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# Connecting Teenage Audiences to Chemistry


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MFA Thesis

Museum Exhibition Planning + Design

University of the Arts

2017

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# **U**npacking the **G**rey **B**ox:
## Connecting Teenage Audiences to Chemistry

A thesis submitted to the University of the Arts in partial fulfillment of the requirements for the degree of Master of Fine Arts in Museum Exhibition Planning + Design.

Amber Luning

2017

# Thanks

For your support, feedback and patience, thanks go out to my committee members: Jane Boyd, David Ucko, Erin Mcleary, and Polly McKenna-Cress. For invaluable insight on the life of chemistry educators in the formal and informal realm, thanks to my friends Chris Homoky and Trevor Taylor. For feedback on their relationships to the chemical world, many thanks to my campers and students, I am so proud of all of you. For translational services and emotional support, thanks to my partner Sean Toland.

For her unwavering support at home, through sickness and health, for every packed lunch and carpool and nice note, thanks and love go out to my sister Alyssa. I would not be here without you.

# Table of Contents

**Grey Box**:
A piece of chemical equipment consisting of a (typically grey) metal box with buttons and dials on it.

**Grey Box**:
a metaphorical zone of nonunderstanding, intimidation and ennui that comes from being told that you need to understand a thing, but are not given the tools to do so.

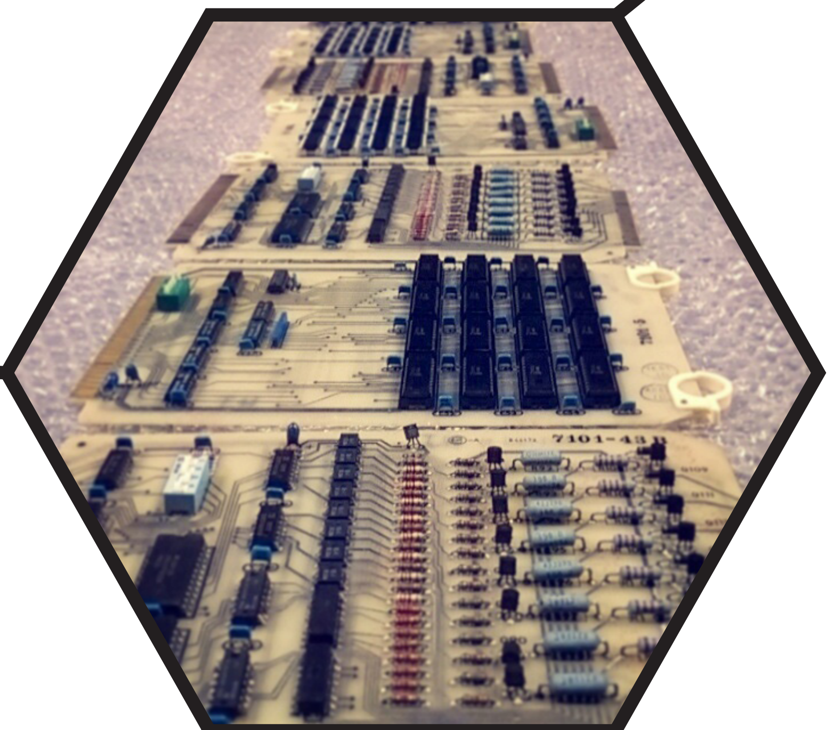
# Prologue:
How did I get to this?

This project was born in a dusty warehouse in New Jersey. In the cavernous space, silent but for the occasional beeping of a forklift, I saw the unboxing of the artifacts of the creation of the modern world. This was the Chemical Heritage Foundation's offsite storage warehouse. My task as an intern was to help with a thorough inventory. I helped unpack spectrometers, glassware, circuit boards, seemingly thousands of rolls of graph paper, and everything I touched sang to me. It sent goosebumps up my arms. But why?

One factor is that some people are simply more prone to feeling these things. Some people like antiques, some don't. Some hold onto their great-great-grandmother's heirlooms for the next generation, and some sell them. This is true of all people, to varying degrees. I'll admit that I like stuff, I like mementos, and I'm sentimental about literally everything. But there's one more factor. Perhaps the most important factor.

I'm a science fan.

Those artifacts and the intimacy of being able to handle them affected me the way they did because I'm a giant nerd. I love it. The weight of what I brought to the table was enough to tip the scales from what could have been a dusty day of hard labor and boring antiques into a treasure hunt filled with fascinating relics of a profound part of human history. But how did I get what I brought to the table? I'm not a chemist. I'm a visual artist. I can't tell you what a benzene does. I kind of sort of know what a hydrogen bond is. But despite not knowing the details, I still consider myself a person who has the capacity to know and appreciate chemistry. How did that happen? When did that happen? And what experiences with chemistry helped it to happen?



# Introduction

We start this thesis with two problems: (1) that chemistry is underrepresented in science centers and museums, and (2) High school students who can benefit from informal learning opportunities in chemistry are often left bereft, contributing to a general decline in interest in the topic. The thesis supports these assertions and proposes that what helps one may also help the other.

Chemistry is a tough topic. The science itself is a feared section of secondary education. The effects of chemical reactions, while clear when demonstrated, are often messy and/or on fire. This makes them usually impractical for stand- alone museum interactives. This is not to discount the real and wonderful role chemistry demonstrations play in current museum education, merely that the goals of this project are very different from the goals of a demonstration. The material culture of chemistry is a mix of gorgeous and perplexing glassware, and gray metal boxes whose purpose is frustratingly enigmatic to anyone not already intimately familiar with them. Despite these challenges, it is extremely important as we move into the future that new generations lose their fear of chemistry. This is not only to inspire budding scientists to take up chemistry, but to help everyone become familiar with the chemistry that shapes their daily lives and the world around them. Not every high school senior must become a chemist, but if every high school senior believes that they are capable of understanding it, we get a generation that is unafraid to learn and be critical.

As a society we have learned hard lessons about the use and misuse of chemistry, from the horrific fallouts of leaded gasoline and DDT, to consumer level debacles like Olestra. Reactionary distrust of chemistry is prevalent, and apparent in the enormous consumer push to eradicate chemicals from our food, cosmetics, and day to day lives[1]. However, chemistry is not solely the domain of malicious multibillion dollar corporations or of endless calculations in a junior year lab class. Its study is a foundation that supports medicine, industry, agriculture, and more. It is matter and energy, and it is present in every aspect of our world. People often use the specter of chemistry to push agendas, whether that's to scare people into not vaccinating their children, or to wrap a blanket of scientific authority around harmful products. Chemical literacy is the primary tool we have to defend against this kind of manipulation. But chemical literacy will only come to those who believe they are capable of understanding it. The gray boxes of the scientific world will only open to those who have not convinced themselves that they are locked out.

Image credit: Weightymatters.ca

1 It should be noted that this task is impossible. All food is made out of chemicals, including naturally occurring ones.


Image credits: Shutterstock (left) Aperimentis (above)

As the roles science museums play in their communities evolve from their roots in corporate collections and cabinets of curiosity to informal centers of inquiry and learning, they must take care to attempt to offer a worthy experience to all learners. This thesis makes the case that by introducing chemistry related content into the realm of possibility for exhibition themes, Science museums can serve an audience of older children whose educational needs are not currently being served by exhibitions in the museum community. It makes the case that it is important to serve this teenage audience because of their unique stage of psychological growth, and the way the subtleties of this stage of growth can impact their attitudes towards continued learning for the rest of their lives. This thesis will attempt to use interactive design principles, interpretation techniques, and design solutions to encourage a high school aged audience to learn about chemistry. But also, to learn that they are the kind of people who CAN understand chemistry.

# Chapter 1

# Better Learning through Chemistry

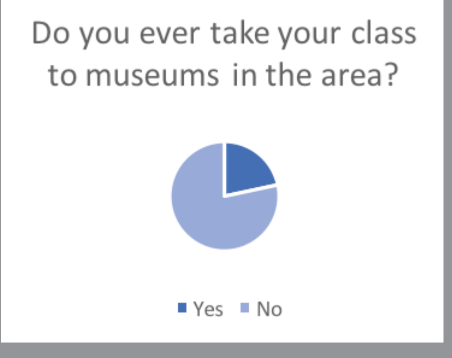
# In the Classroom

When study data finds that students lose interest in STEM subjects as they get older, it's natural to get concerned. Theories as to why this occurs vary widely. Some point to a general downshift in interest in *all* school subjects as students get older. Some point to rigorous testing causing student burnout. Still others claim that science as taught in the classroom is increasingly distant and irrelevant to the lives of students.[2] A 2014 aggregate study distinguished several effective strategies for rebuilding interest in the sciences, or preventing its loss altogether.[3] These studies did not distinguish between chemistry and other physical sciences, it must be noted, but the interventions still prove informative. Whatever intervention technique is used, whether that is a field trip, a group activity, a problem solving or building activity, etc., the surest way to retain and increase interest in students is to provide *consistent positive experience*. Easier said than done, right?

2 "Analysis of the Decline in Interest Towards School Science and Technology from Grades 5 Through 11" Patrice Potvin & Abdelkrim Hasni. *Journal of Science Edcuation and Technology* vol. 23 2014

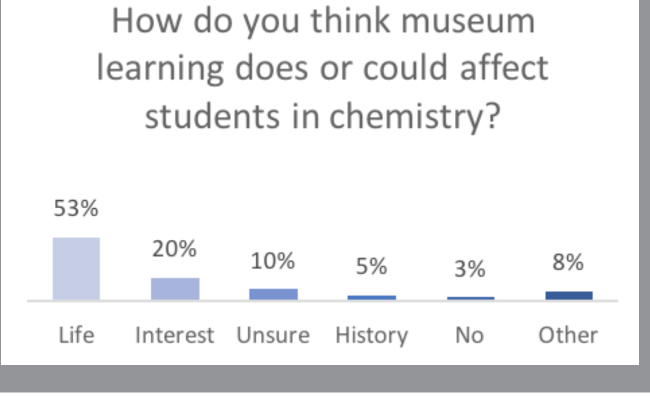
3 "Interest, motivation and attitude towards science and technology at K-12 levels: a systematic review of 12 years of educational research" Patrice Potvin & Abdelkrim Hasni. Published in *Studies in Science Education* vol. 50, 2014

Museum trips have a demonstrably positive effect on students' interest in science at any age group.[3] However, in a survey of chemistry educators only 22% reported taking their classes to museum trips within the last five years.[4] When asked to elaborate on why, the most common response was a "Lack of chemistry related content, it would not be worth the expense". Despite this, when asked to imagine "How museum learning could affect students in chemistry", educators responded overwhelmingly positively, with over half of respondents citing "real life experience" or "a tie-in to their daily lives" as potential learning experiences with students.




Examples of responses coded as "life":

- *"It could put real life application into chemistry"*
- *"It could teach them ways chemistry is everywhere besides the lab or just for scientists"*




4 Survey was conducted through the AACT (American Association of Chemistry Educators) in spring of 2017 for the purpose of this thesis project. Details available in Appendix

# In the Museum

An ASTC survey of science museums and science centers found that less than 30% had chemistry content in their exhibits. This survey was conducted in 1990, however, more recent research still suggests that chemistry remains one of the least popular exhibition topics.[5] When one searches "Chemistry Museum" in any major search engine, the first four results are about the Chemical Heritage Foundation. The next is an academic article that heavily references the Chemical Heritage Foundation. The sixth is an op-ed on Sciencemag.org titled "What would go into Chemistry Museum Displays Anyway?"

That those results are telling is not a reach. Chemistry is a topic largely unaddressed in the science museum world, often taking a back seat in science centers to Newtonian mechanics, magnetism, biology, and electricity. A landmark study by the National Research Council provides some insight, citing, among other things, the abstract nature of chemistry, public distrust and misunderstanding, and messiness as reasons chemistry does not typically appear at science museums.[6]

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5 *"Effective Chemistry Communication in Informal Environments"*, National Academy of Sciences Press, 2016 pg 50

6 *"Communicating Chemistry Landscape Study"*, National Research Council, 2013 pg 10

*"Chemistry, though, is a tough sell. Displays of the elements aren't bad, but many of them are silvery metals that can't be told apart by the naked eye. Crystals are always good, so perhaps we can claim some of the mineral displays for our own. But physical chemistry, organic chemistry, and analytical chemistry are difficult to show off. The time scales tend to be either too fast or too slow for human perception, or the changes aren't noticeable except with the help of instrumentation. There are still some good demonstrations, but many of these have to be run with freshly prepared materials, and by a single trained person. You can't just turn everyone loose with the stuff, and it's hard to come up with an automated, foolproof display that can run behind glass (and still attract anyone's interest)" – Derek Lowe*[7]

This forms a positive feedback loop between museum visiting schools and museums themselves. The museum has no content relevant to a chemistry curriculum, the classes won't come. When the demand is not seen and these audiences don't show up, very few things are planned for them. Considering the challenging design hoops a museum has to jump through to get chemistry content onto the floor, the reluctance is understandable. However, examples of successful chemistry exhibits such as "Everyday Chemistry" (MSI Chicago), and activities in museums like OMSI's Chemistry Lab prove that the challenge is not insurmountable.

Photo Credit:
OMSI Chemistry Lab

7 *"What would go into Chemistry Museum displays anyway?"*, Derek Lowe. Science Translational Medicine 2013

Despite a lack of chemistry content, the affordances of the science museum in regards to this topic are impressive. Not relegated to push-button interactives or static displays of artifacts, museums across the country have partnered with Maker movements and embraced constructivist educational philosophy[8] to create learning labs and spaces in which building, making, and hands on experimentation can be conducted. These spaces promote endless opportunity and the means to create meaning. However, even in the Makerspace Playbook[9], all activities, tools, suggestions, and examples follow a few specific paths towards building, engineering, and robotics. The capacity is there for so much more.

*"…no one questions bringing a snake or a Tesla coil, but try to bring chemicals (even harmless ones), and you face many hurdles."*
– NRC Landscape study participant

8 "Constructivism posits that learning is an active, constructive process. The learner is an information constructor. People actively construct or create their own subjective representations of objective reality. New information is linked to to prior knowledge, thus mental representations are subjective." – LearningTheories.com

9 *The Constructivist Playbook*, MENTOR Makerspace, Maker Media 2013

## The Stuff of Science

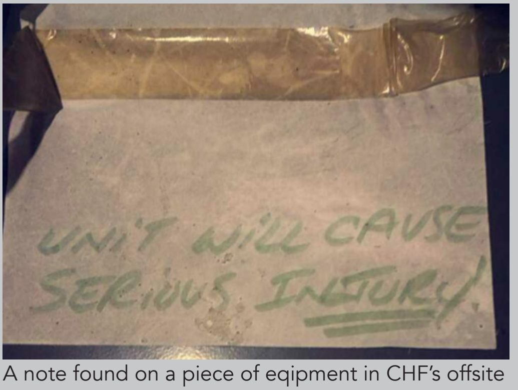
Objects in museums have a particular fanbase and ecology that has grown up with the institution of museums themselves. As repositories of what is culturally deemed important, museums of art and history find themselves bogged down by collections too large to display and often too large to maintain[10]. Science museums often find themselves in an awkward position when it comes to their stuff, what to do with it, whether to have any at all.

*"If we are honest… as often as not, the artefacts of twentieth century science are both mind bogglingly dull and utterly uninformative to behold"*– John Durant

Stuff can serve an important role in the implementation of museum experience. Stuff, through its own physicality can provide a link to another place, time, and context in a way that other methods may not be able to. But when considering the stuff of a Chemistry exhibit, the question of *what* exactly is being linked is a question not to be taken lightly. For a museum like the Chemical Heritage Foundation, the link can seem straightforward: This is history. But is it just history? And what, exactly, is the stuff of chemistry if chemistry is the science of stuff itself? In the end, in a chemistry exhibition, the collection must serve the mission, not the other way around.

10 *"Lost in the Museum: Buried Treasure and the Stories they Tell"*, Nancy Moses, AltaMira Press 2007

The instrumentation of chemistry is, indeed grey metal boxes with dials on them. Chemical instrumentation tends to take on the same hues and shapes. One spectrophotometer looks basically like another. You have no idea how they work unless you yourself are a chemist (of a certain age, since newer machines replaced these long ago).[11] Actually, the stories of those machines are often extremely dramatic, betraying the dullness of their surfaces. Chemists making repairs to needed equipment out of the bones of old equipment, soldering bits together and hoping they hold.[12] Instruments that cost many hours, days, weeks of labor and lots of money and near fist fights with your fellow researchers failing to achieve the results desired. Instruments hurled at walls in fits of rage or kicked in frustration. Broken glass coated in dangerous and mysterious substances crunching underfoot as you reset your dial and place a note on the console that reads "DO NOT TURN PAST 8". It's just that those stories are buried so deep in these bland exteriors that they really do need a lot of help to come out. Interpretation must pull double duty for these objects.




A note found on a piece of eqipment in CHF's offsite storage.

*"Have a story [that] weaves in the chemistry. If it's not a good story, it doesn't matter how good the chemistry."*
*- NRC Landscape study participant*

11 Modern versions of these tools tend to take on a role closer to what would be considered a "Black Box", defined as a "A fiction representing a set of concrete systems into which stimuli S impinge and out of which reactions R emerge. The constitution and structure of the box are altogether irrelevant to the approach under consideration, which is purely external or phenomenological. In other words, only the behavior of the system will be accounted for" by Mario Bunge in his article "A General Black Box Theory", Philosophy of Science, Vol. 30, No. 4 (Oct., 1963)

12 This anecdote came from my time at CHF offsite inventory. One day a group of chemists came with us and spent their time explaining what things were while waxing nostalgic about their old equipment and their lives in the lab.

But the stuff of chemistry isn't just the boxes and glassware. The stuff of chemistry is a nylon sweater. It's a red solo cup, the cup's contents, and the ping pong ball floating in it. The stuff of chemistry is a walnut brownie. It's a bottle of Drano. It's perfume and shaving cream and toothpaste. The stuff of chemistry is a bathing suit banned from the Olympics and a compact fluorescent lightbulb.

The stuff of chemistry is the legacy of mutant and extinct species in the wild. The stuff of chemistry is the survival of Mesoamerican people through nixtamalization of corn flour. The stuff of chemistry is the poison gas used to murder millions of prisoners. The stuff of chemistry is the medicine used to save millions of lives. If it seems like a lot of stuff, that's because it is. Far from being a burden, however, the wide scope of what stuff can support a chemistry exhibit is an opportunity.

For proof, look no further than a single Post-It written by a high school student after experiencing "Second Skin: The Science of Stretch" at the Chemical Heritage Foundation. It simply reads: "I never knew there was chemistry in underwear!"

Not only is there chemistry in underwear, there is chemistry in every-where. .

Second Skin: The Science of Stretch at the Chemical Heritage Foundation.
The story of the Jogbra has become an exhibition fan favorite.


Image Credit: Science Clarified

Above: Two women stand smiling in the wake of a DDT fog machine. The popular pesticide was later found to have a negative impact on wildlife and was banned in the US in 1972.

Right: A neon sign advertising Coca-Cola uses chemistry to produce its vibrant colors, and coke itself uses chemistry in its production.

Below: A delicious pumpkin cake rises thanks to chemical reactions that form the core of baking.


Image Credit: Retroplanet

Image Credit: King Arthur Flour

# Chapter 2

# Audience Considerations

Photo Credit: Andrew Moore, Detroit *Deconstructed*

When determining a target audience for this project, the author, myself, examined a population already familiar and dear to me: Teenagers. Having ten years' experience teaching Batik dyeing (itself a form of artmaking through applied chemistry) to students aged 13-17, listening to their hopes, dreams, woes, hardships, triumphs, and watching their development into adults time and time again, this audience seemed a natural fit for the goals of this project for many reasons, explained in more depth in this chapter. Teaching methods designed for younger children do not always work on teens. They are almost fully developed and do not enjoy being patronized or peddled to. They enjoy creating and establishing ownership of knowledge and in particular, how that knowledge can be used to affect their world.

High school aged students are a very particular and very peculiar audience. During this stage, Identity and one's role in the world become a key part of psychological development. The concept of self at this time is still in formation, in flux, and open to change. However, in the process of defining what one *is*, one must also define what one is *not*. Individual psychology, peer groups, social upbringing, intersecting identities and more all play a role in this process. The end result can determine an individual's attitude toward science for a very long time.[13]

Effective Chemistry Communication in Informal Environments proposes six "strands" of audience engagement

Strand 1: Experience excitement, interest, and motivation to learn about phenomena in the natural and physical world.
Strand 2: Come to generate, understand, remember, and use concepts, explanations, arguments, models, and facts related to science.
Strand 3: Manipulate, test, explore, predict, question, observe, and make sense of the natural and physical world.
Strand 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.
Strand 5: Participate in scientific activities and learning practices with others, using scientific language and tools.
Strand 6: Think about themselves as science learners and develop an identity as some- one who knows about, uses, and sometimes contributes to science.

This sixth strand is the primary focus of this argument for why this audience needs engagement in this way, though other strands are not excluded from influence or participation.

Our cultural attitude towards science literacy is one of division. Most adults have already chosen which side of the fence they stand on, and their choice is so ingrained in their identities that it is difficult to bridge communication gaps between them. Research on adults show The High School aged audience, however, is intelligent enough, self-aware enough, and flexible enough that, given the tools to do so, they may choose to create their own paths towards an integrated identity as a resident of our chemical world.

13 *Effective Chemistry Communication in Informal Environments",* National Academy of Sciences Press, 2016 pg 56

# Identity and Intelligence

Erikson's developmental stages & multiple intelligences

In Erik Erikson's Theory of Developmental stages, this target audience corresponds with Stage 5: Identity vs. Role Confusion[14]. This audience is very concerned with how they see themselves and with how others see them. "During this period, they explore possibilities and begin to form their own identity based upon the outcome of their explorations. Failure to establish a sense of identity within society ("I don't know what I want to be when I grow up") can lead to role confusion. Role confusion involves the individual not being sure about themselves or their place in society". It follows, from the literature and anecdotally, that decisions made at this time are very indicative of a person's life trajectory, not only occupationally (I'm going to be a scientist), but internally and interpersonally (I'm the kind of person who can understand science).

The identity of a person is subject to constant change as it is faced with new opportunities, challenges, and situations. John Falk identifies five different "Museum Identities" in his research.[15] They are:

- Explorers (motivated by personal curiosity)
- Facilitators (motivated by other people and their needs)
- Experience Seekers (motivated by the desire to see and experience a place)
- Professionals/Hobbyists (motivated by specific knowledge-related goals)
- Rechargers (motivated by a desire for a contemplative or restorative experience)

Of these categories, where do high schoolers fall? Somewhere

14 Despite their age and the sometimes controversial views of their author, Erikson's developmental stages see continued use along with other post-Freudian psychoanalysts. This owes to his acknowledgement and establishment of identity as an intersectional creation, as well as his assertion that identity creation is a lifelong endeavor (Freud asserted that Identity development was complete by adolescence)
Sorell, Gwendolyn T. and Montgomery, Marilyn J.(2001) *'Feminist Perspectives on Erikson 's Theory: Their Relevance for Contemporary Identity Development Research'*, Identity, 1: 2, 97 — 128

15 *"Identity and the Museum Visitor Experience"*, John Falk, Ruteledge 2009

inside all of them. One can try to rule out the Professional, since the group is too young, but somewhere in there is the student with an experiment quietly fermenting in her garage. A teacher usually takes on the role of Facilitator, but small groups of students allowed to congregate freely will turn to their leader for what to do and how to enjoy themselves. Recharging students might need time away from the environmental stressors in the classroom. Experience seekers and explorers will also find similar ways to enjoy themselves.

Designing for all of these possibilities, as well as the possibility that all of these identities can exist simultaneously in one person to varying degrees, and shift composition daily or even hourly depending on factors well outside of anyone's control, is challenging. It will continue to be a challenge for as long as there are both museums and people to visit them. For the High Schoolers though, these identities represent an opportunity to engage and shift perception. The way these identities fall may also intersect the learning styles of the students in question, and that can have a profound effect on whether or not that identity will remain open to change.

In Howard Gardener's theory of multiple intelligences, he identifies these types of intelligence:[16]

- Linguistic intelligence ("word smart")
- Logical-mathematical intelligence ("number/reasoning smart")
- Spatial intelligence ("picture smart")
- Bodily-Kinesthetic intelligence ("body smart")
- Musical intelligence ("music smart")
- Interpersonal intelligence ("people smart")
- Intrapersonal intelligence ("self-smart")
- Naturalist intelligence ("nature smart")

16 Gardner, Howard. *Intelligence Reframed: Multiple Intelligences for the 21st Century*. New York, NY: Basic Books, 2000.

Many inroads have been made in the classroom to accommodate for different intelligences, but students may feel that science (and school itself) will always belong to the logical-mathematical and linguistic intelligent students.  A museum has the capacity to address the needs of interpersonal/intrapersonal intelligent students by introducing human narrative to a topic that seems inaccessible to them. It can address the needs of those with naturalist intelligence by relating a topic globally and ecologically. It can address the needs of those with bodily-kinesthetic intelligence by providing activities and space in which to move and experience, and serve those with spatial intelligence in the same vein. Some museums do address these needs but, especially in regards to chemistry, many do not.

*"The image of science that I find in most science centres is one of clear elementary principles waiting to be discovered by anyone with enough child-like curiosity and adult patience to search them out. By contrast, the image of science that I find in most science museums is one of sure and solid progress in the mastery of nature. In both cases, science itself emerges as a fixed body of knowledge and practice, more or less totally beyond either doubt or dispute, and in both cases, two relevant social groups are strangely absent: first... scientists themselves; and second, the wider culture." – John Durant*[17]

In chapter one, the capacity of chemistry was introduced. Does the story of all the stuff in our world have the ability to reach everyone?

17 Durant, John *"Museums and the Public Understanding of Science"*, 1992


# DIVIDING LINES

(The Classical, The Romantic, the Media)

If it has the ability to reach everyone, does it follow that everyone is willing to hear it?

In the narrative parable of Zen and the Art of Motorcycle Maintenance, two travelers experience motorcycle malfunctions. One considers the mechanical workings of the motorcycle to be beyond his comprehension, alien and scary and best handled by an expert. The other, while not himself a mechanic, has familiarized himself with the workings of the motorcycle enough that he can at least diagnose, if not repair any problems with his vehicle. Both started motorcycle ownership knowing nothing about their maintenance. One decided straight off that he was the kind of person who would never know anything about it. The other decided he was the kind of person who was capable of learning. That key difference, not in education, but in attitude, is everything. The *commitment to identity* becomes the lock that seals that gray box shut.[18]

18 Ericksonian development posits this state as the conclusion of Stage 5, the end of "finding oneself" and the beginning of adulthood.

In 1959, the physical chemist and writer C.P. Snow gave a lecture in response to what he saw as an alarming cultural divide between the sciences and the humanities. Though Snow was talking about the world of academia, his *Two Cultures* lecture became a hugely influential book, trickling from high academia, to college, to public discourse. The gulf became ingrained in the way people thought about what it means to be intelligent. Snow's "third culture", the one meant to bridge the gap, had not materialized yet.[19]

Thirteen years later, in establishing his Metaphysics of Quality, Pirsig addresses another false social division, one that is only being addressed recently in popular education and theory. He calls these identities and their corresponding aesthetics "Classical" and Romantic"

*"To a Romantic, this Classic mode often appears dull, awkward, and ugly, like mechanical maintenance itself. Everything is in terms of pieces and parts and components and relationships. Nothing is figured out until it's run through the computer a dozen times. Everything's got to be measured and proved. Oppressive. Heavy. Endlessly grey. The death force.*

*Within the classic mode, however, the romantic has some appearances of its own. Frivolous, irrational, erratic, untrustworthy, interested primarily in pleasure-seeking. Shallow. Of no substance. Often a parasite who cannot or will not carry his own weight. A real drag on society. By now these battle lines should sound a little familiar".*[20] [21]

19 In "*The Hedgehog, the Fox, and the Magister's Pox*,(2011), Stephen Jay Gould offers a thorough critique of Snow's work and a dissection of the "Science Wars" in general.

20 Pirsig, Robert (1974) *Zen and the Art of Motorcycle Maintenance*, pg 74

21 Pirsig's Romantic/Classical dichotomy resembles Nietzsche's Dionysian/Apollonian dichotomy as defined in *The Birth of Tragedy*

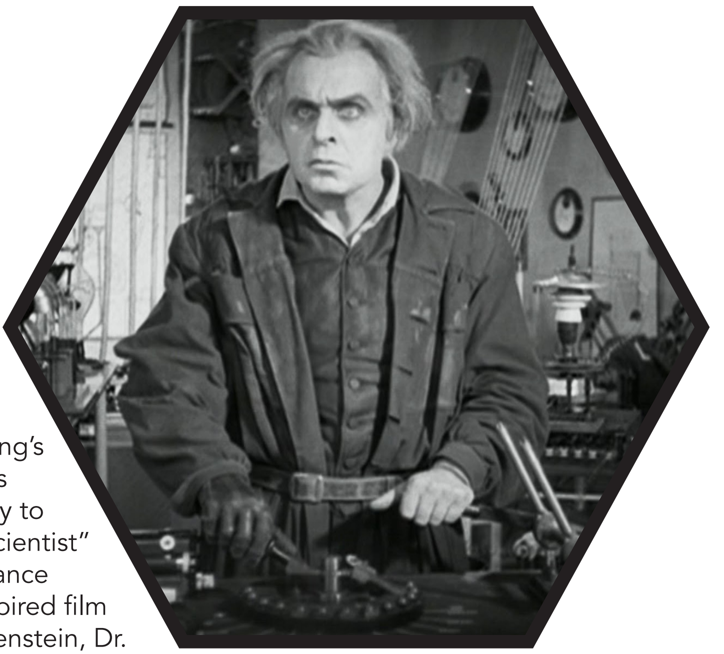

The Left Brain/Right Brain dichotomy has been debunked by neurologists. Why then does it have such cultural staying power?
Image Credit: Shutterstock

In modern times, you can see this distinction in the left brain/ right brain myth, which, while mostly debunked by the scientific community[22], continues to possess staying power in popular culture[23]. This division of identity is not an inborn trait, nor is it even an exclusive one. Though people have a tendency to see the world through one lens or the other, no one uses just one exclusively. Without the Romantic experience of a beautiful protein structure, the protein crystallographer might lose their enthusiasm for cellular chemistry. Without the Classical experience of calculating CoE rates in thicknesses of soda lime glass, the glass artist would never be able to create their work. Pirsig published in the 1970's, as research on split brain patients (the left brain/right brain distinction) was being disseminated through media, resulting in an even greater division between the arts and sciences culturally, a division that we never seem to have completely healed from.

22 Ref: http://www.npr.org/sections/13.7/2013/12/02/248089436/the-truth-about-the-left-brain-right-brain-relationship

23 Ref: https://www.psychologytoday.com/blog/brain-myths/201206/why-the-left-brain-right-brain-myth-will-probably-never-die

Children (and the teens and adults they become) are influenced by the media.[24] There is a demonstrable effect on children when they are exposed to those who look like them in a variety of roles, including as scientists.[25] A study of media portrayals and their effect on the public perception of science found that, conversely to many scientists fears, their representation was getting more positive with time. Scientists have been cast as protagonists and heroes in films and television more frequently since the 1980's, and since the 1990's, an increasing number of these hero scientists have been women and people of color. However, the view of science as a force or concept remains polarized, with heavy entertainment media use linked both to strong reservations about science's negative effects on society, and to higher amounts of belief in science as a vehicle for societal progress. The culprit in this case seems to be an effect of extremity. Science in the wrong hands becomes a terrible weapon, in the right hands it saves the world.[26]



Rudolph Klein-Rogge's portrayal of the antagonist Rotwang in Fritz Lang's *Metropolis* (1927) is considered by many to be the first "mad scientist" on film, his appearance and equipment inspired film portrayals of Frankenstein, Dr. Strangelove, Doc Brown, and more.

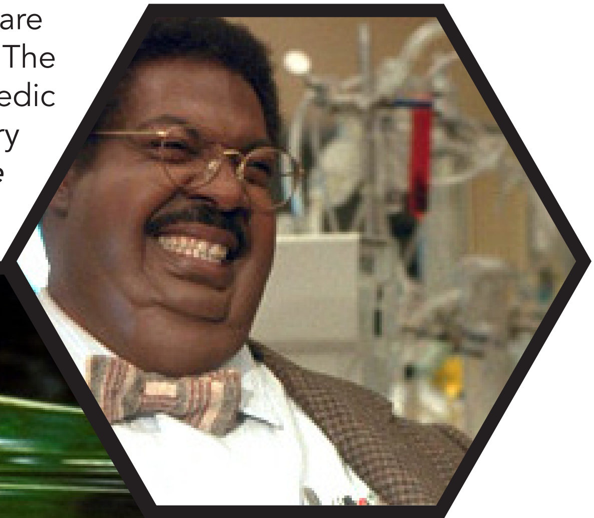
Image Credit: UFA Pictures, Fritz Lang

24 The type and extent of media influence is debated among communication and media scholars and dependent upon the type of media consumed, regularity, gender, age, social class, and ethnicity of the developing person.

25 *"Gender, Race and Class in Media: A Critical Reader".* Gail & Humez, Jean M., Editors (2011)

26 *"Entertainment Media Portrayals and Their Effects on the Public Understanding of Science"* Nisbet, Matthew C. and Dudo, Anthony, American Chemical Society (2013)

It is worth noting that none of the film hero scientists in the last twenty years have been explicitly referred to as chemists. In fact, the last ones who have practiced chemistry at all have been these two comedy films from the mid 90's. Both *The Nutty Professor* and *Flubber* are remakes of 1960's comedies. The Nutty Professor is also a comedic retelling of an even older story about a chemist: *The Strange Case of Dr. Jekyll and Mr. Hyde.*



Above: Eddie Murhphy in *The Nutty Professor* (Universal Pictures, 1996)
Left: Robin Williams in *Flubber* (Walt Disney Pictures, 1997)
Below: Bryan Cranston in *Breaking Bad* (AMC, 2008- 2013)

American television representation of chemists in recent history has been dominated by one character who, while compelling and brilliant, cannot really be called a "hero". The science in Breaking Bad is mostly used to make methamphetamine and explosives, only gaining power when Walter stops teaching it.[27]

27 The "Science as power for ultimate good or evil" trope is also present in Vince Gilligan's previous work on *"The X-Files"*

Crime labs in television:
Upper row, left to right:
NCIS, Bones, CSI
Lower row: CSI New York, CSI Miami.

Other depictions of chemistry in entertainment television are dominated by forensic science in police procedurals. This is a perfectly valid application of chemistry, but it is far from the only one.

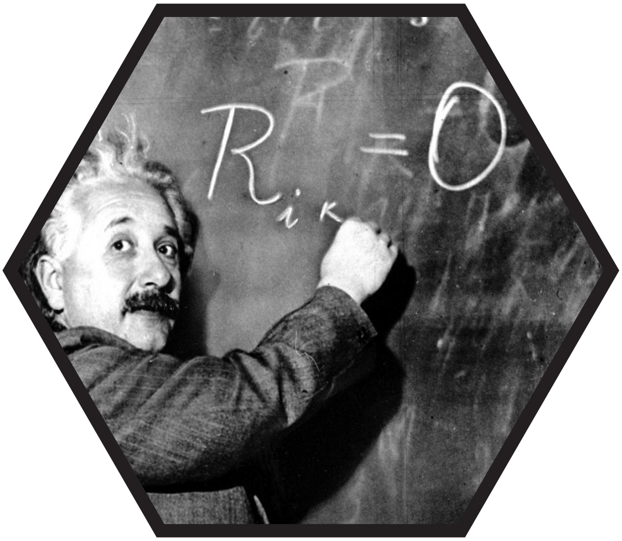
*"It doesn't have the touchy-feely aura of biology, the clean feel of physics, the great outdoors of geology, or the wistful nights of astronomy. It scares people and intimidates them with endless lists of elements, chemicals, and reactions."- NRC Landscape Study Participant.*[28]

28 "*Communicating Chemistry Landscape Study*", National Research Council, 2013 pg 12

# BUILDING BRIDGES

(perfection =/= intelligence, building relevance)

In "Even Einstein Struggled: Effects of Learning About Great Scientists' Struggles on High School Students' Motivation to Learn Science", a comprehensive study found that framing scientists as fallible and real human beings vastly boosted students' confidence when it came to their own ambition. The myth of science as a unified and stalwart force of progress combined with the scientist as an unreachable genius from day one form a psychologically insurmountable obstacle to students who are all too aware of their own struggles. To someone in Stage 5, struggling to discover themselves, perhaps feeling the pressure from social and media forces to align with an identity, a genius scientist might as well be a unicorn for how much they feel they'll ever have a chance to become one (there are, of course, outliers).



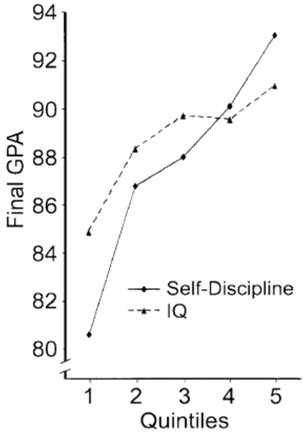

If the man whose name has become synonymous for "genius" had a hard time with his work, perhaps the rest of us aren't so hopeless after all.

Even for the outliers, the ones who up until now flew through school with ease, the wall will come. When they hit it, they also hit the identity crisis that comes with it[29]. For those students,

29 Ref: Gifted Adolescent's Adjustment Problems. Sal Mandaglio, Published in *Gifted Education as a Lifelong Challenge: Essays in Honour of Franz J. Mönks,* Published by LIT Verlag Münster, 2012

suddenly becoming "Not as smart as I used to be" can kill a dream or an identity just as well as never feeling they belonged to begin with. The key piece of advice to getting past the wall is to allow oneself to struggle. Allow one's identity to adjust to its new environment. Bend, don't break.

In fact, it is theorized that genius as we know it is secondary to practice as a means to achieve greatness, or at the very least, proficiency. Malcolm Gladwell in his book *Outliers: The Story of Success* established the oft-repeated claim that it is 10,000 hours of focused practice that grants a person mastery over a skill.[30] This sentiment is backed up by data.




In the Duckworth study, Students with a higher IQ did start the academic year at an advantage, but by the end were overtaken by the students who had ranked higher on measured self-discipline and grit.

In *Self-Discipline Outdoes IQ in Predicting Academic Performance of Adolescents*, psychologist Angela Duckworth measured numerous factors as predictors of success over the course of a school year and found that it was self-discipline in study habits, not IQ, that better predicted a students' final grades.[31]

As established by the effects of media representation, the representation of struggle is relevant to developing people. The representation of human doubt at all levels of education is relevant. The representation of mess and variety is all relevant. Despite this, the common representation of a successful scientist is still an effortless genius, whether good or evil.[32]

So how do we get chemistry into this?

30 *Outliers, the Story of Success.* Gladwell, Malcolm. Little Brown and Company (2008)

31 *Self-Discipline Outdoes IQ in Predicting Academic Performance of Adolescents.* Duckworth, Angela & Seligman, Martin E.P. Psychological Science vol 16 (2005)

32 *"Entertainment Media Portrayals and Their Effects on the Public Understanding of Science"* Nisbet, Matthew C. and Dudo, Anthony, American Chemical Society (2013)

# Case Studies

These case studies were chosen for their subject matter. Both are chemistry exhibitions. They are, in fact, some of the only Chemistry exhibitions currently open and available for study. It should be noted, and emphasized, that the criteria with which these studies are judged in this thesis bear no resemblance to the criteria with which they were created. Both collections are industrial and corporate in origin. Both were designed for an older, or expert audience, using a model of exhibition design which is not visitor-centric. They seem in ways to be relics of the days when science and technology museums were mostly privately funded and held, and served more as propaganda for industry than as an educational space for the public. These exhibitions are not designed for constructivist learning, for children, or for teenagers, so by evaluating them within that framework they will never succeed. However, by using this framework to evaluate these exhibitions, opportunities and affordances for great discussion, reflection, and learning can take place.

# CASE STUDY 1

**Making Modernity**
**The Chemical Heritage Foundation**
**Philadelphia, Pennsylvania, USA**

## The Museum

The Center for the History of Chemistry was launched in 1982 by the University of Pennsylvania and the American Chemical Society. In 1987 it became an nonprofit, and in 1992 the name was changed to the Chemical Heritage Foundation, as in moved to its current location at 315 Chestnut Street in Old City Philadelphia. Their current mission is as follows:

> *"To foster dialogue on science and technology in society. Our staff and fellows study the past in order to understand the present and inform the future. We focus on matter and materials and their effect on our modern world in territory ranging from the physical sciences and industries, through the chemical sciences and engineering, to the life sciences and technologies. We collect, preserve, and exhibit historical artifacts; engage communities of scientists and engineers; and tell the stories of the people behind breakthroughs and innovations."* [33]

CHF is much bigger than its museum. In fact, the public museum did not open until October of 2008. Its feature gallery, Making Modernity, was designed collaboratively by SaylorGregg Architects, CHF's curatorial and exhibition staff, and Ralph Appelbaum Associates. Typical of Applebaum exhibits, Making Modernity has very few affordances for changing artifacts or signage after the fact. The museum at CHF has three temporary galleries for changing exhibitions. However, one of them is available for viewing by appointment only, limiting its exposure to the general public. The bulk of the real estate that is the Chemical Heritage Foundation is taken up by the

33 Mission at https://www.chemheritage.org/museum-at-chf

conference center with its in house catering kitchen, library, spaces for scholars to do their research as historians of science, administrative offices, and the media offices that handle the production of Distillations Magazine and its sister podcast. The museum is free and open to the public if you know where to find it. The entrance to the building looks much like any corporate office building. A reception desk, a few chairs, scattered pieces of wall art. The entrance to the museum is to your left as you enter the foyer. Once through the glass doors, the world of the history of chemistry opens up

A corner of the ground floor of Making Modernity


A view of Making Modernity from the upper balcony.

## The Space

Making Modernity occupies a two story gallery. An open floorplan allows visitors to explore the ground floor freely, though a narrative of sorts is present in the space. The Applebaum signature glass and glow guides visitors around the perimeter of the ground floor, looking at themed wall bays, each telling a small story of a particular time and practice in chemical history. There are 8 thematic areas and 24 subsections. The wall bays and their individual stories continue on the second floor of the gallery, up a glass staircase. The entrance to the conference center is here as well. Except for a single stanchion and a well-meaning clerk behind the conference center desk, it's incredibly easy to wander in accidentally. The clerk will direct you to circle the upper balcony, which terminates in another stanchion, forcing you to go back down the way you came.

The center of the space is occupied by Making Modernity's core experience: a two story media column playing a continuous loop of a video that goes through the periodic table of elements one by one and provides visual information about its atomic shape, its physical form, and its use in modern society. This installation is one of the most popular and longest visited pieces of Making Modernity. Comfortable benches allow visitors to sit and watch the periodic table come to life, and they often do. On four freestanding areas sit chemical equipment. Each area is themed for the story it tells. Each area is uncovered; no glass sits between the visitor and the tools they get to observe from all sides.

The overall colors of Making Modernity are grey, blue, and gold. The blue and gold accents exist exclusively as panels of glowing light, leading visitors from one island or nook to another.

**The Stories**

Making Modernity packs an entire world of history into two floors of space.[34]

**Four freestanding areas:**

- Name: Corrective Lenses
  - Story: How to see chemistry, advances in visualization of atoms and molecules
    - Artifacts: protein crystal Mylar, ultracentrifuge
- Name: Soul of an Instrument
  - Story: The tools of lab work and the human cultures that form to conduct research
    - Artifacts: DNA instruments
- Name: Under the Skin
  - Story: Disease and illness
    - Artifacts: bleeding bowl, insulin
- Name: One in a Trillion
  - Story: Contaminants in air, soil, and blood.
    - Artifacts: electron capture detector, TOMS ozone instrument, image of bucket brigade

**First floor wall bays:**

- Name: Materials for the Masses
  - Story: Textiles, dyes, Bakelite, chemistry in consumer products
- Name: Empowering Technologies
  - Story: Electricity, semi-conductors

**Second floor wall bays:**

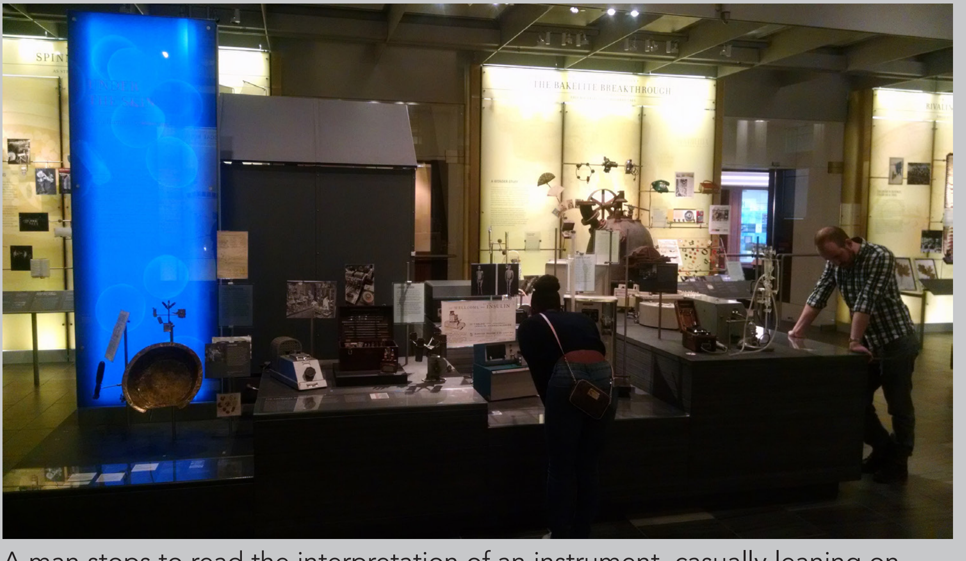
- Name: Becoming a Chemist
  - Story: chemistry at home, in education, chemistry sets
- Name: Chemistry in the Wider World
  - Story: cultural impact and influence, pollution

34 Source: Christy Schneider, Chemical Heritage Foundation

Overall, the chemists and scientists mentioned seem to suffer from a heroic lens. They are people, yes, but all we know of them is their success. The grouping of stories into thematic sections, the length the text goes to to give a more realistic portrayal of science than the "great march forward", the everyday artifacts, the personal quotes, all of these are almost there when it comes to creating any access points for its non-expert visitors. But in the end, the people featured are faces of their work and a non-expert visitor is not going to have any reason to connect with them on a personal level, or in some cases, even find the human stories at all.

**Interactions and Artifacts:**

Artifacts artifacts artifacts! Every wall and platform in Making Modernity is covered in artifacts. These range from the grey boxes of chemical equipment to Bakelite buttons to fabric swatches and lightbulbs. Along the cove displays, the artfully arranged objects give a sense of design and flow to their stories. On the islands, the larger pieces of equipment sit quietly, offering their secrets only to those who stop to read the rather small interpretive panels beside them.



A man stops to read the interpretation of an instrument, casually leaning on the platform to do so.

The Bakelizer gets touched a lot.

There are really two sorts of design principles at work here, the wall bays and the islands. The design of the wall bays is so consistent and the arrangement so intentional it can become easy to tune out the fact that there is a LOT here. Redundancy in commercial artifacts are used like staccato points, driving home the notion that these things are mass market, they are mass culture, they are society itself. The interpretation of these objects flows with grace, though something about that very designerly quality gives the impression that the artifacts could well be replaced with cardboard cutouts without losing any of the narrative or impact (With the notable exception of the Bakelizer, which juts out of its bay like a potbellied stove, breaking with the visual consistency of the other bays in its thematic section to amusing effect. There are few opportunities for interaction here. A single button affixed to a reader rail, a patch of fabric for the texture-hungry, no more (the Bakelizer, incidentally, gets touched all the time because it breaks its fourth wall, though nobody is actually supposed to touch it). The connection forged by the use of common recognizable materials is tested by their distance and inaccessibility, despite the open air between them and the visitors.

The four freestanding areas consist of rectangular blocks at varying heights and focus more heavily on the laboratory than the mass market. These "islands" are where most of the grey boxes live. The equipment is uncovered by glass and unobstructed by barriers, but the design of the pedestals still says "Do Not Touch" in a very official way. The blue glowing obelisks in the center of each island give an overview of the story these machines are meant to tell. However, the writing on them is white and it's difficult to make out unless you're standing at the correct angle. Information on the platforms themselves do much the same as the reader rails in front of the nooks, and can be difficult to read. The size and weight of these machines carries most of the importance of the islands. As opposed to the bays, where everyday objects and stories are placed into a chemical narrative, the gray boxes, displayed as appealingly as possible, should invite the visitor to think "What is that thing? What does it do?", allowing the reverse to happen: allowing the chemical and alien to become human. However, the answers to those questions are seldom to be found in the interpretation.

**The Response:**

Making Modernity was designed for a specific audience of older chemists. These chemists to not require a personal connection with the subject, they already have one. For this audience, the exhibition is wonderful.  However, CHF has also seen a steadily growing influx of laypersons, general population science enthusiasts with their families, and even school groups. For these audiences, the inaccessibility of the main gallery can leave them exhausted and baffled.

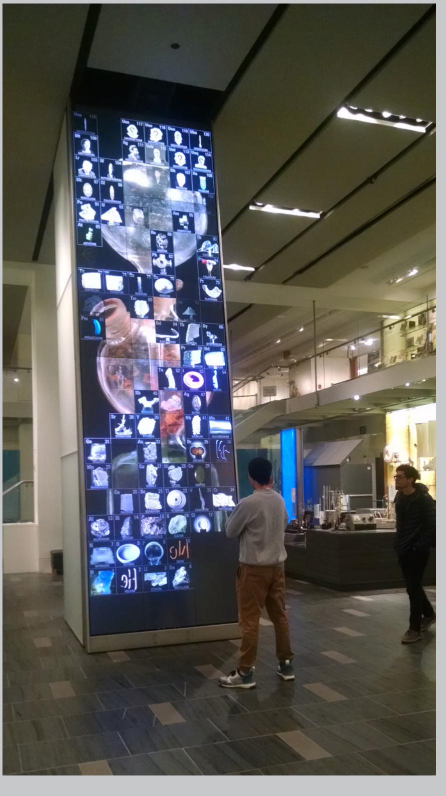
**The Criteria:**

**Does this Exhibit link chemistry with personal relatable narratives?**
It tries. The scientists in the narratives in Making Modernity are mostly one liners, single photographs, or a few sentences. This is most likely because of overambitious content. When you're dealing with the weight of the whole of the history of chemistry in one large room, there is only so much space for the small or strange details that link people with people.
**Does this Exhibit use its material culture in a way that supports that narrative?**
This exhibition uses all the artifacts it could find affordances for in the design. It's bursting with material culture. As far as supporting the design, it varies widely by section. In the Dyeing subsection, the use of the swatch book as a link between the intimate and industrial supports its story very well. In other

sections, an artifact might be there as an unneeded redundancy or as an uninterpreted showpiece for aesthetic value without context.

**Does this exhibit allow for meaningful creative experience within that narrative?**

There are no opportunities to engage with the story presented by the artifacts and interpretation, either verbally (as in a response wall or some other form of feedback creation), or more constructively (as in a building/making). The caseless design of the exhibition is inviting, but only up to a point. Few attempts are made to engage a visitor in conversation with a story or an object. The space is almost always rather eerily quiet save for the looping video on the media column. It has an air almost like a cathedral, and for all its small attempts to bring chemistry to a human level, the glowing glass, lofted designs, and altars to progress all reaffirm and reinforce that cathedral-like quality.

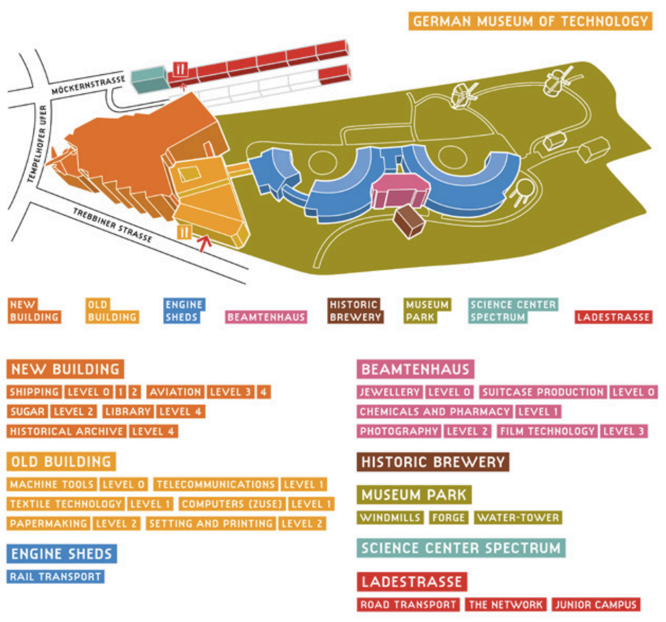


# CASE STUDY 2

**Pillen Und Pipetten (Pills and Pipettes)**
**Die Deutches Technikmusem, Berlin, Germany**

## The Museum

Die Deutsches Technikmuseum (The German Museum of Technology) is a museum of Science and Technology in the Kreuzberg neighborhood of Berlin. Its original collection and mission was to collect trains. To this effect, it is situated on an old train yard and boasts a collection of 40 trains on 34 tracks. Since its inception it has expanded to include aviation, shipping and automotive collections. It also boasts exhibits or entire buildings on seemingly every industry Germany has ever called its own, from suitcase making, to beet sugar, to, of course, beer. It also boasts a large museum park.




In between the engine sheds, in the middle of the sprawling campus is the Beamtenhaus (Office Building). Inside lives an eclectic assortment of exhibitions of industries. On the ground floor you'll find a fully functioning Jewelry studio, often full of craftspeople using the machinery that in any other museum would sit quietly. You'll find a suitcase production studio across that hall, humming with the same activity. The second floor contains a history of photography, showcasing cameras and photographic technology. The third floor contains the same for film and the moving image.

On the first floor lies a story about chemistry, pharmaceuticals, and the evolution of the modern world. The bulk of the artifacts and tools in this space are the collection of the former in-house museum for the Schering Corporation. After Schering was purchased by Bayer, the museum and its assets fell into the hands of the Schering Foundation, a nonprofit dedicated to exploring the boundaries of art and science. The Schering history museum "The Scheringerium" had always been technically open to the public, but was very hidden and explicitly about its own corporate history. When the Schering foundation sought out a partnership with the Deutsches Technikmusem, they sought to preserve the Scheringarium, make it more broadly about chemistry than company, and "more than anything, to make it open to the public."[35]

## The Space

Pills and Pipettes is divided into three sections. The right side, as you enter, leads into "Pipetten", an exploration of chemistry. The left side leads to "Pillen", a history of chemistry as applied to medicine in pharmaceuticals. The hallway between them contains a history of the chemical industry in Germany, a wall of German Nobel Prize winners, and a light up map of the berlin area that shows the locations of past and present chemical companies.

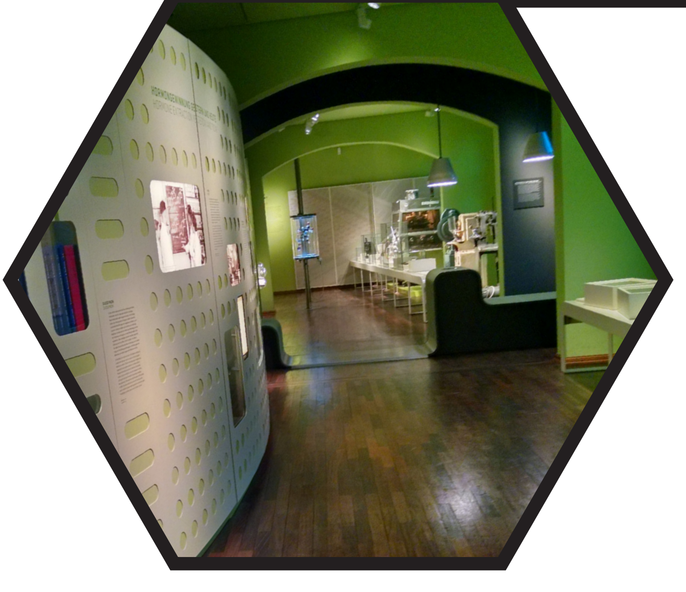
The building was the office center of the old train station. Its interior architecture has remained mostly intact. The central hallway would once have held offices on either side. Supports and columns are in place. Windows were covered in blue transparencies to lend atmosphere to the wall décor and to

35 Ref: "Die Transmutation eines Firmenmuseums" (The Transmutation of a Company Museum), A document on "Pillen Und Pipetten" sent to me by Volker Koesling (Head curator of the exhibition). Translation by Sean Toland.

protect the artifacts in the exhibition. On both sides of the exhibition space, rounded carpeted bumps rose out of the floor. This was the only seating in the exhibition, and each set of bumps contained some relevant push-button audio display so that those talking a rest could sit and listen.

Each side of the exhibition made use of perforated temporary walls. In "Pipetten" this wall had a hexagonal honeycomb (Or Benzene!) shape. In "Pillen" these walls had oblong, pill shaped, perforations. In each section the walls curved around supports and corners, making the rectilinear space more rounded and inviting.

"Pipetten"



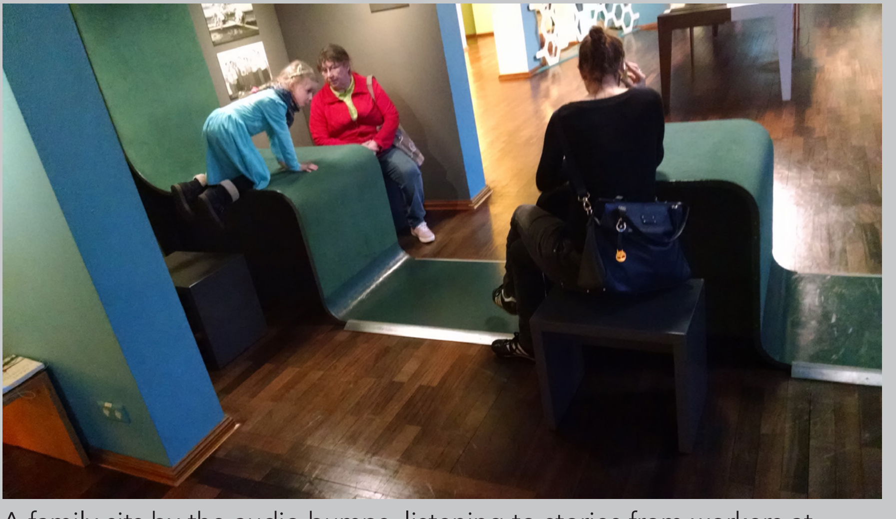
"Pillen"

## The Stories

### Pipettes

Pipettes tackles a lot of stories in its attempt to present the chemical industry. Camphor, safety glass, the invention of the research laboratory, and the rise of capitalism as a motive for further innovation. A fireworks interactive invites visitors to mix their own explosives and watch the results on a monitor. A freestanding table features two molecules: Urotropine and Piperazine.

The carpeted humps in the middle of the room tell the specific story of the Schering company. Besides being a service to their funder, the stories of workers, their relationships with their work and with one another in the 1920's really serves to place people inside an industry that can seem so mechanical. Placed on the oddly shaped eats are buttons. Each button triggers a snippet of audio from a company worker, describing their life at the company.



A family sits by the audio bumps, listening to stories from workers at Schering.

After the hump nook, the room turns to machines and devices. Glassware and equipment adorn a long table. A pipetting machine sits to the right, fully functioning, taking samples from tubes and dropping them into other tubes, whirring softly in the background.

Towards the end of the room, the story shifts into agriculture. A freestanding model of DDT stands surrounded by its own story and several pieces of agricultural equipment.At the left before you exit Pipettes, an electroplating display appears as a table with magnifying glasses built into it. As you look into these windows into the table, you see the fine details of circuit boards, aerators, and eyeglass frames.

## Pills

Pills starts its narrative with a model of Salycilic Acid. You can follow its history from willow bark to capsule as one of the most potent and beloved analgesics of all time. It sets the tone: Medicine is chemistry too. It is joined by the story of penicillin, the classic petri dish accident that saved millions of lives. On the opposite wall is a timeline of medication delivery. An apothecary's mortar and pestle are joined by a suppository press, injection kits and pill presses. Industrial tablet machines stand behind this table like sentinels, chutes pointing towards the visitor as if at any moment they would wake up and start spraying aspirin all over the place.

A tablet pressing machine stands behind its apothecary predecessors

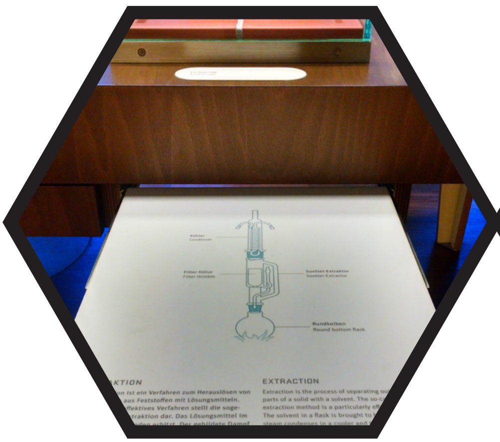
The carpeted audio humps on this side of the exhibition introduce another chemical pharmaceutical story: Birth Control. Audio clips here range from reports by doctors to outraged radio talk show hosts decrying the moral failure sure to follow the "Antibabypille".[36] This rest and respite introduces the next section: How soybeans and Barbasco root spurred a race to

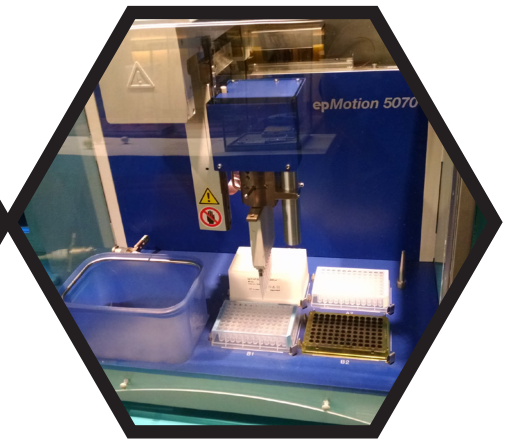
36 Yes. The German word does translate, literally, to "anti-baby pill".

develop synthetic estradiol and progestin in a social climate with increasing demand.
Artifact cases and pull out drawers with additional information are built into the pill shapes in the wall, and as you round the wall, you enter the world of pharmaceutical testing. A creative light up display demonstrates how many pharmeceuticals make it through each round of testing, and what each round of testing consists of. Against the window wall sits a bank of blank monitors. I assume this was, at some point, an interactive.

**The Interactions and Artifacts**

This exhibition uses its artifacts precisely and meticulously. Every one exists in the space to assist in the telling of its story, and it's clear that the artifacts and the design of the exhibition developed simultaneously. The pull out drawers beneath the condensers and other glassware were a very nice touch, allowing people who just wanted to admire the glass to do so, but still leaving room for those who wanted to investigate their purpose. The fact that the pipette machine was running was a surprising thing for an exhibit of this nature, and yet entirely consistent with the aesthetic of the in use jewelry studio just downstairs.




Pull out drawers containing additional information about artifacts and a constantly running pipetting machine were a few of the nice touches this exhibit used to try to give life to its subject matter and its collection.

Meaningful real interaction with the content, beyond sliding out a drawer or lifting a panel was sparse, and of all of those opportunities, the passive audio selection on the central humps seemed to be the most impactful for any visitor I observed. A camphor smell interactive also got a reaction from those I observed, but really, anyone will make a face when they get a nose full of camphor. The fireworks game seemed out of place with the narrative of the rest of the exhibition.

**The Response**

The Deutsches Technikmuseum (like many museums in Europe) does not typically evaluate their exhibitions in the same fashion as American museums do. However, I had a chance to observe my own responses, casually observe several visitors through the space, and speak briefly to a docent about the general visitor response to the exhibition.[37]

> I observed 19 visitors in two hours of observation.
> 13 spent longer than two minutes there.
> 12 were within my target audience.
> Of those within my target audience, 6 stayed for longer than two minutes.
> 5 of them were a group of girls, pressing buttons and talking amongst themselves.
> 1 was a teenage boy with his father. The father seemed enthused. The boy did not.
>
> The average length of time stayed by any visitor was roughly five minutes. The visitors who stayed the longest was the group of teenaged girls, who spent about ten minutes pressing buttons and taking photographs.

From the docent:

> "I like this exhibit. It's pretty. The colors are good. Some people see "Oh, it's science" and walk out.[38] Some

37 My response was like a kid in a candy store. I loved the design. I loved the layered information. I loved the bilingual signage (Thank goodness it was there, my German is at a kindergarten level). But I expected this. I am not my target audience for this thesis. My enthusiasm, however, seems to be out of the ordinary.

38 It's interesting to note that this is the response this gallery gets. "Oh it's science", at a science and technology museum!

people walk through it quickly. A few stay for longer but it isn't very popular. School groups are mostly young and there's so much here that it just.. few people. I don't know this topic well so I can't explain any equipment. It's a nice place for us (the docents) to rest since the rest of the museum is so crazy. This is not a popular time (Early January), after the holidays. No… Excursión? (Field Trips) and no tourists."

**Case study evaluation criteria:**

**Does this Exhibit link chemistry with personal relatable narratives?**

The stories of the Schering employees and the people who poured their blood sweat and tears into creating birth control are both compelling stories about people in chemical industry. Of the two, the latter references the chemistry as an active agent in the story more often, creating an affordance for a visitor to literally sympathize with a chemical. The former is still a compelling narrative, but is more of an historical snapshot of the office ecosystem in a burgeoning industry. It should be noted that little mention is made of the enormous sociopolitical consequence of the birth control pill, and the role the chemical industry had in WWII was glossed over (In the English-language text, anyway).

**Does this Exhibit use its material culture in a way that supports that narrative?**

In this the exhibition finds its success. From the gnarled barbasco root in its jewel-like wall case, to the humming pipetting machine, each artifact in that exhibition existed in support of its own narrative. There was no redundancy. There was no visual overload of stuff. But at the same time, the artifacts did not have the feel like you could replace them with a photograph and have the same exhibit. The mass and material of the glasswork, the looming pill press, each of these objects lent character to their stories in a way that only objects can.

**Does this exhibit allow for meaningful creative experience within that narrative?**

This exhibition was lacking in this category. The one "game" interactive, the fireworks simulator did not tie into the narrative of the chemical industry. This exhibition invites visitors to wander, read, and sometimes listen. In comparison to the hustle and bustle of the jewelry and luggage exhibitions just downstairs in their mélange of living history and living industry, this floor seems almost sterile.

In conclusion, Pillen und Pipetten does a good job of setting up the stories of chemistry. It does a good job populating those stories with artifacts in character roles. But what it does not do is provide an entrance for the visitor into that narrative

# IMPLICATIONS

Both “Making Modernity” and “Pillen und Pipetten” are chemistry exhibits about the history of chemistry. Both target an older, more well versed audience. Neither aims to teach chemistry concepts within its exhibition. Neither invites too much in the way of interaction, either with the artifacts or with the subject matter.

Making Modernity and Pillen Und Pipetten may well be sister exhibitions. Both collections come from corporate industry. Both tell the story of that industry, its tools, and its human characters as best they can.

Neither exhibition engages its audience with lessons about chemistry itself. Neither exhibition allows for a hands-on experience with it. But then, *neither of them are designed to do so.*

The implications drawn from these cases are as follows:

- Current chemistry exhibits tend to be “history of science” based
- Current chemistry exhibits tend to be geared towards learned adults and experts
- Current chemistry exhibits do not draw younger audiences
- There is room in the world for an exhibition about chemistry itself.

# Chapter 3

# Applications

Chemistry demos already exist and already serve a good and important role in the science museum community. A demo, however, is always conducted by a demonstrator. It's a show, extensively monitored and moderated by trained staff who work very hard to ensure that any dangerous substances do not touch the audience. This is *not* the goal of this thesis. Constructivist learning can only take place in an environment where one can make meaning from their choices and experience. The development of this prototype came in several waves; Research, planning, performing and evaluating. The primary question and goal in mind was simply this:

What access points can be used to relate chemistry practice to identity formation and real lived experience? How can those access points become nucleation sites for the development of experience?

# RESEARCHING THE PROTOTYPE

(What can I do?)

After conversations with advisors, chemists, and teachers, several access points were identified.

- Failure/Screw-ups/Struggles/Accidents: Compelling personal narratives. Safety Glass. Mauve. Penicillin. LSD. Post-it Notes, Worcestershire Sauce[39]

- Cooking/Baking: Already used by chemistry teachers (Making brownies by measuring moles was… less than successful). However, for something so vital to human experience in every aspect, there is a lot to unpack and a lot that can still be done.

- Color/Dyeing: Mass media saturation of pop stars with pink hair, TV shows about sculpting prosthetic aliens, and a greater general tendency for generations to push the appearance envelope more and more in fashion. The role of pigments in fiber, cosmetics, and the world may especially create access for girls and those with traditionally feminine interests. These things are all factors that can lead into a conversation about the chemistry of color, dyes, and pigments.

---

39 Worcestershire sauce was created by British chemists looking to replicate Indian curry. Truth is stranger than fiction.
Ref: http://www.huffingtonpost.com/2012/09/05/worcestershire-sauce-history_n_1855872.html

**Accidents**: While this would make an interesting exhibition, the worry is that it would make a less than effective activity. With the exception of Safety Glass and Post-its, each of these accidental discoveries would be time consuming, not dramatic looking, potentially deadly, or illegal. Leading students through a story in the lab by parroting "Now do what I do!" is effectively no different from a lab class that a student would have back at school, and a facilitator demonstrating something that could potentially go horribly wrong would be a demonstration.

Bunsen and Beaker mess up all the time, one of the reasons they are so accessible and beloved.

**Cooking/Baking**: Still an option. The chemistry of baking is not a new concept for educators. There's a great Magic School Bus book/episode about it. There are numerous books, textbook chapters, lessons, guides, and youtube videos on the chemistry that goes into cookies and cakes. There is also a lot about the chemistry of brewing/distilling, but considering the audience, it might not be a good idea to encourage making moonshine. If this access point is chosen, the challenges will be:

- How will this activity differ from every other "Science of Cooking" activity that has come before it?
- What will it communicate?
- What are its affordances for creating meaning, relevance, and allowing creativity to play a role in chemistry?

Still from the Magic School Bus episode: Ready, Set, Dough!

**Color/Dyeing:** The chemistry of colors and color shifting is periodically explored in high school chemistry. So it follows, dye is usually at least given a passing mention. The chemistry of dye, from available research, tends to remain in arts school fibers departments and enthusiastic laypersons. Dyes (Particularly natural dyes) have a great affordance for talking about the roles acids, bases, binders, and catalysts play in this process. Depending on the type of mordant[40] and PH level of the dye bath, a single root, flower, or bark can manifest in a rainbow of colors. This process is not particularly toxic, nor is it physically dangerous. It also allows for freedom of experimentation, exploration and creativity. Color, dyes and textiles also have connections to fashion, beauty, and femininity that can serve to offer opportunity for girls and others with traditionally feminine interests to find an immediate ground of interest.[41] It also happens to

40 A mordant is defined as: "a chemical that fixes a dye in or on a substance by combining with the dye to form an insoluble compound" or "a corroding substance used in etching" Ref: Merriam-Webster.com

41 In this, being accessible to girls does not necessarily make the activity inaccessible to boys. It is still a chemistry-based process, and in the author's personal experience teaching

be the subject the author knows most about. Also, wouldn't it be poetic in a way, to bring students out of the gray box on a rainbow? This approach is not without its own challenges, however.

- Washing, Mordanting, and Dyeing can take several hours. How to plan an activity with enough preparation to minimize time, but enough flexibility to maximize creativity?
- Not every student is going to be into dyeing wool yarn. How to construct an approach that incorporates different materials or maybe prefabricated garments?
- Running water, heat, and ventilation.

For reference, every different color of yarn on this thing was dyed with the same plant (Madder), with a different mordant.

The third option presented the most opportunity for exploration and growth. Further research into the use of natural dye led to several rounds of personal exploration and

adolescents and teens of all genders and persuasions how to dye fabric, there has been little difference in the quality of work or investment of interest based on sex.

prototyping of the techniques, tools, and time needed to complete this task took place over the course of two weeks.

Using the techniques detailed in "Natural Dyeing" by Jamie Crook, the first round of testing on wool yarn was completed in two days' time.[42] For the plant material, red cabbage and yellow onion were chosen, primarily for their ease of access and relatively low cost. Alum (potassium aluminum sulfate), Copper (copper sulfate), Tin (stannous chloride), Chrome (potassium dichromate), and Iron (ferrous sulfate) mordants were used along with a control that was not mordanted at all.

The yarns produced from this round of testing were indeed, strikingly different in color and intensity thanks to their presoak in metal solutions. Altogether, this process took an entire weekend of heating, chopping, boiling, simmering, and carefully weighing potentially toxic metal powders.[43] As a home project or even a multi-session school project this process has the capacity to be an amazing chemistry lesson that produces tangible workable material for other projects. However, for the purposes of a museum experience, the time frame is prohibitively long.

Experimental yarns hung out to dry

42 See Appendix for details of that experiment.

43 An amazing weekend for the author. However, we have established that the author is not the intended audience of this project.

A short round of secondary experimentation was performed on the alum-mordanted yarns. These yarns were introduced to acidic and alkaline solutions as an aftersoak modifier. The change on the onion-dyed yarn was noticeable but insignificant. The yarn on the red cabbage-dyed yarn, however, was immediate and dramatic. From a lavender grey, the acid-soaked yarn became much pinker. The alkaline-soaked yarn turned yellow. Remarkably, these yarns, if switched to the other bath, would color change the other way, the pink turning more blue, then green, then yellow as the yellow yarn did the opposite. This color change is due to the remarkable properties of flavin, the pigment that gives cabbage its color.

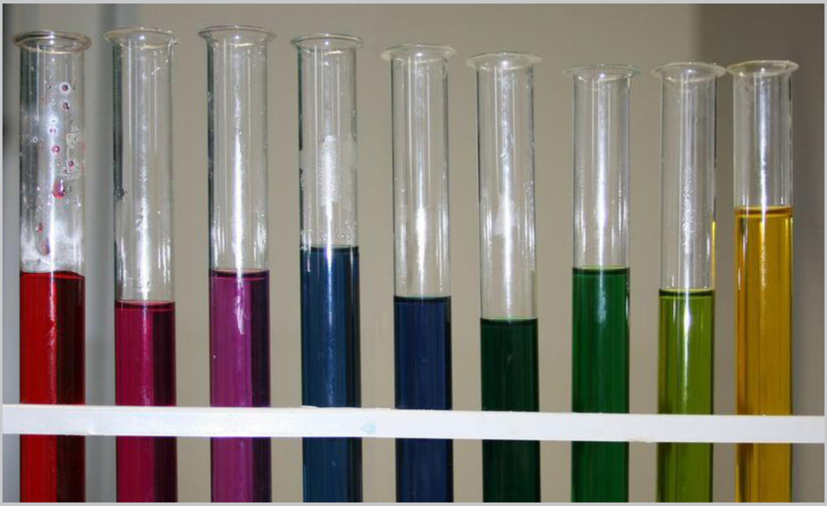
Experimental pH shifted yarn samples.

Flavin is an anthocyanin. Anthocyanins are found in cabbage, berries, eggplant, anything in nature expressing a deep blue-purple is likely to contain it, and most will express the same halochromic (color shifting in response to pH) properties as Flavin. Anthocyanins are also antioxidants, and much research has been done into their effects on human health[44] and as

44 Ref: "Anthocyanins—More than Nature's Colors" – Konczak, Isabella and Zhang, Wei. Journal of Biomedicine and Biotechnology

organic food coloring.[45]

More research revealed that making pH strips from cabbage juice, or measuring the pH of different household liquids by testing them with cabbage juice, is a fairly common chemistry lab experiment at middle school, high school and collegiate levels, with dozens of links to lessons found in a simple google search. This experiment is often chosen for its ease of use, its instant and colorful results, and its low material cost. This lead is promising, but there are still questions to be answered.



Example of a "Red cabbage indicator lab". The red test tube is highly acid, the yellow test tube highly base.

At this point, these experiments had been done on wool yarn. Wool yarn is not a universally attractive object.[46] Also, wool is heavy when wet, slow to dry, is likely to itch and has a tendency to felt[47] if agitated too roughly. For this reason, it is typical that one dyes the yarn before one makes the hat. However, there is another animal protein fiber that is commonly used in dye and clothing manufacture: silk.

Silk has a special place in the folklore of fashion. For thousands of years, silk has been revered as the finest, lightest, and most

45 Ref: Personal interview with Alyssa Luning RDN

46 No object is, but wool yarn has specific appeal to knitters, cats, and few others.

47 Felting occurs when individual wool fibers escape their twisted strands and become entangled with the fibers in adjacent strands. This can result in inflexibility and shrinkage.

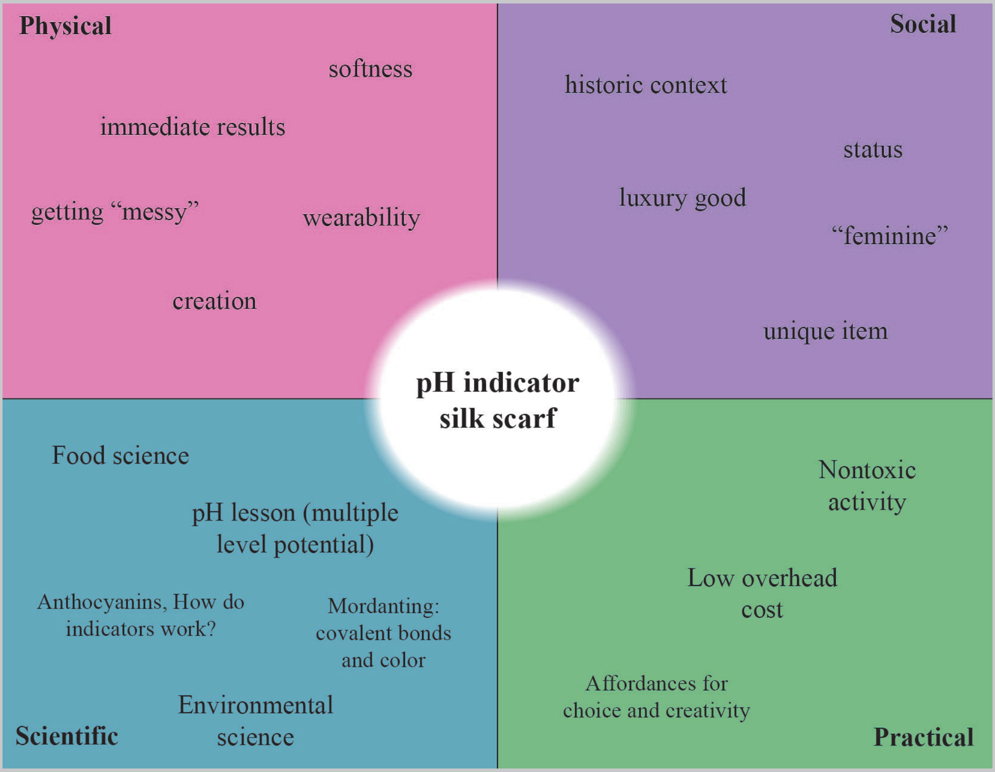
luxurious of fabrics. Idiomatically, it is commonplace to describe something with exceptional smoothness as being "silky". In its heyday, the silk trade built and toppled empires, and today remains a global business, with 50% of the world's silk produced in China.[48] Artificial fibers have come close to replicating silk's texture, but none have managed to match all of its lightness, smoothness, and luster. For this reason, silk is still regarded as a luxury item. But does silk exhibit the same properties as wool when dyed with anthocyanins and introduced to different pH solutions? Absolutely. Textile artist Dahea Sun, in her "Rain Palette" project, created a series of silk garments designed to react to pH levels of rainfall, as a wearable pH indicator but also as a statement about acid rain and consumer responsibility.[49]

Photograph of "Rain Palette" dress

48 Ref: http://www.silk-road.com/artl/silkhistory.shtml

49 Ref: Sun, Dahea, "Rain Palette" https://www.sundahea.com/rain-palette

At this point, an application took shape, and after thinking about its qualities, the decision was made to go ahead with it.



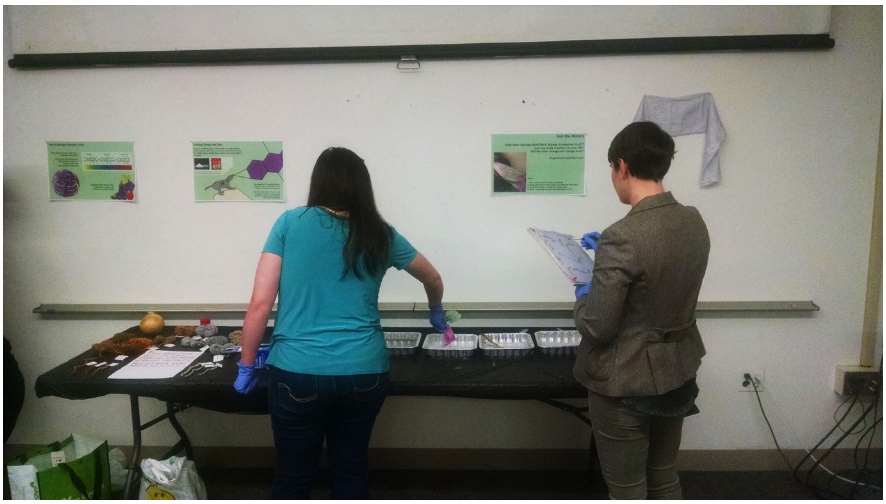

A qualitative breakdown of the pH scarf prototype activity.

Armed with this knowledge, medium weight silk fabric was dyed with red cabbage and alum mordant, clumps of stray fibers tested for pH sensitivity, and the cloth cut into small handkerchief sized pieces. Armed with silk, baking soda, vinegar, a tea kettle, and a few pieces of tabloid-sized paper, the prototype experience began to take shape.

# PERFORMING THE PROTOTYPE

(What actually happened)

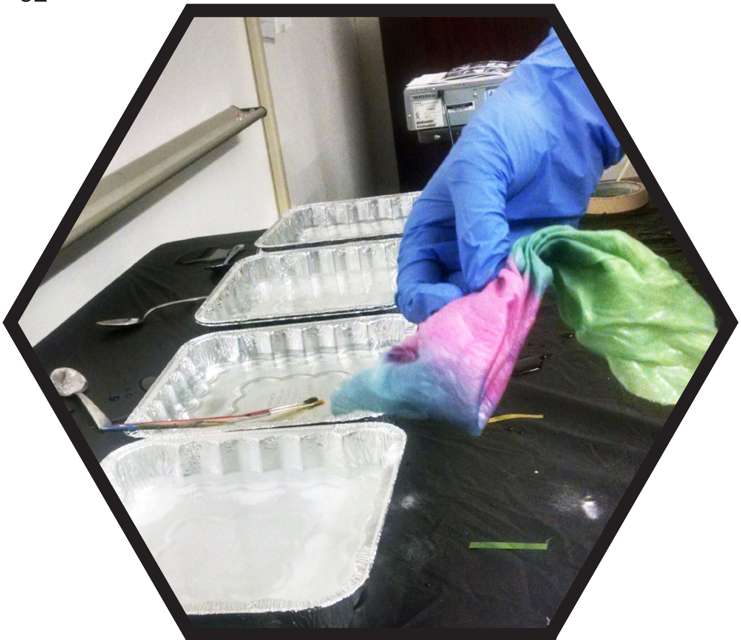
Prototyping was performed on one occasion over the course of two hours. A few quick pieces of signage about pH reactive cabbage, Mordants, and instructions for the activity were designed and put up.[50] A display of the multiple-mordanted yarns was accompanied by the vegetables that produced it. Alongside this display was a creation station containing a pile of silk pieces and five aluminum trays containing baths of clear solutions of different pH levels, ranging from 10 to 2.



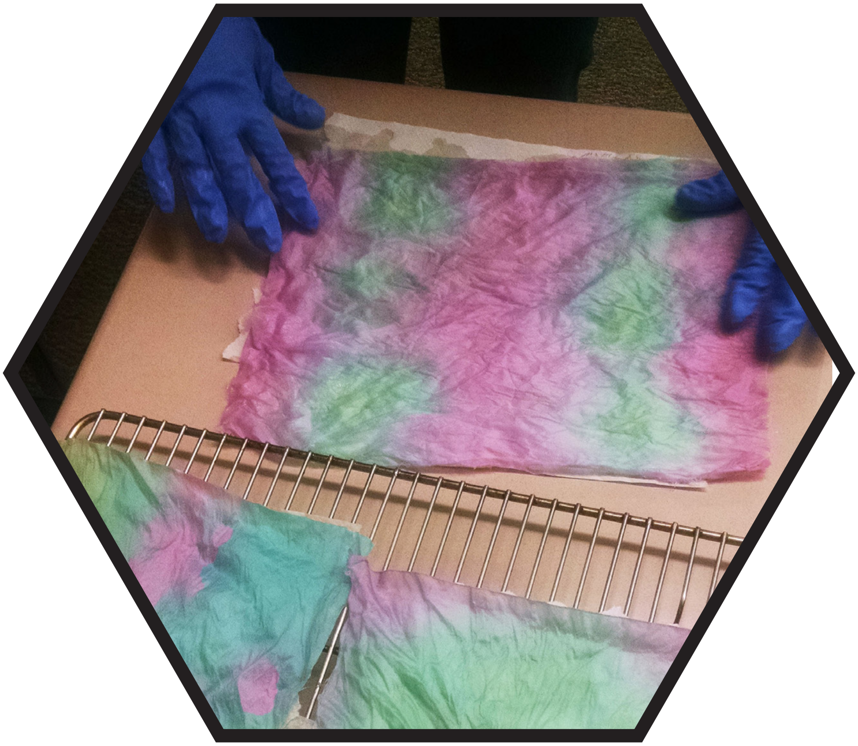
Two visitors participate in prototyping

My role in this activity was as facilitator. Knowing an activity like this would require a staff member, there was little point denying the presence of one. Proposed installation was, hypothetically, a tie-in activity in a makerspace to an exhibition about chemistry or textiles, or a making area within such an exhibition. A total of ten participants created projects, nine of whom filled out exit surveys about their experience.

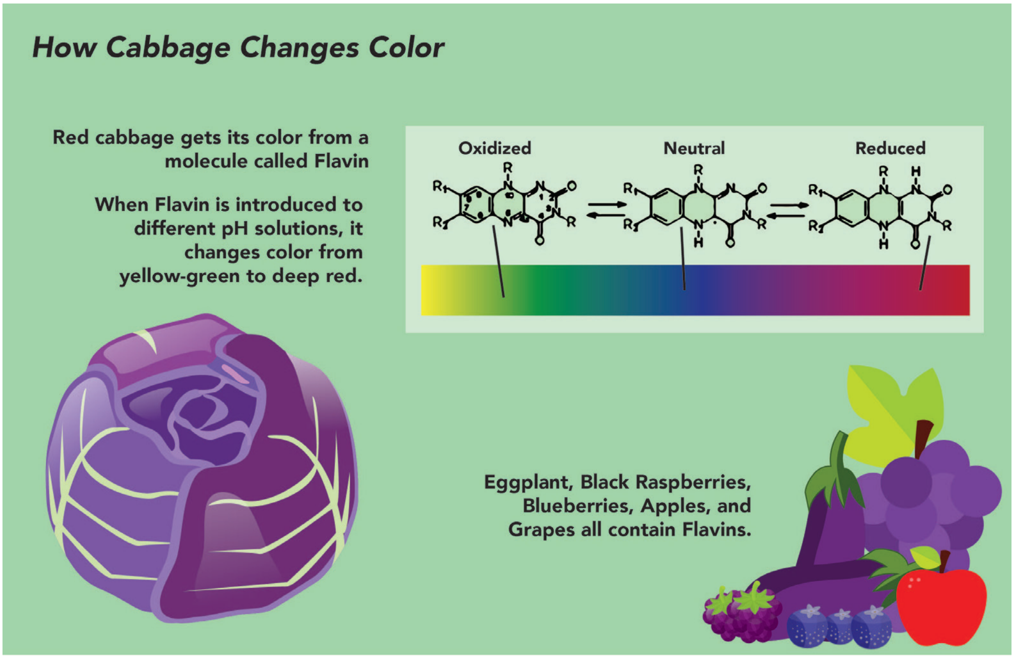
50 Signage and evaluation instruments can be found in the appendix




Above: Participants color their silks with the different pH solutions.
Below: Initial yarn experiment are displayed.



A participant places their work on a stack of paper towels to dry.

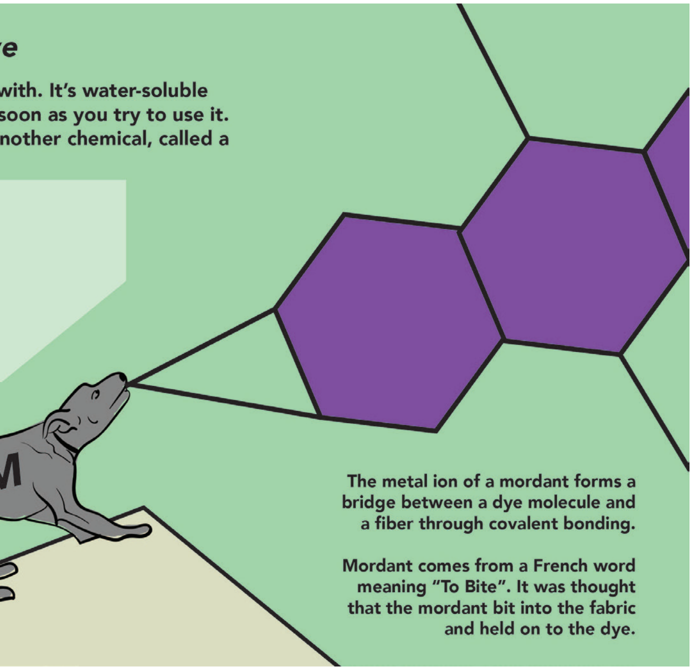



A quick panel introduces Flavin, what it does, and where its from

## *Locking Down the Dye*

**Flavin is a difficult dye to work with. It's water-soluble which means it will rinse out as soon as you try to use it. So a little help is needed from another chemical, called a mordant.**


Potassium aluminum sulfate, or Alum, is a common food preservative and mordant.




**The metal ion of a mordant forms a bridge between a dye molecule and a fiber through covalent bonding.**

**Mordant comes from a French word meaning "To Bite". It was thought that the mordant bit into the fabric and held on to the dye.**

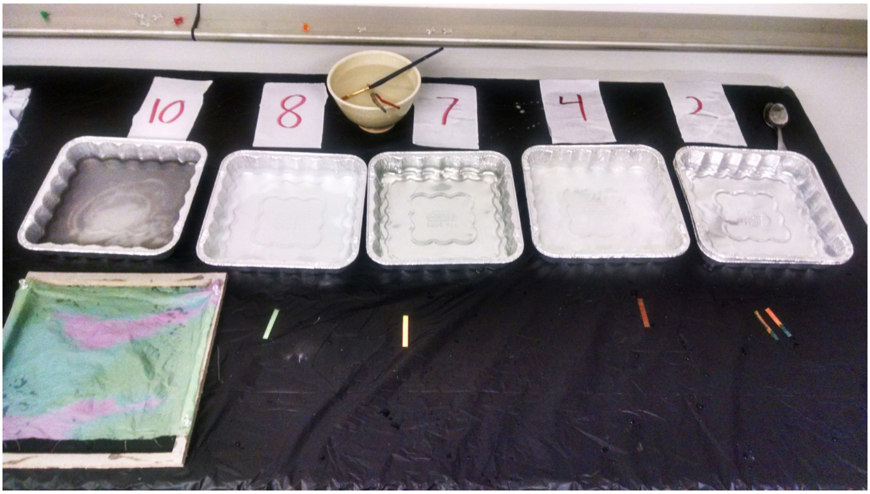
## *Test the Waters*

**How does cabbage-dyed fabric change in response to pH?**
**Can you make a pattern in your silk?**
**Will the color change and change back?**

**Experiment and find out!**

**Rules:**

1. Wear gloves when handling chemicals
2. Return brushes to their water once finished with them.
3. Do not drip acids or bases off of the table.
4. Make something amazing with the power of pH!




Pans of solutions from basic (left) to acidic (right).

# EVALUATION

(What did I expect? What results did I get?)

Expectations for this prototyping event were mixed. Due to time and material constraints, the event was not fully publicized, nor was the target audience for this thesis able to be present. However, the results of testing on an adult population seem to have hopeful implications for its use on a younger audience.

When asked about their typical relationship to chemistry, three participants mentioned using it as a part of another creative process (printmaking, baking). Three expressed disdain or fear ("I feel intimidated by it"). Two indicated a nonexistent relationship to the subject ("Nonexistent, but it's cool!"). One was a former chemistry teacher.

When asked if they liked the activity, all participants indicated that they did enjoy it. Reasons cited for enjoying it included the creative aspect of painting, the ability to take home the project, the lack of pressure to fully understand the underlying science, the new perspective on an old chemical concept, and the tactility of the material.

When asked how the activity made them feel about chemistry, six participants cited a positive emotional response ("Chemistry is cool!" "I felt awe" "Warm + Fuzzy"). Two participants cited increased curiosity about the subject ("Felt more intrigued, interested"). One responded with "Engaging for kids!".

When asked if they were curious to find out more about how the process worked, all participants responded in the affirmative.

When asked if they would like to see more chemistry related content in museums, all participants responded in the affirmative. Three elaborated further, stating a desire to "make chemistry seem less scary", a desire to "(learn about chemistry) via informal learning", and a desire for "more activities that show the 'magic' of chemistry"

The mean age of participants was 30 years old. All participants identified as female. All had completed bachelor's degrees, eight were working on or had completed master's degrees.

## TAKEAWAYS

(What do those results imply?)

Early results from this experience are promising. The universally positive reactions from all participants is telling that something good is there. However, the audience present for prototyping was entirely well educated adult women, many of whom were predisposed to creative endeavors. This does form a bias towards this type of experience.

For future rounds of prototyping, it would be important that this activity be performed with its intended audience, and in an exhibition context, whether that be within a museum, or as a pop-up in a school or community space. This kind of testing will get this project closer to true viability as an interpretive approach.

# EXHIBITION CONCEPT

Throughout this thesis, the relationship between material culture, chemistry, teenagers, and informal learning have all been explored. In the prototype, an experience was demonstrated. However, an experience in an exhibition setting must serve the goals of the exhibition and institution. It mustn't simply be a "cool activity" but a catalyst for learning, a moment of "bringing it all together".

When placing this prototype in a hypothetical real-world scenario, a number of options were considered. What would it do in a science museum? In a history museum? A design museum? There are possibilities for all of these locations. For the purposes of this example, a different location was chosen, for its unique challenges offered unique affordances.

**Location:**
Textile Museum at GWU in Washington DC

**Mission:**
Through exhibitions, programs, and academic courses, the museum integrates with diverse disciplines to enrich research, education, and cultural understanding both across and beyond the university. The museum also strengthens the established reputation of GW as a leader in training the next generation of museum professionals. Finally, it welcomes the public into the life of the university and, through its collections, creates

opportunities for exchange and collaboration throughout the world.

## Proposed exhibit:

*Cultures of Color:*
*Textiles at the intersection of Time, Place, Science, and Society.*

**Big Idea:** So many factors I never thought about can influence the way a culture uses color and cloth.

**Mission:** The exhibit aims to introduce a behind the scenes story of the web of factors that goes into textiles through several "snapshots" of different times and cultures. By gaining an "insider look" at these stories, set roughly 300 years apart from one another. From Medieval Europe, Edo period Japan, and 1960's America, exhibition content, historical artifacts, and hands-on experiences will encourage visitors to think differently about the fabric they experience in their day to day lives.

**Audience:** Textile Museum's primary audience of GWU students. Additional focuses on freshman taking general courses, and area High School audiences engaged in world studies, arts, and science.

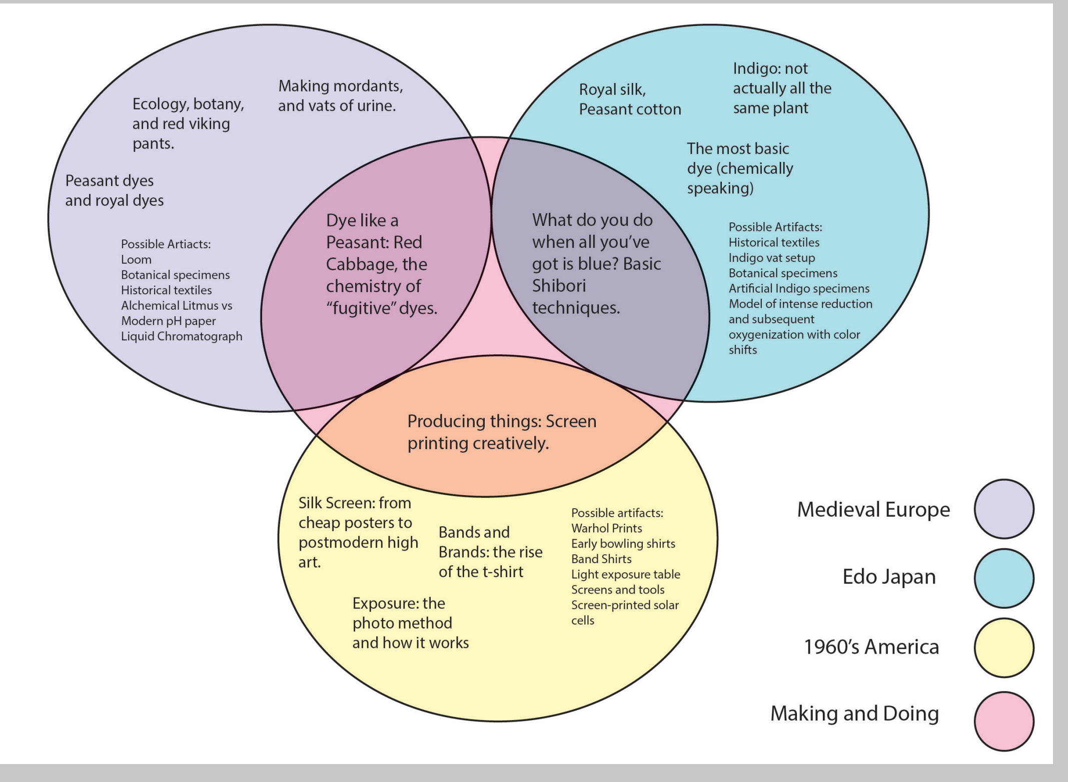
**Goals:**

- Visitors will encounter three very different ways to create color and pattern on cloth
- Visitors will be exposed to the stories of how each came to be.
- Visitors will be exposed to scientific concepts integral to those production methods.
- Visitors will be exposed to the ways those scientific concepts and production methods are a core part of the story of their societies.
- Visitors will have the opportunity to practice a piece of textile production from each section, and derive aesthetic experience, historical, and scientific knowledge from each.

## Development team needed:

- Medieval textile historian
- Edo period textile historian
- Modern fashion historian
- Chemist who works with colorants and dyes
- Textile conservator
- Designer/Developer
- Prototyper/Surveyor

## Bubble DIagram:



As evidenced by the bubble diagram, this exhibit would allow textiles to act as a springboard for conversations about social structure and class throughout history, and about science and chemistry through technique and application. As envisioned, each more traditional exhibition area would encircle the "exploratory" area. The area would most likely be set up for one experience at a time, allowing those engaged in it to get a richer experience, and enticing them to come back later to check out "the next thing" while taking in the exhibit information and artifacts in a new light, not as observers but as members of this club of textile workers. Ownership of the subject through making can establish a bigger target for empathy towards the historical and physical aspects of the exhibition, allowing the dusty tools and grey boxes to take on a lively glow, no longer alien but personal.

Left: A screenprinting workshop at the Fabric Workshop and Museum Right: a shibori workshop at Studio 8 in London

Other concepts for exhibition themes that can support this activity:

- *How do we know? How testing created the modern world*
- *Super Staples: the secret powers of our most common foods*
- *What's it pHor? Acids and bases from our fields to our faces*
- *1001 Ways to Dye: Alder, Xanthene, and everything in between*

Top: Medieval British Dyers (c.a. 1400's)

Middle: Two high-class women examine a length of shibori dyed fabric (c.a. 1790)

Bottom: Andy Warhol uses silk-screen printing to produce a Campbell's soup can. (1962)

# Conclusions

# Considerations for Practice

# CONSIDERATIONS FOR MUSEUM PRACTICE

Museums at this time are all engaged in the slow process of breaking down their silos and welcoming in the strange, the alien, the multidisciplinary. We are, as a field, questioning the ownership of history, what it means to engage in art, and how scientific learning really happens within our walls. That being said, change is dependent on time, money, and inertia. That considered, here are some takeaways that the field can think about, that may make all the difference in audience engagement and response.

- The march of progress is an uninteresting narrative for the modern audience. True stories are messy. Embrace the mess. Talk about the petty disputes, the egomaniacs, the reckless daredevils and the meticulousness that hardly seems human. History is a story about stuff but also about people. People love stories about people.
- Framing is everything. We've shown that "chemistry" alone is a poor way to entice an audience. Processes and materials that are chemical in nature are a good way to introduce the subject without scaring anyone off.
- The boundary between what is serious scientific content and what is a hands on activity is blurrier than one would think. A generation ago, chemistry was both a serious discipline and a household toy. The only thing that has changed since then is attitude.
- Scientific content is not limited to science museums! Don't be afraid to acknowledge and embrace that. The universe doesn't fit into our boxes easily. Why try to force it?
- Constructivism and making can, and should, come out of its designated corner within the museum and take a place within exhibitions as a tool for contextual learning.

- Teenagers are often served by science centers with after school programming and special activities, but rarely are their curricular needs addressed in a typical exhibition. Activities, clubs, and leadership programs serve mostly students who have an established interest in science and the time (and money) to participate. Including teenagers as a target audience from the beginning of exhibit development can serve to create an informal learning experience relevant to their needs, and help to assuage the sharp decline in interest in the sciences for the more general student population.

**Areas for future research:**

- How has constructivist learning been used in other museum contexts for any age group? What kinds of successes or failures did they encounter?
- What other processes, activities and approaches can serve as a “bridge” between science, history, and art?
- How does the “making and doing world measure engagement and outcomes from its participants? How can these rubrics be integrated with more traditional methods of measuring audience engagement?
- What would teens really like to see in a museum exhibition targeted towards them? Surveying required.

# CONCLUSIONS



Chemistry is sometimes called the invisible science. It hides under other sciences, forming their backbone, their methods, their tools, but it never takes the spotlight for itself. Not now anyway.

In a museum context, the role of chemistry is complex. The palaces of industry and technology designed to inspire the best and the brightest to pursue a life of science became outdated as museums evolved. "Chemophobia" became commonplace. The invisible science grew dimmer. Museums did not touch such an unpopular subject. Students general attitudes toward chemistry are of fear, mistrust, and boredom. Their teachers are unable to provide consistently positive extracurricular tie-ins to their subject matter, because very few exist. Students of chemistry in high school are at a critical time in their lives for identity development, and establishing a relationship of inquiry and understanding at this time in life can serve those students for the rest of their lives, whether or not they ever work in the sciences.

This thesis has made these assertions and sought out a means of addressing them. By using the tools introduced to the science museum by constructivism, the museum can provide chemistry based content that is accessible and relevant to visitors of multiple age ranges. With a location and program to visit, high school students can get an informal learning experience that allows them to think laterally and critically about how chemistry shapes their lives and the world around them. It can allow them to form a personal relationship with the tools and literal grey boxes of science, and in a moment of aesthetic experience, begin to unlock the psychological grey boxed they may have otherwise found themselves trapped in.

While the activity established in this text is one way of attempting to solve this problem, it is by no means the only available method. Its early success and promise show that the underlying chemistry of many things, perhaps anything, can become an access point for learners of any age, but particularly learners who are in the process of defining themselves within their chemical world.

# Appendix

# NOMENCLATURE

**Grey Box:** A piece of chemical equipment consisting of a (typically grey) metal box with buttons and dials on it.
**Grey Box:** A metaphorical zone of nonunderstanding, intimidation and ennui that comes from being told that you need to understand a thing, but are not given the tools to do so.
**Science Center:** An institution established for the purpose of educating the public about science. These institutions are experiential, heavily driven by visitor participation, and interactivity. They often do not consider collections to be of great importance to their mission. Their audiences, except for special adult programming, tend to skew towards younger children.
**Science Museum:** An institution that also has a scientific focus, but collections and scholarship from those collections are a major part of their mission. Their audiences tend to skew more towards older adults. They are often full of grey boxes.
**STEAM:** An acronym standing for Science, Technology, Engineering, Arts, and Mathematics. STEAM is a movement in education to promote cross disciplinary, design oriented, and critical skills in schools.
**Chemistry Demonstration:** A fairly common form of educational outreach in which a principle of chemistry is facilitated live by a member of the museum staff.
**Romantic Aesthetic** (Pirsig): Used to describe an aesthetic experience that is linked to an intuitive sensational event, such as the viewing of ne art or a grand landscape.
**Classical Aesthetic** (Pirsig): Used to describe an aesthetic experience that is linked to a logical and methodical event, such as figuring out a puzzle or fixing machinery.
**Stage 5:** A developmental stage defined by Erik Erikson as corresponding to what we typically consider to be late adolescence.
**Mordant:** A chemical compound used for dyeing that forms a bridge between a fiber and a pigment.
**Halochromic Pigment:** A pigment that changes colors in response to different pH concentrations.

# Survey for Chemistry Educators:

(Administered with Google Sheets through the American Association of Chemistry Teachers listserv)

## Unpacking the Grey Box Survey for Educators

Survey for chemistry educators for "Unpacking the Grey Box", a Masters Thesis Project

* Required

At what Grade Level do you teach? (Check all that apply) *

- ☐ 9th Grade
- ☐ 10th Grade
- ☐ 11th grade
- ☐ 12th grade
- ☐ College or University

At what type of educational institution do you teach? (Check all that apply) *

- ☐ District public school
- ☐ Private school
- ☐ Magnet school
- ☐ Charter School
- ☐ Homeschool/Tutor

Do you ever take your class on field trips to museums in the area? *

- Yes
- No

If yes, Which ones and why?

Your answer

If no, Why do you think this is?

Your answer

How would you describe your students overall attitude towards chemistry? *

Your answer

How do you think museum learning does or could affect students in Chemistry? *

Your answer

Is a narrative based, humanized view of your subject something that you would be interested in seeing in a museum setting? *

- Yes
- No
- Maybe

How do you think your students might respond to such a presentation? *

Your answer

# Unpacking the Grey Box Survey for Educators

* Required

## Demographics

Demographic data

Gender *

- ○ Male
- ○ Female
- ○ Prefer not to say
- ○ Other:

Age *

- ○ 18-25
- ○ 25-35
- ○ 35-45
- ○ 45-55
- ○ 55-65
- ○ 65+

Education Level Completed *

Your answer

Zip Code

Your answer

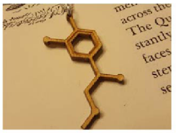
Additional Comments

Your answer

Optional thank you gift

As a deep thank you to all my participants, I am offering a hand written thank you note aa well as a molecule keychain of your choice. All molecules will be laser cut from 1/8" ply or 1/8" clear acrylic. Try to keep your molecules keychain sized (Oxytocin is very sweet, but it is too large for this process!). If you would like this gift, please specify your molecule of choice, name, and mailing address. Ship dates should fall around mid April.

Example (Adrenaline)



Write your gift option and mailing address here.

Your answer

# Educator survey results:

| Q1 Grade level taught | |
|---|---|
| | |
| 9th grade | 18 |
| 10th grade | 47 |
| 11th grade | 52 |
| 12th grade | 41 |
| College | 2 |
| | |

| Q2 What kind of school do you work at? | |
|---|---|
| | |
| District Public School | 40 |
| Charter School | 3 |
| Private School | 18 |
| Magnet School | 1 |
| Homeschool/Tutor | 0 |

| Q3 Do you ever take your class to museums in the area? | | |
|---|---|---|
| | | |
| Yes | 22% | 13 |
| No | 78% | 47 |

| Q3b If No, Why Do You Think That Is? | | |
|---|---|---|
| | | |
| Relevance | 36% | 17 |
| Money | 30% | 14 |
| Admin | 28% | 13 |
| Distance | 11% | 5 |
| Other | 13% | 6 |

| Q4 How would you describe your students overall attitude towards chemistry? | |
|---|---|
| | |
| Positive | 40% |
| Negative | 25% |
| Both | 22% |
| Neutral | 13% |
| | |

| Q5 How do you think museum learning does or could affect students in Chemistry? | |
|---|---|
| | |
| Life | 53% |
| Interest | 20% |
| Unsure | 10% |
| History | 5% |
| No | 3% |
| Other | 8% |

| Q6 Is a narrative based, humanized view of your subject something that you would be interested in seeing in a museum setting? | |
|---|---|
| | |
| Yes | 62% |
| No | 5% |
| Maybe | 33% |

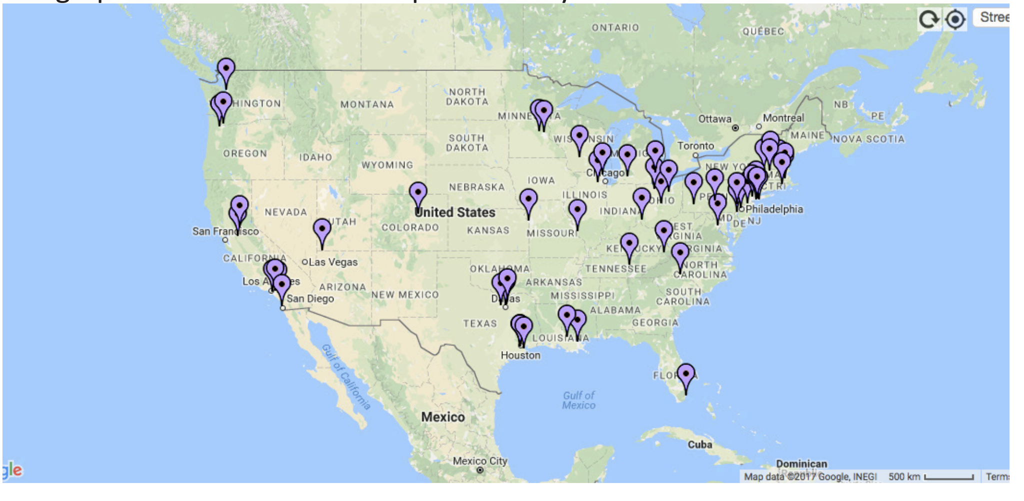
| | |
|---|---|
| | |

Demographics

| Education level | | |
|---|---|---|
| | | |
| Bachelors | | |
| Masters | | |
| Doctorate | 5% | |
| Certification | 2% | |
| Age | | |
| 18-25 | 3 | |
| 25-35 | 23 | |
| 35-45 | 19 | |
| 45-55 | 11 | |
| 55-65 | 4 | |
| 65+ | 0 | |

| Gender | |
|---|---|
| | |
| Male | 25% |
| Female | 75% |
| Other | 0% |

Geographical distribution of respondents by ZIP code



# Prototyping Survey Instrument

-----------------------------------------------------------

Creating through Chemistry is a prototype of a making experience. The text on the walls is meant to give you some context for what you can do, and I will be there to facilitate and answer questions, but not lead.

Feel free to do whatever you like, but observe the rules!

1. Wear gloves when handling chemicals
2. Return all brushes to their water
3. Do not drip acids or bases off the table
4. Make something amazing with the power of pH!

---

When finished, please take a moment to answer a couple of questions.

What is your usual relationship to Chemistry?

Did you like or dislike this activity, and why so?

What did it make you feel about chemistry?

Are you curious to find out more about how this process works?

Would you like to see more chemistry related content in museums?

Any additional thoughts?

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Age: Gender: Grade Level (or highest completed):

# Unpacking the Grey Box: Dye Experiments

One skein of white wool yarn was purchased and divided into ten roughly equal bundles. Two of each bundle were mordanted in one of 5 metal solutions according to the tables in "Natural Dyeing" by Jackie Crook.

| | |
|---|---|
| Alum: | 20g dry yarn<br>2g alum (potassium aluminum sulfate)<br>1.8g cream of tartar (tartaric acid) |
| Chrome: | 22g dry yarn<br>1g chrome (potassium chromate) |
| Copper: | 20g dry yarn<br>1g copper (copper sulfate pentahydrate)<br>1oz white vinegar |
| Iron: | 20g dry yarn<br>0.5g iron (ferrous sulphate) |
| Tin: | 21g dry yarn<br>0.2g tin (stannous chloride) |


Weighing alum and cream of tartar

During the mordanting process, the dissolved metal solution is placed into a pot with the yarns, brought to a simmer for 1 hour, and then left to cool.

*Note: It is ill advised to use dye pots for anything but dyeing, as the metal compounds are potentially toxic. The exception to this is alum and iron, which are both food safe.*


It is interesting to note that specific mordants, such as chrome and iron, lend their own colors to the yarns. However, these colors do not "blend" with the final dyes, the way overdyeing a color with another color would. Cool chemistry here!


Red cabbage and yellow onion were chosen for this experiment. This is due to ease of access (they are both available at the supermarket) and for their very different color effects.


The dye recipe called for a 1:1 ratio of dyestuffs to dry weight of material. 100g of yarn was in each pot. I was easily able to obtain 100g of red cabbage. 3 leaves was plenty. However, the onion skins weighed so little that I was only able to obtain 41 g total. This turned out not to be a problem, however. The colors showed up stronger with the onion than the cabbage!

The dyestuff was roughly chopped and set to simmer for 1 hr., then set aside to steep and cool.

Once drained of solids, the dyes were added back to the pot with the mordanted yarns. These were left to simmer for another hour, then cool.

Hung to dry, the yarns express a range of colors.


The finished yarns.

## Conclusions from this activity:

For me, this was great fun. However, it took multiple sessions of bringing things to a boil, letting them cool down over the course of several hours, and doing it again. The ideal mordanting time is "overnight", so this process took an entire weekend. This is much too long for an activity, and if parts of the process were removed (weighing the powders, boiling them, making the dye, dyeing the yarn) it would turn a deeply involved process of creation into the dyeing equivalent of making top ramen instead of pasta. It's good chemistry, and it's really fun, but I cannot recommend its use in a makerspace or museum exhibition setting. There is also the toxicity problem. While alum and iron are safe enough to work with, and can be dumped down a sink drain, tin and copper can be harmful if breathed in as fumes or if allowed to touch the skin and must be dumped on waste ground. Chrome is absolutely the worst, and if worked with in large amounts would necessitate hazardous waste removal. So for safety reasons too, I can't recommend this as a minimally-mediated activity.

Disheartening, but there was one more experiment to try.

*modifiers*

You can make color changes to dyed fabrics and fibers by gently heating the dyed and rinsed material for five minutes in one of the following modifier solutions. Then rinse it again before drying. Note, however, that the color may not remain true if the dyed material is washed in a liquid with a different pH level to the pH of the modifier, either more acidic or more alkaline.

The effect of modifiers varies with the original plant material used, but generally an alkaline modifier (washing soda) shifts the dye shade towards blue; an acidic modifier (vinegar) shifts the dye towards red; and an iron modifier darkens or dulls the dye color.

| | |
|---|---|
| **Clear vinegar:** | 1 tsp per ½ pint (250 ml) water |
| **Washing soda:** | 1 tsp per ½ pint (250 ml) water |
| **Iron:** | ¼ tsp per ½ pint (250 ml) water |



At the bottom of a page in the dye book, was a small called out section mentioning that after-dye modifiers can be used to shift the color of certain plant dyes. It used red cabbage dye as a direct example so I thought it was worth a try.


The small pieces of alum-mordanted yarn were dipped in an acidic bath (white vinegar), and an alkaline bath (washing soda). The color shift was immediate and dramatic, and the materials used were all minimally toxic (washing soda is not edible, but it will not harm your skin).

After researching cabbage dye, its role as a pH indicator and as a common feature of many lab exercises, I repeated the red cabbage experiment on medium weight silk fabric.

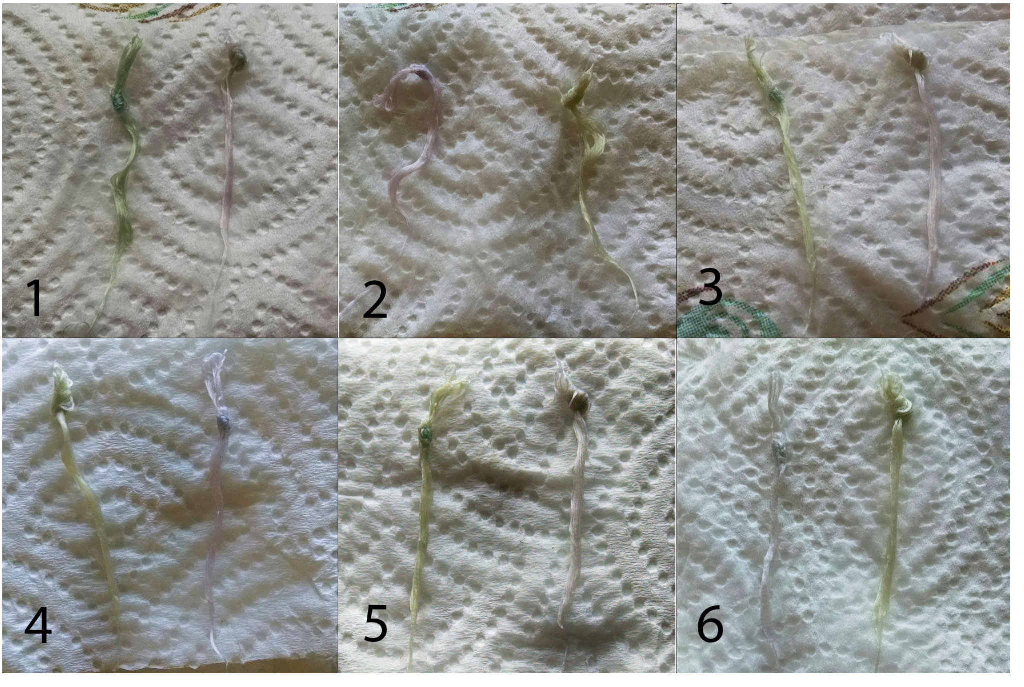
Mordanting in alum, then dyeing the silk.

Finished dyed silk.
Once dry, loose fibers were taken from the silk to perform pH testing on.


An alkaline solution of washing soda (pH ≈ 10), distilled water (pH ≈ 7) and white vinegar (pH ≈ 4) were mixed in glass containers. Bundles of silk fibers were left to soak in these solutions for 5 minutes.

The results were immediate and striking, as with the wool yarn. However, the colors created on silk are more lustrous and strong than those created in wool. A few spare fibers were selected to attempt another test: how many times can this fabric shift back and forth?

*Note: The alkaline solution is overly strong and does not need to be that way. A pH of 9 would result in a stronger yellow-green and preserve color-shifting ability for longer.*




Small clumps of silk fibers were switched back and forth from alkaline to acid six times with a rinse in neutral water in between. Each time, even to the end, the color did change. However, each time, the resultant color lost some pigmentation. Considering that fibers are always darker when wet, the clumps in panel six are barely pigmented at all.

## Conclusions from this activity:

The silk takes up the dye well, changes color well, and keeps changing color pretty well. This activity provides affordances for creativity while engaging in a type of chemistry that results in something tangible and beautiful. While there are many potential ways to place chemistry into a museum setting, this is the one I have researched, and this is the one that I will pursue.

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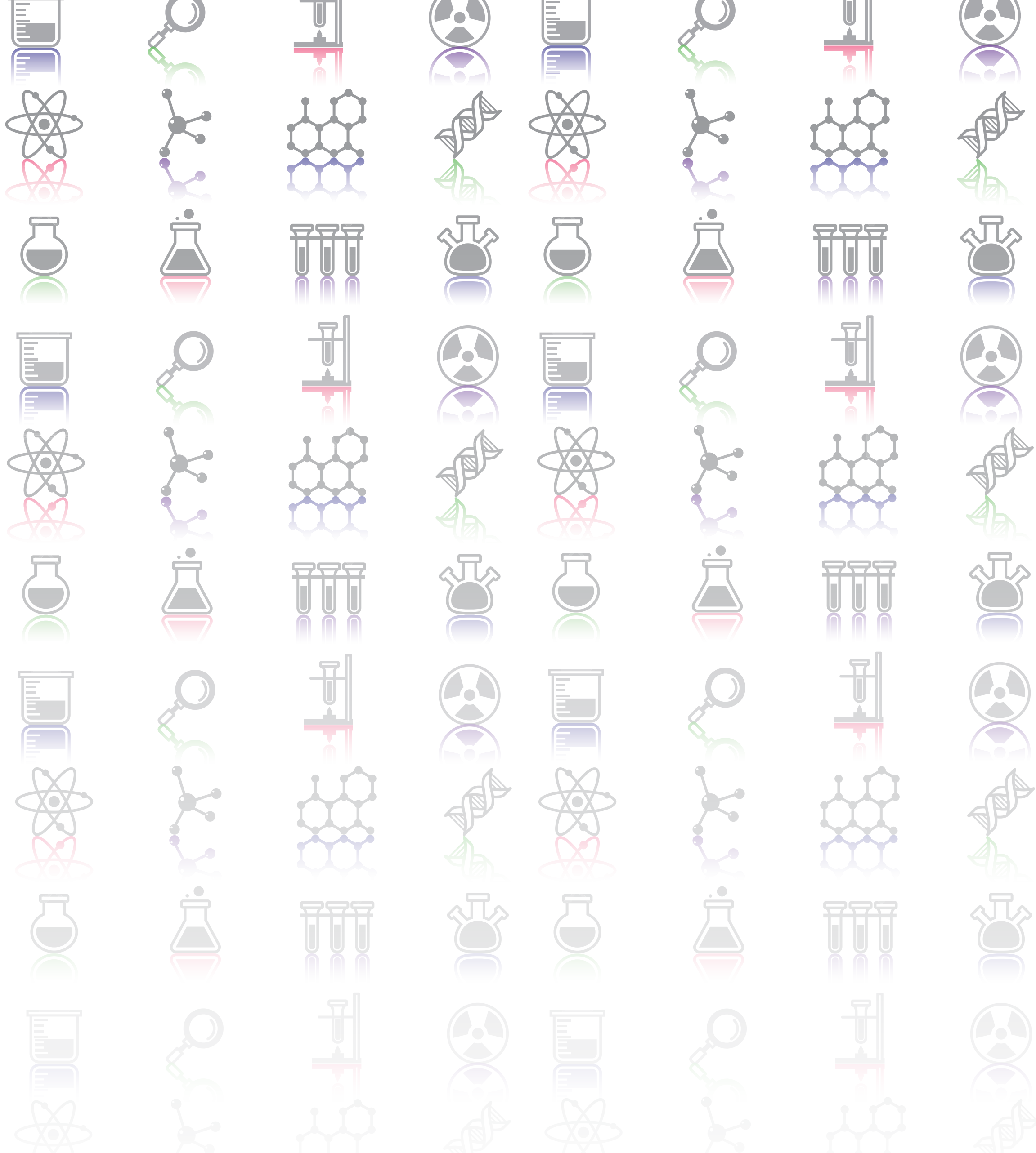

Unpacking the Grey Box attempts to link an underserved topic in science exhibitions (Chemistry) to an underserved audience in exhibitions (Teenagers), to the benefit of museums, schools, and the teens themselves. As we progress, science literacy remains critically important to the health of our society. By providing positive, thorough, and relevant experiences with chemistry to teenaged audiences, museums can contribute to the continued engagement of people with the subject of chemistry and its application in the world at large.