. The graphic also shows the difference in the length of interactions, with longer bars representing longer interactions (and more facilitation moves). These data indicate that the expert facilitators we studied were moving through different techniques continuously during an experience to support participant learning. This visualization includes the data for the activities that were included in the *Let's Do Chemistry* kit.

We also used the videotape data to examine how often facilitators used different types of techniques. Not surprisingly, the most common technique to invite participation was providing an introduction or activity overview. The most common technique used to support engagement was offering positive feedback. To deepen engagement, facilitators frequently provided information and supported making connections outside the activity.

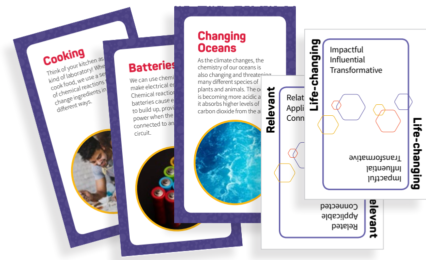
Overall, we found that the majority of facilitation moves were related to supporting exploration. Skilled facilitators focus on guiding participants and letting them do the activity as much as possible, rather than demonstrating or explaining things themselves. This finding suggests that in order to increase interest, relevance, and self-efficacy, facilitators should focus on supporting learners' own active exploration.

In sum, our data show that facilitators are moving through different types of techniques continuously during an activity to meet the needs of different groups and to promote their learning and engagement. Facilitators spend time throughout an activity inviting participating, supporting exploration, and deepening understanding.

Training facilitators

The *Let's Do Chemistry* kits are designed to help ensure that facilitators will be successful in sharing hands-on chemistry activities with learners in informal settings such as museums or during National Chemistry Week. Our experience shows that educators, chemists, and museum volunteers can all do a great job delivering hands-on activities in a way that encourages 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 that makes science engaging and accessible to diverse audiences, while chemists can contribute knowledge and enthusiasm for chemistry.



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 relationship to everyday life. In this word association game, players use their hand of "word cards" to select words 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.

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 the following chart we contrast the approach this project uses with other ways that people may teach chemistry (or have been taught chemistry).

Training strategies

We recommend that all facilitators—whether they are educators, chemists, or other volunteers—participate in a training session prior to doing *Let's Do Chemistry* activities with public participants. The *Let's Do Chemistry* kits include a full range of flexible training materials that 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
- **Review and practice the steps and procedures** for specific chemistry activities
- **Demonstrate and utilize safe practices** for hands-on chemistry with public audiences

Fostering Positive Attitudes Toward Learning 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.

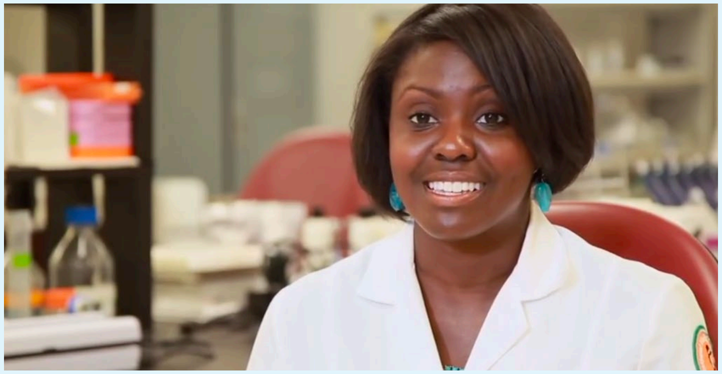
Safe chemistry practices

It is essential to use safe practices while doing hands-on chemistry activities in informal settings. In fact, learning and using safe practices is an integral part of learning chemistry.

Let's Do Chemistry activities have been designed to be safely used in informal learning settings with family audiences, and have been reviewed by experts in both chemistry safety and museum safety standards. The activities follow the ACS risk management process known as **RAMP**: Recognize the hazards, Assess the risks, Minimize the risks, and Prepare for emergencies (Hill and Finster, 2016). 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 activities in the kit (Museum of Science, 2018).

The *Let's Do Chemistry* kit includes supplies to ensure the safety of facilitators and learners. For example, many activities include eye protection.

Eunice Cofie-Obeng is a cosmetic chemist and entrepreneur who founded Nuekie, Inc., to create skincare and hair products for people of color, including African/African-American, Hispanic, Asian, Middle Eastern, Native American, and Pacific Islander groups. Neukie's moisturizers, cleansers, and other products are inspired by modern science and traditional African botanicals.



Girl Scouts of America, Headshot: Allen Cooley

Eunice Cofie-Obeng is involved in all aspects of creating her skincare products, from formulation to safety testing, manufacturing, and marketing.

APPLYING WHAT WE LEARNED

The table below summarizes key findings related to facilitation techniques. It also provides tips for facilitating hands-on chemistry activities that are designed for use in museums and other informal settings.

USING THE FRAMEWORK TO FACILITATE ACTIVITIES

What we found	How you can use it
The most important role of the facilitator is to create a positive learning environment. Practice and preparation are important to feeling comfortable and being flexible and responsive as you facilitate hands-on chemistry activities.	With a little practice and willingness to learn alongside participants, everyone has something to offer as a facilitator. It's not necessary to be an expert at chemistry or education.
Comprehensive training and preparation for facilitating hands-on chemistry activities include: • **Reviewing participant learning goals** for the activities • **Understanding the role of the facilitator** in supporting participant learning • **Defining chemistry** in ways that are accessible for people of all ages and backgrounds • **Practicing key facilitation techniques** for hands-on chemistry activities • **Practicing the steps and procedures** for specific chemistry activities • **Using safe practices** for hands-on chemistry with public audiences	If you're responsible for training other people, consider what your group is likely to already know and how much time you have to prepare them. Plan to review familiar concepts and skills quickly and spend more time practicing new things. If you're preparing by yourself, be sure you practice the hands-on parts of the activities and rehearse key talking points. Remember that facilitators improve their own techniques and practices as they do the activities with participants. You'll get better as you go!
Our research identified three kinds of facilitation techniques that help participants develop positive attitudes toward learning chemistry: **invite participation, support exploration, and deepen understanding**.	Keep in mind that you'll be doing lots of different things as you guide participants through the activities. At some points you may be showing or telling. Often, you'll be watching, asking, listening, or suggesting.

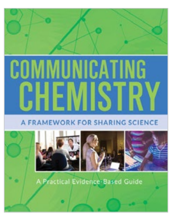
Experienced facilitators shift back and forth among different types of moves during an interaction.	Be aware that participants may need different kinds of guidance at different times, and that all learners are different. Try to respond to each groups' needs and ideas as the activity unfolds.
Experienced facilitators most frequently use techniques that support participant exploration (58% of their moves).	As a facilitator, focus on helping learners to do the activity themselves.
The facilitation techniques in our framework are likely to apply to other sciences and other kinds of hands-on learning.	You may already have many of the tools you need to successfully facilitate hands-on chemistry activities. As you build your toolbox of facilitation techniques, you'll also be able to apply your skills to other kinds of hands-on activities.
It is essential to use safe practices when doing hands-on chemistry activities with the public. In addition, safety is an important dimension of chemistry for participants to learn about.	Use and model safe practices during activity setup, delivery, and cleanup. When you do an activity with the public, be sure you explain what the safety protocols are and why they are important—and make sure everyone follows them.

Additional resources

There are many additional resources that can support educators and chemists in using the facilitation techniques identified in the framework. Most of these suggested materials listed below are available online and can be downloaded for no charge.

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).

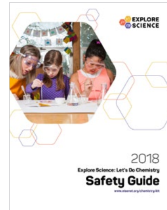


Communicating Chemistry: A Framework for Sharing Science by the National Academies of Sciences, Engineering, and Medicine shares evidence-based practices for chemistry communication and engagement, and suggests ways that chemists and chemistry-related professionals can partner with science centers and similar organizations to develop and implement engaging chemistry experiences for both children and adults (NASEM, 2016b).

Activity delivery

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.

Safe chemistry practices



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 activities in the kit (Museum of Science, 2018). 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 with embedded 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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