CARDBOARD COLLABORATIVE

A guide to creating more inclusive museum makerspaces

Science Museum of Minnesota®

IMAGINE A SPACE FILLED WITH CARDBOARD AND ENDLESS POSSIBILITIES...

We wanted to build a space where early engineering and creativity thrive. We've worked for over ten years to build an inclusive makerspace that works for a diversity of visitors, and can work in many different settings. We've tested and iterated to make it a reality, and our iteration continues. This guide shares some of the successes and challenges behind Science Museum of Minnesota's Cardboard City exhibition and our partnership with museums across the country through Cardboard Collaborative.

What's in this guide?

This guide has a little bit of everything for putting together a cardboard makerspace experience. Everyone should start by checking out the SMM Making Design Principles, as they are the signposts to everything that follows.

Most sections, including this welcome page, share the 'What' - the key concepts or ideas, the 'Why' - the importance of those ideas to visitors or our colleagues, and the 'How' - the nuts and bolts to replicating pieces of our design and overall ethos.

Why 'more families, more museums'?

The underlying motto of our work has been 'more families, more museums' – how can we be deliberate in developing a makerspace experience that works for a diversity of visitors and for more museums to take on these inclusive design principles? We intentionally partnered with organizations who work closely with BIPOC families, and much of the visitor feedback we share in this guide comes from Cardboard Engineering Family Days held collaboratively with these community partners. We also partnered with three other museums that differ geographically and in organizational size from the Science Museum of Minnesota. We share here inspiration and feedback from moving our design principles to new sites with their own sets of successes and challenges.

How can I get the most out of this guide?

The table of contents on the next page provides an overview; here are a few helpful tips to navigating this guide:

First, check out the **Making Design Principles**, which are research supported strategies for engaging many learners with different needs in making – how might they challenge ideas you had about designing a makerspace; what ideas would you want to try out in your spaces?

If you're looking for information about how we put things together – our staffing philosophy, community informed design, materials management, fabrication and more – look at **People, Materials, Process**.

We also provide **Activity Guides and Inspiration** if you are looking for straightforward guides on implementing cardboard activities. How can you take Cardboard City and inspire STEM learning in your context?

TABLE OF CONTENTS

Recommended Citation: Bequette, M., Geake, L., Goeke, M., Lukowski, S., Callahan Schreiber, R., & Schmit, B. (2023). Cardboard Collaborative: A guide to creating more inclusive museum makerspaces. Science Museum of Minnesota.

You can access all the Cardboard Collaborative materials at smm.org/cardboard-collaborative.
This material is based upon collaborative work supported by the National Science Foundation under Grant #1906884, Building More Inclusive Makerspaces to Support Informal Engineering Learning Experiences. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

MAKING DESIGN PRINCIPLES

Our research supported strategies
to building a more inclusive makerspaces

Science Museum of Minnesota®

IF YOU WANT TO DESIGN A DROP-IN MAKERSPACE THAT IS INCLUSIVE TO A VARIETY OF FAMILY NEEDS, YOU SHOULD TRY TO...

Focus on **rich materials**

Acknowledging the role that materials and tools play in making, "rich" materials are widely available, do not require specialized tools for manipulation, and can be used for a variety of functions.

The Benefit
Allows for continued making outside of the makerspace and supports creative engagement.

Include **example pieces**

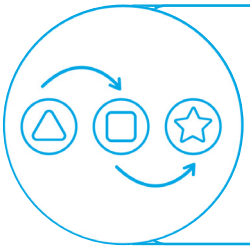
Physical creations seeded in the space that show a variety of skill levels.

The Benefit
Serves as inspiration for what to make and an information source for how to make with particular rich materials.

Include open-ended **activity prompts**

Any sort of museum-provided direction as to what to make, ideally ranging across assembly, creative construction, and tinkering-style prompts.

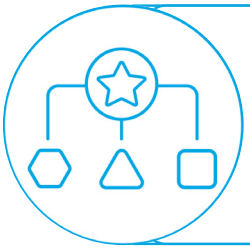
The Benefit
Provides an entry point into making for people who need more structure or guidance in order to get engaged.



Use **icons** to convey information

Using accessible icons in instructions instead of words whenever possible to provide support for visitors.

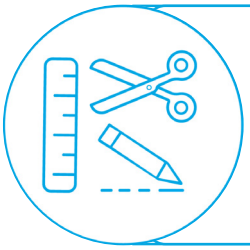
The Benefit
Supports accessibility for visitors who are preliterate or who read languages other than those provided.



Provide opportunities to **contribute to something larger**

Clear opportunities and invitations for visitors to leave something behind as part of a collaborative effort.

The Benefit
Communicates honor and value for visitor-made creations.



Provide **workstations** for making

Provide a full complement of tools, supplementary materials, and seating at each family workstation.

The Benefit
Supports accessibility for visitors with limited mobility and ease of locating tools for making.

If you want to design a drop-in makerspace that is inclusive to a variety of family needs...

FOCUS ON RICH MATERIALS

What is it?

Rich materials refers to the role that materials and tools play in making. Specifically, we consider a material "rich" if it has the following characteristics:

1. Widely available, which allows for continued making outside of the makerspace
2. Does not require specialized tools for manipulation, which again allows for continued making outside of the makerspace
3. Can be used for a variety of functions, which supports creativity

Our makerspace always centered cardboard because it was identified as part of existing BIPOC family making practice in the Making Connections project, but the theme of rich materials could be extended to any material that provides relatively easy on-ramps to making yet also supports highly sophisticated practice.

Why is it important to visitors?

Familiarity — both with materials and tools — shaped how families engaged in this makerspace. Based on survey data collected at the 2021 makerspace events, the majority of makerspace visitors already enjoyed making in their everyday lives, and 25% reported having personally made something out of cardboard in the prior year. During making, we saw some evidence that visitors were more familiar with tools such as the scissors and roller for perforation — which looked like a "pizza cutter" — including use of these tools independently (without need for staff demonstration) and earlier in their making process. Unfamiliar tools such as the klever cutter (safety box cutter) needed some onboarding by staff, but were adopted rapidly, proficiency easily achieved. Finally, visitors who engaged in a follow-up interview offered stories of how their families continued to make with cardboard after the makerspace experience, including creating a cardboard "slide" from a bunk bed.

What does it look like in practice?

In practice, providing rich materials involved storage of copious amounts of materials and some figuring out of specific materials. For example, we found that with new cardboard, a particular cardboard heaviness — E-flute with light substrate — worked best for minimal tool manipulation, and we needed 39 miles worth of tape for a three-month makerspace.

Material storage room in 2021

Creative Use of Tape

Tape is a central feature of the cardboard makerspace. Originally selected for its use holding cardboard together, tape has proven to be another rich material with visitors innovating new creative uses for it in their making. While the first 2015 makerspace iteration only included blue painters tape, the 2016 makerspace introduced tape of multiple colors. Early in the three-month run, a museum staff member wrote “Be Creative” with tape on a black makerspace wall, and thus, Tape Graffiti was born! In 2021, the makerspace was held in a sunlit room. Instead of Tape Graffiti, visitors spontaneously created a Tape Stained Glass area, using tape’s translucent quality as a new affordance.

This visitor used tape’s sticky quality to give their graffiti a 3D quality.

Visitors used the tape’s translucent quality for artful making.

How does it relate to theory?

A makerspace is fundamentally shaped by the materials and tools housed within. Specifically, materials shape making in three ways: existing relationship or familiarity, overall physical affordances and constraints, and the in-the-moment process of becoming. First, people live in a material world and may enter the makerspace having already experienced a material, including for making purposes. As noted earlier, our choice of cardboard as the primary material was based on existing familiarity; participants in the Making Connections study explicitly named cardboard as a material they used for making (Bequette et al., 2018). Second, affordances and constraints can be understood as what is easy or difficult to do because of the physical properties of a material.

For example, the filament used in 3D printing (PLA) melts at 180° Celsius or 356° Fahrenheit, which is an affordance. However, in order to perform the additive fabrication style of 3D printing, the maker needs to have a small amount of the filament reach that temperature at a particular time, which is a constraint. While all materials have affordances and constraints, we emphasize minimizing the constraint of specialized tools for manipulation because that constraint holds greater threat of limiting at-home making. Finally, making is a process of becoming for both the person-becoming-maker and the material-becoming-creation. Posthuman perspectives highlight that human and materials are enmeshed in complex intra-action (Barab, 2003); when making, people leave their imprints on materials, and materials make imprints back. A posthuman perspective on rich materials would focus on how a maker comes to know and create with a particular material and how that material contributes to the making process.

How have SMM's thoughts changed over time?

> *It's like an imagination vessel, and environment for creation. You don't need many materials for an imagination vessel. The box can be a car. It can be a plane. It can be a rocket. It can be a house. It is everywhere and it can be anything. (Goeke & Braafaldt, 2019; internal report)*

Our choice of which cardboard to provide has evolved. The early makerspace iterations focused on cardboard boxes to evoke connections to at-home making, that children often spontaneously engage with cardboard as an imaginative material. In earlier iterations, cardboard was always supplied in box form to support those connections. Relying on donated cardboard reduced the overall cost of the makerspace, but typically required a prolonged period of collection and storage ahead of the exhibition. In 2021, we shifted to providing primarily "clean" cardboard sheets, meaning new cardboard donated through a sponsorship. This decision was made for two reasons: 1) as the makerspace was opening during the COVID-19 pandemic, "new" cardboard was potentially more comfortable for visitors, and 2) we wanted our visitors to see the experience we provided as high quality, not as providing cast-off materials. We have not seen a change in engagement based on the form of cardboard; the material itself is rich, not how it looks.

Additionally, materials are supported by tools, and in the Cardboard makerspace, we provide a large number of a select set of tools to support cardboard making. In the initial iterations, these included safety scissors, cardboard saws, and masking tape. By the 2018 iteration, we had settled on safety scissors, safety klever cutters, and tape in a variety of colors as the core tools. In 2021, we added pencils, rulers, and a roller for perforation to the toolbox (see Workstations section below for greater detail).

If you want to design a drop-in makerspace that is inclusive to a variety of family needs...

INCLUDE EXAMPLE PIECES

What is it?

Example pieces are physical creations seeded in the space. Ideally, example pieces will show a variety of skill levels, such that visitors can see the "floor" and "ceiling" of possible creation with a material. Example pieces may be created by museum staff or visitors.

Why is it important to visitors?

When visitors enter the cardboard-focused makerspace, we have anecdotally noted that visitors will explore the space and existing creations before settling into making themselves. These examples serve as direct inspiration for what to create. For example, adults sometimes direct children to look at examples to spark making ideas or families will first play with existing creations before making their own version (Lukowski et al., 2023). Example pieces are also used to understand how to make something. For example, our shadow puppet theater activity did not include instructions for how to make puppet, but pre-built examples available in the theater demonstrated the critical construction techniques.

What does it look like in practice?

2021: Hanging example made by staff

2021: Cityscape tables held staff and visitor-made examples

2018: Artist-in-residence

2021: Wall-mounted example piece, made by staff with a visitor-added bee

Parallel Making of Guitars
We encouraged staff to create example pieces while working in the makerspace both to seed complex examples and to generate embodied experiences of cardboard creation. When talking about facilitation of the space, one of our core staff facilitators, Jonah, shared the story of creating a guitar while working in the makerspace. While he made it, young visitors would come up and ask if he would make a guitar for them. Jonah would say, “No, but you can make your own.” This story — creation becoming inspiration becoming a new creation — is exactly the process example pieces are intended to serve.

How does it relate to theory?

Example creations reveal the complexity of how to make with a material and serve as inspiration pieces for what to make. In maker education where persistence through failure is a central value (Dougherty, 2013; Martin, 2015), designers need to actively decide where there is more meaningful and less meaningful struggle for learners in order to manage levels of frustration (Anderson et al, 2019). Example pieces address two core sources of frustration in making: deciding what to make (Sawyer, 2017) and understanding how to make. Any example piece, from a helicopter created by an artist to a robot created by a preschooler, can provide the spark of inspiration for a new helicopter, robot, or maybe a combined flying robot. Including highly complex creations where learners can look closely at how a more expert maker created an object alleviates some questions about how to make. In both cases, educators may be concerned that learners are “just copying” examples. However, learning in a makerspace is all about participating in construction. Even if a learner is creating another robot, their robot is unique and they have to figure out how to construct something that meets their vision (Keller & Keller, 1996). Even if a learner is replicating a technique used in an example, they have to fit that technique into their own plan. The inspiration and know-how supplied by example pieces are building blocks supplementing making, not overtaking making.

How have SMM’s thoughts changed over time?

While visitors had left behind example creations in early iteration, 2018 was the first intentional introduction of examples in the form of artists-in-residence, a creation display area, and a techniques board. The artists-in-residence program highlighted complex cardboard making, while the creation display area honored the making of museum visitors. The techniques board supported initial making.

In 2021, as we shifted to a themed makerspace (see the Contribution to Something Larger section for further detail), we shifted to premade example pieces. Example pieces included high sophistication items installed out of reach of visitors, such as a whale and city arch, and seed creations interspersed with visitor creations, such as Spider-Man on a construction crane or wearable hats. The example pieces were created by SMM fabrication and facilitation staff who eventually worked in the makerspace with the public, supporting staff buy-in around the makerspace.

If you want to design a drop-in makerspace that is inclusive to a variety of family needs...

INCLUDE OPEN-ENDED ACTIVITY PROMPTS

What is it?

Activity prompts are any kind of guided direction on what to make. They may be highly specific or more open-ended. Open-ended activity prompts are a powerful tool for balancing novice-maker's need for direction and expert-maker's desire for open creativity.

For example, consider two prompts for a car-making activity. A more specific prompt may read "make a car that travels down the ramp at exactly 1 mile per hour." In this case, item, setting, and success conditions are predetermined and presented in the prompt. Alternatively, the prompt may read "make a car that works on many terrains" (this prompt was actually used in in our Cardboard City makerspace). In this case, the item is predetermined but the maker gets to determine what terrains or settings to consider and how to define the success condition.

Why is it important to visitors?

Activity prompts give direction for what to do in the makerspace. Our makerspace included a range of making activities — from completely undirected making, lightly prompted creation of a cardboard city, wearable and theater stations where examples showed specialized construction techniques, and a Gravity Racer activity with step-by-step instructions for vehicle assembly. The variety of activities created multiple entry points for engagement so that families with different preferences and comfort with making could locate an activity suited for their needs. Importantly, because activity prompts were phrased in an open-ended way, there were no "wrong" forms of engagement; creations such as political flags and dinosaur models were not intended by the designers of the makerspace, but they were embraced by visitors.

The Gravity Racer activity was undoubtedly the most popular activity in the Cardboard City makerspace. Physically, it involved pre-cut wheels of multiple sizes, an icon based graphic, square cardboard sheets to cut the car body from, and a ramp to test creations. In surveys and interviews with families who experienced the makerspace before Gravity Racer was installed, families with young children (ages 4-7) and families with less comfort or enjoyment in making talked about needing more direction. The families who returned and experienced the Gravity Racer activity described it as providing that needed direction. The provision of any type of intentional prompt in this makerspace was new for the museum, and we are continuing to explore how to balance providing direction and encouraging creativity. We are not advocating that all activities fall into assembly-style making, but having at least one assembly-style activity provides an entry point for those less comfortable with making practices.

What does it look like in practice?

Below are prompts created for three activities in the Cardboard City makerspace showing how the same base activity can be evoked with assembly, creative construction, or tinkering style prompts.

Wearables

Creative construction prompt

A hat that fits your mood

Make a hat for a special occasion or just for fun. Try it on and model it on the runway.

How does it look? How does it fit?

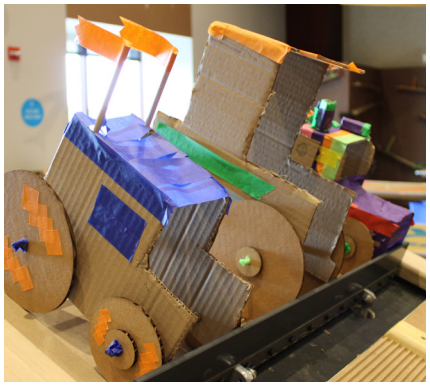
Does it stay on your head if you jump up and down?

Tinkering prompt

Inviting imagination

This is where ideas can come to life, from one-of-a-kind fashion items toworld-changing machines. What will you make?

Gravity Racer



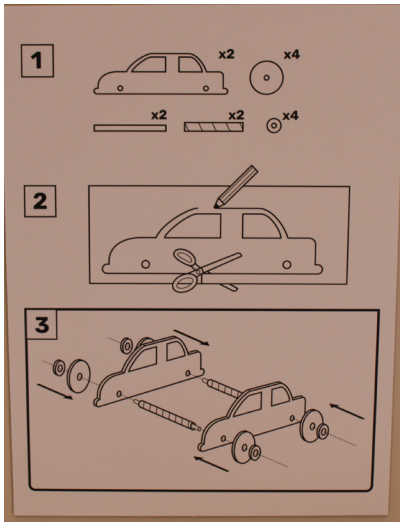
Creative construction prompt

This city is known for rough roads and steep slopes.

Build a vehicle that can safely reach the bottom on any road condition.

Assembly prompt

A graphic shared assembly-style instructions



Creative Cars

Providing an open-ended prompt does not limit creativity. With the Gravity Racer activity, we observed visitor-generated goals concerning the speed of the car (i.e. make the car go faster than other cars) that contrasted the written prompt concerning "safe" descent. Second, while the icon-based instructions showed a single style of car, visitors widely expanded upon this form, as can be seen in the examples below. Providing a prompt does not restrain creativity as long as materials can be used in many ways.

How does it relate to theory?

It does not take large conceptual leaps to understand that different types of making require different skills and produce different learning. Bronwyn Bevan (2017) talks about educational making as a trajectory of skill development with STEM making activities falling into one of three categories: assembly, creative construction, and tinkering.

Assembly-style making is characterized by a preset design goal and construction steps, often looking like off-the-shelf kits with step-by-step instructions. Close-ended, assembly style making supports skill development and building material fluency. Creative construction is characterized by a general preset goal but opportunities for creative agency. Creative construction making supports skill development related to the predetermined elements and development of problem solving and creativity skills. Finally, tinkering style making is entirely open-ended, with the maker determining their own goal and requiring creative and skillful use of materials to achieve it. Tinkering is prioritized in educational making, but it relies on skills developed via assembly and creative construction style making to prevent complete frustration. Recognizing that a museum makerspace needs to engage both novice-makers and expert-makers, activity prompts across the makerspace should hit on each of the three categories.

How have SMM's thoughts changed over time?

While earlier makerspaces at SMM emphasized open-ended creation, including a variety of activity prompts provides multiple entry points for families with different needs. Until 2021, no explicit prompts were supplied in the makerspace. At times, a volunteer-led activity was available in the space, but nothing in the makerspace design directed visitors on what to make. The addition of light activity prompts was directly intended to support visitors who may have less existing practice in making and/or are unsure where to start in the space. The activity prompts were based in five activity areas: shadow puppet theater, ball run, wearables, Gravity Racers, and city skyline buildings. These activities can be seen as generally supporting one of Bevan's (2017) three types of maker activities: Gravity Racer is assembly, puppet theater and wearables are creative construction, and ball run and city skyline buildings are tinkering. Each prompt involved light narrative connecting it to the city theme and opportunities for engineering challenges (i.e. "safely reach the bottom" or "stay on your head").

If you want to design a drop-in makerspace that is inclusive to a variety of family needs...

USE ICONS TO CONVEY INFORMATION

What is it?

Icon-based labels refers to the intentional use of static images to convey information instead of written text.

Why is it important to visitors?

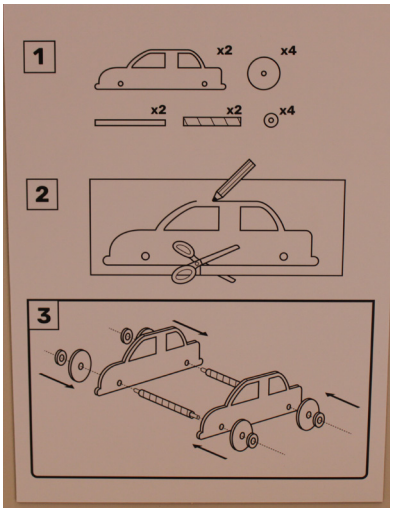
With the activity prompts, icon-based graphics for instruction are more accessible for preliterate visitors, visitors who read a language other than those provided, and visitors who are uninterested in reading signs (sign fatigue). Additionally, icon-based graphics may be advantageous for demonstrating actions. In the Gravity Racer activity, we provided basic step-by-step instruction through icons. In video data with this activity, we specifically saw children using the icon-based label as a reference point for engaging in making and conversation with adults. In future iterations, we are considering how icons can be used to communicate more ideas — such as how to use less familiar tools like the safety klever cutter and roller for perforation — for supportive on-ramps for making.

What does it look like in practice?

2018: Joinery technique board

2018: Decorative technique board

2021: Joinery technique board



2021: Icon-based assembly instructions

Wheels on the Car

Icon-based labels can be used by preliterate children to participate in family making in ways not necessarily possible if information is only conveyed via text. One Family Engagement Partner visiting the 2021 makerspace recorded their interactions while gathering materials to make a car. While the adult in this group is listing out the materials to collect, she directly points at the icon-based label. Her 5-year-old daughter notices that the adult miscounted the number of necessary wheels, pointing again at the icon-based label. While this moment is not momentous, the icon-based label usage supported the mother and daughter's joint participation in the act of gathering materials.

How does it relate to theory?

The benefit of pairing imagery with text for learning is well documented. Here are a few research findings noted in Connie Malamed's (2015) book on using visual design in learning contexts:

- The pairing of text with relevant visuals produces better learning than text alone
- Visuals capture and hold attention longer than text alone

Turning to visuals without extensive text, major companies such as IKEA® and LEGO® both use icon-focused instructions to convey how to build their complex products (Pavlus, 2015). Generally, information is conveyed best when cognitive load — or the amount of work someone has to do to understand — is reduced. This reduction is facilitated by reducing extra material and redundancy, highlighting essential features, and increasing contiguity across representations (Mayer, 2008).

When investigating how to convey human/motor manipulation — such as knot tying or origami — specifically, the research evidence is somewhat mixed in terms of best practices. Preservation of movement is critical, either through display in a dynamic visualization (i.e. video clip; Wong et al., 2009; Lee & Shin, 2012) or through display of movement icons (Michas & Berry, 2000).

How have SMM's thoughts changed over time?

As a museum, pairing images with text is common practice (Piehl, 2020). Signs identifying available tools included images of those tools in the early makerspace iterations (2015 and 2016). However, the joinery techniques board developed for the 2018 makerspace iteration was the first attempt in this development trajectory to convey information about how to make through images alone, no paired text to repeat the information. The joinery techniques board included a title for the technique, such as "slot," and a physical representation. When the technique required two actions, such as cutting slots in two cardboard pieces and then wedging them together, two physical representations were connected with mathematical symbols, such as plus or equals signs. In 2021, the use of icons was taken to a new level, with arrows indicating assembly processes.

If you want to design a drop-in makerspace that is inclusive to a variety of family needs...

PROVIDE OPPORTUNITIES TO CONTRIBUTE TO SOMETHING LARGER

What is it?

Opportunities to contribute to something larger may look like areas to leave creations as examples or to collaborate on larger structures. These designated areas convey a sense of honor and elevation of visitor-created pieces, and are distinct from making workstations.

Why is it important to visitors?

Visitors spend considerable time in museum makerspaces, and this investment is enhanced when visitors feel that creations they leave at the museum continue to be honored and valued. Earlier iterations were harder on museum staff members, in part because they witnessed visitors pour labor into a creation and leave it for others to enjoy, only for another visitor to remix the creation. The initial display area (2018) provided an opportunity for staff who observed visitors spending extra care on their creations to select and reward those works. After seeing the display, many visitors wanted to add their items. Thus, we adjusted practice so that any creation could be placed on display. We heard the value of the change during our 2018 Member Study, when members in focus groups talked about Cardboard Engineering being a highlight experience at the museum because of the chance to contribute to something larger. In 2021, the opportunities to contribute to something larger were focused on leaving example pieces at each of the activity zones, with contribution to the collective “City Skyline” being a focal opportunity.

What does it look like in practice?

2018: Creation display area

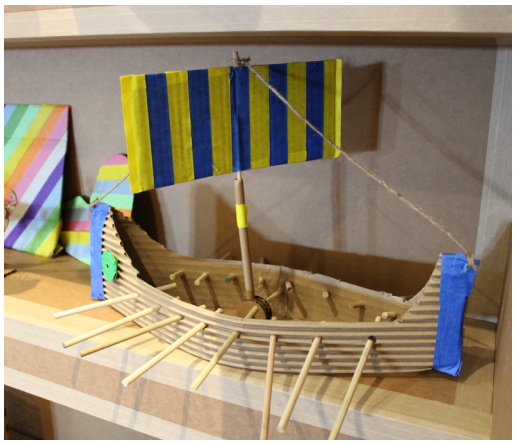
2021: City skylines

2021: Welcome graphic

Staff Curation in Cardboard City

The Cardboard City exhibition had multiple areas where visitor creations could be honored and become part of the growing, collective space. These included cityscape tables where visitors could leave their creations to be part of the city, a 'garage' shelf near the Gravity Racer ramp where cars were left behind, and a set of shelves near the entrance that highlighted visitor creations.

Staff were crucial in curating these spaces, selectively recycling some creations and keeping others at the end of each day. While this practice generated example pieces for future visitors, it also prevented us from being overrun with creations across the 3-month exhibition run.



How does it relate to theory?

In educational making, process is more important than product (Honey & Kanter, 2013). In reality, any creation left behind in a drop-in makerspace is disposed of, either through remixing or waste. However, people feel strongly about items they create. The "IKEA effect" is a psychological phenomenon where people value items they have poured labor into over identical items made by another (Norton et al., 2012). The IKEA effect has been documented in children as early as 5 years old (Marsh et al., 2018). Additionally, it is not moderated by effort. A person can put a low amount of effort into creating something and still value it more than an identical item they did not create (Marsh et al., 2018). Recognizing the IKEA effect produced in a makerspace, having the disposal of a high effort creation being front and center can create negative feelings. Opportunities to contribute to something larger physically elevates visitor creations in a similar way to their personal elevation of it, even if that display is temporary and the item will ultimately be disposed of as well.

How have SMM's thoughts changed over time?

In 2015, the collective project involved large fort building, while later iterations emphasized remixing existing projects (2016), tape graffiti (2016), and inclusion in the creation display area (2018). In the museum's 2018 Member Study, members named the cardboard makerspaces as a highlight of their multiple museum visits, specifically because it prompted contribution to a larger or ongoing creation. The 2021 makerspace built on this insight with the introduction of a theme. For example, Cardboard City included city skyline display tables where visitors could leave their building. Additional themes such as "space" were explored for future iterations. The photowall used in Cardboard City (2021) also supported the sense of contributing to something larger for visitors who chose to take their creation home.

If you want to design a drop-in makerspace that is inclusive to a variety of family needs...

PROVIDE WORKSTATIONS FOR MAKING

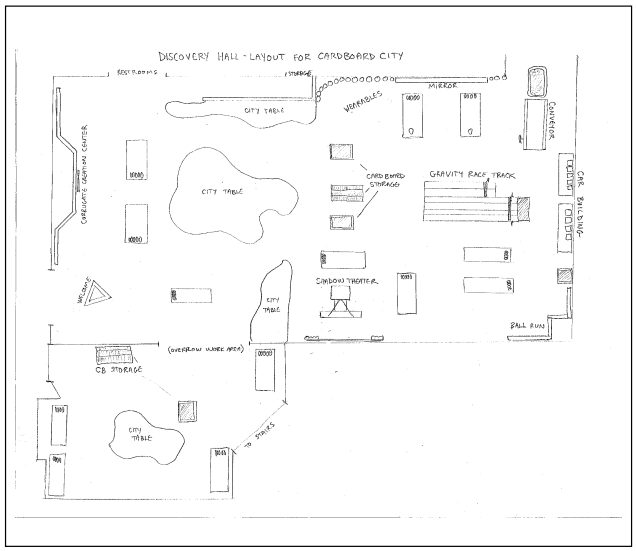
What is it?

Workstations refers to a designated area for making that includes all the necessary tools, a work surface, and seating.

Why is it important to visitors?

Creating multiple tabletop workstations with materials and space for making is superior to centrally located materials and distributed making locations. Creating workstations was a "happy accident" brought on by the COVID-19 pandemic, but comparing the experiences in the 2018 makerspace where materials and tools were centrally located to the 2021 makerspace where materials and tools were distributed at workstations, the latter created numerous benefits. First, workstations raised making off of the ground, which had important accessibility benefits. Adults with limited mobility were no longer required to sit on the ground to collaboratively make with their family, and the walkways remained clear for visitors using wheelchairs or strollers. Second, staff could easily identify when a family completed making and left the makerspace, prompting them to "reset" the workstation for the next family. Similarly, staff were no longer required to stoop to the ground over and over again when cleaning the space. Finally, having tools at the workstation aided locating and returning tools. In previous iterations, tools would be lost underneath creations and families would hold onto tools they were not actively using, creating artificial tool shortages. These issues disappeared with the workstation system.

What does it look like in practice?



2021: Sketch of Layout for Cardboard City, the rectangle tables are workstations

2021: Workstations in cardboard City

Learning to Cut

As an unfamiliar tool in the makerspace, learners needed some instruction to understand how to operate safety box cutters, called Klever cutters. In the two images below, we see two different attempts at using the klever cutter. In the first image, a child attempts to use the klever cutter, spontaneously figuring out its use but ultimately abandoning the tool. In the second image, a child of similar age is shown how to use the tool and ultimately goes on to use the klever cutter through his making. We call out this contrast to make clear the role of familiarity in tool selection and that even easy-to-manipulate tools and materials may require some orientation to get makers started. Development of this tool fluency appeared to happen faster with teenagers.

Image 1: This visitor spontaneously figures out how to use the safety klever cutter.

Image 2: This visitor is shown by a staff member how to use the safety klever cutter.

How does it relate to theory?

Workstations support the ergonomics of two groups: visitor family groups and museum staff. Task Analysis — a description of the totality of demands imposed on a worker in a given job — is a methodological tool for understanding how a job is demanding (Landau et al., 1998). Actions such as frequent stooping to the ground or sitting without a chair are considered higher strain and thus greater demand. Additionally, walking compared to sitting is considered higher strain, causing fatigue. Having a workstation reduces excess strain for both the task of making and task of facilitating/cleaning.

How have SMM's thoughts changed over time?

Our cardboard iterations between 2015 and 2018 utilized a Cardboard Corral, with cardboard boxes available in a single location. Tools were also centrally located at a few tables scattered throughout the space or held by staff for distribution. Families would retrieve their cardboard material and tools, then find a place on the floor for intensive creation. This system meant making was distributed across the space and sometimes resulted in limited tool supply. Additionally, the cleanup required of the staff was physically strenuous, involving stooping down to the floor to retrieve cardboard scraps.

In 2021, the iteration implemented a workstation system. The space's designers distributed fifteen workstations across the makerspace, stocked with multiple tools and colored tape. Cardboard material was available throughout the makerspace in smaller cardboard supply stations. The workstation was intended to allow family members of different skill levels to work together on independent or collective projects and ease logistical challenges for staff cleaning up. Staff members reported that the workstations made it easier to keep the space clean because they could see when a family was done making and had left the space. Instead of the entire makerspace needing monitoring and maintenance, the staff "reset" workstations when needed, resulting in the sense that cleaning was a smaller part of their overall duties.

PEOPLE, MATERIALS, AND PROCESS

The nuts & bolts for making
Cardboard City a reality.

Science Museum of Minnesota®

COMMUNITY INFORMED DESIGN

Cardboard City was developed across ten years of research and design iteration work and involved ongoing collaboration with community organization partners from across the Twin Cities. As our original goal was to understand how makerspaces can be designed to invite and engage many families, with particular attention to BIPOC families, seeking and being led by community voices was critical. Of course, our practices for doing this work have shifted over the ten years as we learn more, but by examining documentation from across the development of Cardboard City, we saw five consistent patterns to how we invited, listened, and acted based on community voice, which we now call Community Informed Design. Here, we will provide an overview of Community Informed Design.

What does Community Informed Design look like?

Community Informed Design is a type of community engagement that falls between collaboration (where external partners give input on design) and co-creation (where external partners lead design). Recognizing that design work takes considerable time and effort, and diversity-focused change work requires emotional labor, Community Informed Design emphasizes community voice in the naming of direction for design while placing the responsibility of work on a collective of museum staff. Community Informed Design is characterized by five features, detailed below.

Naming our Values and Assumptions: Museums need to be transparent about what their needs and boundaries are when initiating work so that community organizations and individuals can honestly assess if the partnership is of interest.

Emergent Planning: Too clear of plans at the beginning of work can create resistance to change when community voices signal the need for a different direction. Naming high-level plans is important for establishing partnership, but let specifics — for example, theme, specific learning goals, length of program, primary audience, etc. — be open for direction from community voices.

Flexible and Distributed Staffing: Within an organization, distributing responsibility and contribution across staff can reduce burnout (i.e. a small number of staff will not be tasked with pushing against many systems) and identify productive solutions earlier (i.e. staff in different roles have different expertise about making things work within existing systems). Our internal project team included staff from visitor services, finance, development/fundraising, research, access and equity, and museum experience design.

Organization-to-Organization Relationships: Similar to potential burnout with internal staff, potential burnout — or simply life changes — with external partners is also a risk. Creating enduring organization-to-organization relationships supports partnership across transitions.

Layered Data: Finally, relying on a single or small number of people to be your source of information or ideas can create a tokenizing effect. While doing deeper design work is more effective with a constrained number of community organizations and individual partners, augmenting their insights with broader data efforts helps relieve any sense that someone has to “speak for” an entire community.

STAFFING AND FACILITATION

What you need to know about staffing:

1. Be flexible
2. Work as a team
3. Celebrate staff or volunteers as makers

"[Cardboard City] thrived on creative chaotic energy while still being a place that largely was controlled and relatively easy to maintain. I had great conversations with guests here and was delighted to see so many families either work together or give one another space to build that they needed."

-Science Museum of Minnesota Visitor Experience Facilitator on working in Cardboard City

Why Your Plan for Staffing and Facilitation Matters

The Cardboard City gallery is an 'all hands on deck' experience! Your team, across the museum, is needed for a cardboard-focused makerspace to work.

Staff activate a makerspace: They can make and inspire, provide support for visitors, and ensure that the space is clean and comfortable. However, makerspaces are also labor intensive and can lead to burnout. Planning your staffing and facilitation strategy carefully makes you more likely to create an experience that works for visitors and staff.

What this looks like in practice:

championing staff as makers,
planning for visitor interactions,
and cleaning or maintaining the makerspace.

To engage staff and support a positive visitor experience, one Cardboard City facilitator at the Science Museum of Minnesota recommended a 20 Minute Model. That means that within each hour in the cardboard gallery, facilitators spend about 20 minutes making on their own, 20 minutes checking in with visitors directly, and 20 minutes cleaning. That said, a 20 Minute Model isn't always feasible. A rush of children on a field trip or a busy weekend might affect front-line workers' ability to do much more than try to keep the space tidy. Others emphasized the importance of a team approach, Cardboard City required lots of stocking, cleaning, and organizing. Our team at the Science Museum of Minnesota emphasized being flexible. Sometimes the mess of cardboard making can feel overwhelming; call in team members to assist! This was only possible because the entirety of the staff was onboard.

Facilitation of cardboard experiences differs from other museum spaces, so training is strongly encouraged as a way to grow confidence in supporting visitors and increase team cohesion when supporting each other in creating meaningful and enjoyable experiences. We also liked to save time in the gallery to play with cardboard together as a staff before opening so people could connect with each other and learn more about the space and tools.

Championing Staff as Makers

Staff who spend time making in the gallery have the chance to inspire visitors — maybe in sparking an idea or seeing a new way of working with the materials and tools. These are not formal demonstrations. Instead, staff "looking busy" with their own creations communicates to visitors that a skilled facilitator is nearby for support. Making in parallel with visitors gives staff something creative to do and creates another entry point to lure visitors into trying something new in the space.

Staff creations also help staff to develop a sense of ownership over the space. Through their own making, staff develop expertise in what cardboard can do. Example pieces set the tone for the immense possibilities of cardboard making. High-quality examples — those that may go beyond the tools available in the space — can be made by staff as well. For example, at the Science Museum of Minnesota, these pieces were designed using the Adobe Creative Suite, Blender, and Pepakura software and laser cut. Staff-made creations, whether made with special tools or parallel to visitors in the gallery, provided an additional jumping-off point for staff to share their skills and excitement for cardboard engineering with visitors.

Interacting with Visitors

Staff play a key role in supporting visitors in Cardboard City, especially in introducing the concept of a "makerspace" and helping folks with various levels of comfort with making to get started in the space. For example, a facilitator might help a child choose something to make, direct a family to an open workstation, or give an adult tips for using a tool. Preparing staff for a variety of scenarios and deciding upon your organization's approach to supporting visitors is key.

[picture here] Designated shelving allows for staff to retain their favorite pieces that also then serve as example pieces for visitors. Previously, it had been difficult for staff to see items that they or other visitors worked hard on remixed into something else by someone else. Cardboard City encourages visitors to contribute to something larger — such as the cityscape, theater display, or leaving behind vehicles for the Gravity Racer track — and staff help curate that collection over time.

Cleaning and Maintaining the Makerspace

"Find a cleaning system with your other team members. Cardboard can be too much for one person all at once, so please be mindful of whoever is running it and their needs."

-Visitor Experience Facilitator, Science Museum of Minnesota

Cleaning: there's a lot of it! Staff members shared that cleaning felt more manageable when they could rotate cleaning with making and interacting with visitors in the gallery. It was also essential to communicate and work as a team. Managers of floor staff conducted 1:1 meetings with their Cardboard City staff to clean the space as they touched base. Staff from other departments also stopped by, especially on particularly high traffic days. Seeing everyone contribute to the space improved morale.

In the day-to-day operation of the space, groups leaving a workstation was a good sign that the area was ready to be "reset" compared to previous iterations without tables that required constant monitoring for areas of the floor that had become too messy. Workstations also helped to lift making activities off of the floor, which was more ergonomically comfortable. However, scraps still fell to the floor and needed cleaning. Overall, with a full gallery and just a few staff members in the space, staff shared to be aware of your colleagues in Cardboard City and help out where you can with maintaining the gallery.

What Did This Look Like in Cardboard City?

At the Science Museum of Minnesota, Visitor Experience Facilitators support visitors on the museum floor. Typically, one to two facilitators were in the Cardboard City gallery at a time, a space that can easily hold 80+ visitors. This made the overall experience for visitors what one facilitator called a "self-engagement gallery". Staff were not typically working one-on-one with visitors, but rather ensuring that conditions supported all visitors in trying something creative in the space, by rotating making with visitor support and cleaning. A six-month run of the Cardboard City gallery in 2022 was considerably harder on staff than a three-month run of the gallery in 2021. Consider the length and intensity of staff time and effort needed to run high-quality cardboard experiences over lengthy periods of time.

Here is what we heard from facilitators in the space:

What was a favorite visitor moment you observed:

"I loved when the adult visitors became invested in building their own creations. Adults, especially parents, often seem to have trouble letting go of the idea that the museum is a children's space. It was nice interacting with adults who wanted to get the weight distribution just right on their car or wanted a particular color of tape for their art piece."

Another favorite moment:

"I loved seeing families work together and bridge huge age gaps. I loved seeing grandparents and grandchildren both have their hands on the same project. I especially liked to see the way in which they interacted. It seemed very equal. Usually when I see children and adults work together on a project, I see the adults guiding and instructing the children. In cardboard, it seemed that the lack of instructions allowed children and adults to work on an equal plane."

How could we continue to improve the experience:

"I think having the car area be more in the middle and not in the way back. A lot of people who are intimidated by the space don't often even see the cars and just turn around and leave. Also, making it clear anything the kids make they can take home."

Overall we heard simply from our facilitators about the visitor experience:

"PEOPLE LOVE IT!"

SELECTING A THEME

Why themes are useful

We —and others who have designed cardboard-focused programs and makerspaces — have found a unifying theme to be beneficial for visitor engagement. First, a theme operates as a light prompt in even very open-ended making. If a visitor misses all signage regarding the designed activities, the theme provides a visual starting point for them. Second, themes allow the same base activity to be lightly reimagined based on an alternative theme to support visitor's repeat visitation and the needs of specific programs. For example, we reimagined the open-ended skylines activity in the Cardboard City as creating a new city on Mars. Finally, a theme can support the design of new activities. With Cardboard City, the city concept generated many divergent activity ideas, of which we settled on and implemented five specific activities. When reimagining the experience as a space exploration program, the new theme prompted the creation of a rocket-making activity.

Building on a city theme

While Cardboard City adopted a city theme, we do not know for certain that this theme would be superior to other approaches. We ourselves had adapted the core activities to reflect a space exploration theme, with similar engagement results. We believe that strong themes should be relatable in some way to many visitors. When unsure, front-end evaluation — particularly with underserved visitors — can be used to assess current and potential visitor receptiveness to specific themes.

We communicated the theme to visitors both explicitly through our written labels and implicitly through the visual design of the space. The exhibition title and introduction panels all emphasized the idea of building a city together, and each activity's written prompt included a narrative connection to the city. Visual elements such as laser cut cardboard "skylines" decorated the walls and example pieces at activity stations showed what final products may look like.

WHAT'S IN A WORKSTATION?

Why workstations?

Workstations are ultimately about ergonomics: Can I work for a period of time in this place? Do I have to hold my body in an odd position or can I move comfortably? Do I have the tools I need here, or will I need to move frequently? Can I find the tools and materials I need quickly? Can I easily locate a space for my group to work together? A strong workstation has nearly everything a maker needs to complete their task in an easily identifiable and accessible location.

Workstations in Cardboard City

In Cardboard City, our workstations involved a standard-height table, wooden benches, a wooden organizer divided into five compartments, six tool types (safety boxcutter, roller for perforation, medical scissors, hole punch, pencil, and ruler), and a stationary colored tape dispenser. Cardboard was available at separate stations throughout the gallery. The 6-feet-long tables were positioned away from walls, allowing all sides to be used for making. Maintained walkways between tables allowed for wheelchair and stroller accessibility. Further, 6-feet-long and single-person wooden benches were placed along the sides of the tables for adults to sit on (and younger children to kneel to reach the table). We separated tools by type in the organizer and placed the organizer and tape dispenser at opposite ends of the table. While the distance between ends means that rarely could a maker reach both the tools and tape from the same exact position, we generally observed single-family groups using an entire workstation together and collaboratively passing materials and tools from opposite ends of the table.

Specialized tools

Workstations near particular activities should include the specialized tools or supports that are useful for that space. For example, in our wearables area, workstations included a wooden mannequin head that visitors could build hats on. At workstations near the cars activity, we pasted copies of the assembly instructions onto the table surface. For supports that are more general, such as basic joinery techniques, we positioned them near the workstations for the open-ended city skyscapes activity.

MATERIALS MANAGEMENT

Here, we are sharing considerations to plan for material life cycles and the actual material list that we used in Cardboard City.

What is material management?

Cardboard City required a lot of consumables — the cardboard and tape, but also copious amounts of tools. The gallery required frequent stocking and restocking. As you plan activities for a cardboard-focused makerspace, you also have to keep in mind how you will manage supplies — collecting, storing, and disposing them.

WHAT IT LOOKED LIKE IN PRACTICE

In general, when planning ahead for the material needs of Cardboard City, consider where you can gather supplies, if you have the space to store supplies, and how you will handle materials at the end of their lifecycle — through recycling or other disposal.

Material Life Cycles

Gather

The first step is to source all the materials. You may choose to fabricate, order from suppliers, or seek sponsorships to gather materials.

Storage

Given the resource-intensive nature of makerspaces, a place to store the materials is needed — whether for a gallery or pop-up events. The picture shows a portion of the storage area used at the Science Museum of Minnesota in 2021.

Within the gallery space we also used storage to reduce any resource-hoarding that might otherwise occur. Each workstation housed a tray with several tools. Stations for visitors to gather cardboard supplies within the gallery were distributed across the space.

Disposal

Ideally the cardboard in the space not used by visitors — off cuts from projects or even entire projects left behind that cannot be kept in the gallery — can be recycled. However, not all makerspaces will have access to robust recycling programs in their communities, and increasing recycling can come with added costs. Consider the material waste and what your site can feasibly do with it when taking on a cardboard-focused makerspace.

Prepping materials for recycling may also be important — for example, cardboard covered in masking tape may not be accepted in recycling facilities. In addition, as more and more visitors come through the space, more cardboard waste is produced. One way to reduce some of the cleaning needed, and include some encouragement around recycling, is to create a Recycling Center.

In Cardboard City, the Recycling Center contained graphics overhead and a conveyor belt. Visitors that wanted to recycle any remaining cardboard (or even their whole creation) could spin the wheel on the conveyor belt to move the cardboard into a waiting recycling receptacle. Reducing waste, as well as making recycling and cleaning fun, serves as a benefit for both staff and visitors.

WHAT TO INCLUDE IN A CARDBOARD CITY

Fabrication of Cardboard City

At the Science Museum of Minnesota, we have a large exhibit production shop with full-time exhibit fabricators and exhibit maintenance technicians. We created all of the exhibit infrastructure and interactives for Cardboard City with a team of 2-3 full time fabricators for about 2 months, and an additional 4 staff members focused solely on the cardboard sculptures for about a month. We recognize that many institutions do not have this type of team in place. Fortunately, the complexity of a cardboard maker gallery can be scaled up or down to match the capacity of any institution. A successful gallery should focus on the material itself, and offer visitors approachable interactives with comfortable accommodations for making.

Cardboard

- 48” x 36” sheets heavier substrate (we used a more durable corrugate made with an A Flute or C Flute internal structure, with a #56 or #59 substrate), 420 sheets for car wheels (sent to a vendor with a laser cutter);
- 48” x 100” sheets for sculptures we will be cutting, 100 sheets;
- 48” x 100” lighter substrate, 280 sheets for car sides;
- 48” x 48” sheets lighter substrate, 2500 sheets for the gallery; we found that when we put large sheets on the floor people tended to build giant forts so we cut them down and tried to keep the largest size at 2’x4’ in the exhibit

- Wheels: we laser cut them from heavier substrate and also contracted a vendor to make them
- Dowels (used primarily in Gravity Racer Activity): ¼” wide dowels cut down to be 6” long each
- Paper: copy paper and cardstock (used primarily in Stomp Rocket Activity)
- Tongue depressors (used primarily in Theater Activity)
- Yarn (used primarily in the Wearable Activity)
- Balls (used primarily in the Ball Run Activity)
- Ball run ramps (used primarily in the Ball Run Activity in 2022)

Tape

The most commonly used joinery technique was taping. Colored tape offered visitors more choice, creativity, and the option to “decorate” creations. Tape was attached to the table on a large dowel with a C-clamp.

Things we purchased direct from suppliers:

- Colored Masking Tape

Things we fabricated:

- Tape Dispenser on Table

Reflections on tape: The variety in colors were appreciated, some visitors had fun taking the C-Clamps off the tables which was unintended and posed a hazard that facilitators needed to monitor.

Tools

Items we purchased direct from suppliers:

- Medical scissors
- Klever cutters
- Hole punch
- Rulers
- Carpenter pencils
- Tray for tools

Items we fabricated:

- “Pizza cutters:” a perforation tool with a plastic perforator and handle

SOURCING AND RESOURCES

We're sharing sponsorship and resource sourcing ideas for developing a Cardboard City exhibition.

Why your sourcing plan is important

Makerspaces often are intensive both in the material and labor resources needed to create a fun and engaging experience. Creating a plan for sourcing external and internal resources early in project development helps ensure sufficient time to establish relationships and gather materials and tools.

Identifying External Sources of Support

External support may activate the experience beyond what is possible on your own!

Where are you getting the cardboard?

Cardboard galleries have two general options — source cardboard through recycling used cardboard or use "clean" cardboard.

Used/recycled cardboard: Requires lead time and space to store large amounts of cardboard. Consider what types of donated/used cardboard would be optimal for your visitor experience.

For example, in 2022 at Science Mill in Johnson City, TX, repurposing corrugate and cardboard allowed the museum to reuse much of the corrugate and cardboard that was coming into the museum for prototyping different experiential elements of their cardboard-focused events. Donations can also help. Iowa Children's Museum partnered with a local bank in 2022 to donate cardboard bank boxes for events.

Clean cardboard or corrugated: Requires lead time to identify a supplier and space to store ordered materials. These materials are an added expense, for which identifying external sponsors is helpful. In 2021, Science Museum of Minnesota transitioned to "clean" corrugate as the primary material in Cardboard City. Sponsorship from International Paper supported ongoing Cardboard Engineering initiatives alongside in-kind materials donations by the International Paper factories in Minnesota.

The main message: No matter how you source corrugate or cardboard in your space, plan on plenty of lead time to plan and organize your materials (see the Materials Management section for more information about the cardboard materials, tape, and tools used in the gallery) as well as managing the life cycles of materials in the space.

What local partnerships may offer support?

As you plan for a making experience, consider your local ecosystem around making, engineering, design, and more. For example, local universities may have access to speciality tools, such as a laser cutter, for sourcing pre-cut materials.

Here is a more expansive list that you might consider:

- Solicit companies to provide volunteers to help engage visitors with cardboard. You could also ask them to donate to support supplies needed for engaging visitors with hands-on activities.
- Rent out your cardboard exhibition during non-peak or closed hours to groups or companies for employee–family gatherings.
- During outreach events, ask a sponsor for a grant that will support your staff and offer additional value to the community (example: providing meals and take-home materials at events). Volunteers from the company's affinity groups can participate in events with wayfinding or activity tables.
- Envision what sort of local partnerships you can develop. For example, engineering and architecture firms may have a shared interest.
- Schedule a meeting with sponsors to involve them in how cardboard activities will look and be presented.

Prioritizing Internal Resources

Maintaining a cardboard gallery requires dedicated space and staff time, and even smaller pop-up events have a footprint to consider. Regular cleaning and resupplying materials is necessary throughout the space.

Internally, consider roles for staff and volunteers. If you don't have an active volunteer program or resources to supplement additional volunteers, you might solicit companies in your area with a shared interest, such as engineering or architectural firms to support the space or events with volunteers. You may consider training volunteers similar to staff.

Internal resources may also be needed to prepare materials, especially any examples you plan to seed in the space. When applicable, these can create meaningful professional development opportunities and ways for staff to become more deeply connected to the space.

ACTIVITY GUIDES AND INSPIRATION

SMM's history of cardboard making and straightforward guides to inspire a cardboard exhibition of any size.

Science Museum of Minnesota®

HOW DID WE GET HERE?

History of Cardboard Making at SMM

Cardboard has inspired SMM staff and visitors to explore, make, and play for many years. Activities on the museum floor, at summer camps, and out in the community have included cardboard as a material and tool to spark STEM learning.

In 2013, we began conversations and work with local families of color to understand the hands-on making they valued and did. Themes of food (cooking and gardening), art, reuse/thrift (sewing/clothing, fixing, low-cost materials), and music were prominent. Cardboard was specifically named by families as a readily available and low-cost material, and the museum decided to pursue cardboard making as one of the activities for further experience development. For detailed documentation of this earlier work, see the Making Connections Practitioner Guide, which complements our current thinking shared in this Cardboard Collaborative Guide.

Through grant-funded (*Making Connections: Exploring Culturally-Relevant Maker Experiences through an Iterative, Cross-Institutional Approach* [DRL-1323584] and *Cardboard: Building More Inclusive Makerspaces to Support Informal Engineering Learning Experiences* [DRL-1906884]) and everyday work, the museum has pursued this interest in cardboard making, working with BIPOC families for more than a decade and across four distinct design iterations.

What Did This Look Like?

In 2015, as part of *Making Connections*, the first “Cardboard Day” was held, when the museum gathered cardboard recycling donations, purchased large amounts of masking tape and scissors, and used an open rental space in the museum for the single-day event. The event was messy, experimental, and exciting. The families who had been working with museum staff were invited in specifically to test the space, along with museum visitors. Even during the single day it was open, we saw visitors who were inspired by other visitors’ creativity , sometimes adding to their creations. This single-day event sparked the potential of a large-scale joint build.

The cardboard makerspace was scaled up to a three-month exhibition-makerspace in 2016, hosted in a special exhibition space and accompanied by expanded tool options. We added benches, tables, and centralized storage for tools. We noticed that visitors were, again, inspired by each other and able to construct bigger builds together than they could do alone. We began to experiment with themes and challenges and watched how visitors responded. We also paid attention to how this space suited staff. The nature of the makerspace — free-flowing creation and construction — breeds mess and disorganization, which presents a unique challenge for staff.

A third iteration, *Cardboard Engineering*, opened in 2018, adding to the 2016 design by including artists-in-residence to demonstrate the potential of cardboard as a maker material and additional graphics at the entrance of the exhibition-makerspace with techniques for cardboard manipulation. We improved our staff training and support. We troubleshooted about how to organize tools and materials so that visitors could all receive access to them and weighed important decisions about how to share and display (and when to recycle) visitor creations.

In the summers of 2021 and 2022, our fourth and fifth iterations of the exhibition-makerspace opened with significant adjustments from the previous designs, supported by the NSF *Cardboard* funding, and responsive to previous challenges in our makerspace designs. A theme, *Cardboard City*, and areas with activity prompts and example creations, were developed to allow families who were less familiar with making to have on-ramps into the space. We presented all text in four languages, better reflecting the language diversity of the Twin Cities, as well as implementing graphical icons for simple instructions. We created workstations equipped with tools and cardboard materials to support family group making. Formal display spaces allowed for short- and long-term display of visitor and staff creations. Community organizations partnered with us to co-host spring family events in the exhibition space, and family research participants recorded video data to help us understand how they use the space.

We've also been experimenting with pop-up cardboard events associated with the exhibition-makerspace. Figuring out how to take a sizable exhibition on the road, how to make the event work in a park or a parking lot, has been a challenge that we continue to wrestle with. In 2022, we partnered with three other museums to share cardboard ideas with them; all of our different needs and dreams helped us all to push the boundaries of what is possible.

Cardboard continues to be compelling to us because of its ubiquity and potential. Most visitors come in with some familiarity with how cardboard behaves. They are inspired by the things others have made, they get ideas from the prompts throughout the space, and we want them to be empowered to make something bigger, or cooler, or more ingenious, than they might do on their own. We also want them to go home and continue to make, and maybe with new ideas inspired by their time at the museum.

We don't feel like we're done with Cardboard: Plans are underway for new exhibition-makerspaces and every time we walk through the exhibition, we see things we want to tinker with. Our inspiration for that tinkering comes from visitors and what we notice them doing. It comes from community partners through formal and informal conversations; it comes from staff, who quickly become experts in the space.

CARDBOARD MAKERSPACE HISTORY

The cardboard makerspace at SMM has involved 4 distinct iterations. Each iteration involved significant refinement, learnings which have been translated into the design principles in this document.

Iterations of SMM's cardboard makerspace, 2015-2021

Iteration	Year	Photograph	Description	Design Points of Note
Cardboard Days	2015		Weekend event with open-ended makerspace and paired table top activities throughout museum	• Room filled with reused/recycled cardboard • Very experimental • Partnership with BIPOC families through Making Connections who were our early testers
Cardboard Gallery	2016		3 month makerspace exhibition emphasizing open-ended making	• Central location for cardboard and tools • Bench seating and a few tables available for making • Extended time allowed for bigger/thematic builds
Cardboard Engineering	2018		3 month makerspace exhibition emphasizing open-ended making	• Exemplar pieces via artist-in-residence • Joinery techniques graphic • Display area for creations
Cardboard City	2021		3 month makerspace exhibition emphasizing making within theme and activity zones	• New/fresh cardboard instead of recycled boxes • Activity prompts presented in zones • Workstations for making • Distributed locations for cardboard and tools

Photographs from Cardboard Iterations

2015 Cardboard Days

2016 Cardboard Gallery

2018 Cardboard Engineering

2021 Cardboard City

BALL RUN

Materials

Workstation:

- Colored masking tape
- Medical scissors
- Klever cutter
- “Pizza cutter” (perforating tool)
- Rulers
- Pencils

Additional materials:

- Large peg board
- Dowels
- Example pieces of ramps (folded flat cardboard), or pre-cut cardboard half cylinders
- Clothespins
- Balls

Prompts We Used

Some city dwellers use the public transit system to move around. Develop a fun route that moves them safely from top to bottom. Work with others to make the route longer or more complex.

Design a route that works

- Make a plan.
- Build your route.
- Test your route.
- Make improvements and try again.

Make and attach ramps

- Place the ramp template in the middle of your cardboard piece.
- Use the cutting wheel to score each side for easy folding.
- Attach two dowels to the wall to hold your ramp.
- Place the ramp on top of the dowels.
- Use clothespins to create a snug fit against the pegboard.

FACILITATOR NOTE:
While we have some suggested materials in this guide, creativity is encouraged. Facilitators and visitors should be encouraged to use any resources available across the different activities in the space.

Activity Prompts

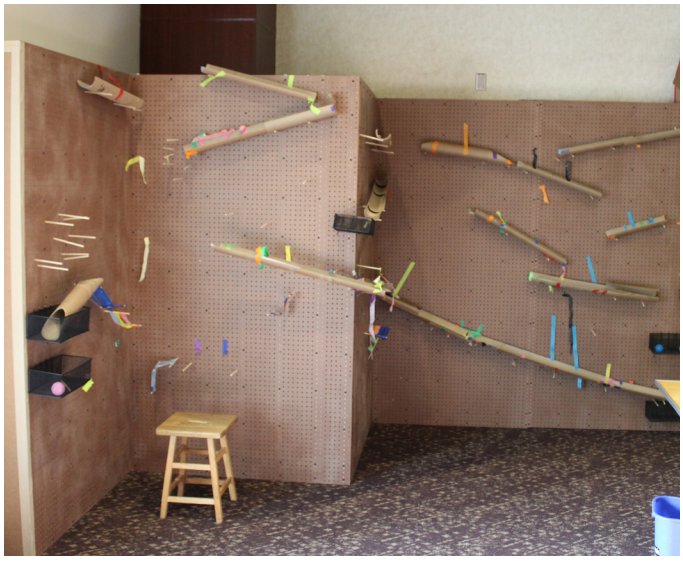
The Ball Run offered a range of activity prompts. Visitors might take on a creative construction mode of making to attach ramps using pre-fabricated pieces or examples left behind.

They might also tinker to build their own ramps, route, and improvements on their designs.

Examples

We found that examples were helpful for engaging visitors. When staff or visitors left their ramps attached to the peg board, other visitors could come up and run a ball down the ramp as an entry point into the activity.

It made it more clear that making new routes and testing them was an activity available in the space.



CARDBOARD CITYSCAPES

Materials

Workstation:

- Colored masking tape
- Medical scissors
- Klever cutter
- “Pizza cutter” (perforating tool)
- Rulers
- Pencils

Additional Materials:

- Negatives of laser-cut wheels
- Irregular cardboard pieces

Prompts We Used

Creating a homey, welcoming city
What makes a community a good place to call home? Is it houses, apartments, shops, and schools, or something else? Build your idea and add it to the growing city.

Building an equitable, accessible city
How can communities provide positive spaces for those who call it home?

Making a lively, friendly city
A city needs places where everyone can go for fun and enjoyable experiences. Make a park, a pool, a shop, or other fun place. Build your idea and add it to the growing city.

Create a structure that can fit in the palms of your hands.

What kind of building would you want next to your school, home, etc.?

FACILITATOR NOTE:
When facilitating the space, we found that supplying 2’ x 4’ flat cardboard worked best. Irregular pieces add creativity and present new affordances for visitors.

Contribute to Something Larger

The growing cityscape highlights the Contribute to Something Larger Design Principle – visitors have the option to leave their creation behind to contribute to the city!

GRAVITY RACER

Materials

Workstation:

- Colored masking tape
- Medical scissors
- Klever cutter
- “Pizza cutter” (perforating tool)
- Rulers
- Pencils

Additional Materials:

- Cardboard wheels
- Bee tubes for axles
- Cardboard axle ends
- Racer body templates
- Ramp with different surfaces

Prompts We Used

Gravity Racer - build for speed
This city is known for rough roads and steep slopes. Build a vehicle that can safely reach the bottom on any road condition.

Vehicles big and small
What different vehicles do you see in your community? Each one has a purpose. What does your vehicle do?

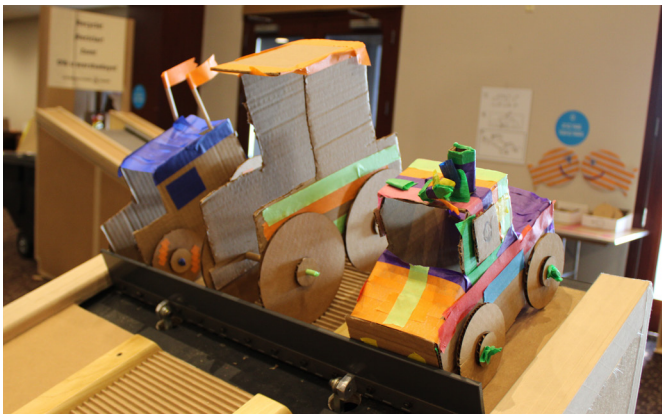
Mechanics needed!
Our garage has many vehicles that need a bit of work. Test one at the ramp to see what can be fixed.

Garage racers
Try out what has already been made. What did others do to make sure their racer made it down the ramp?

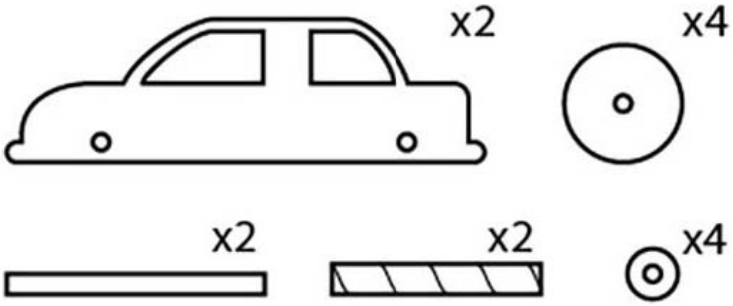
FACILITATOR NOTE:
We found that templates and directions helped visitors get started without hindering creativity. We saw turtle cars, boats, and even a cookie cart all from the same directions!

Icon Based Instructions

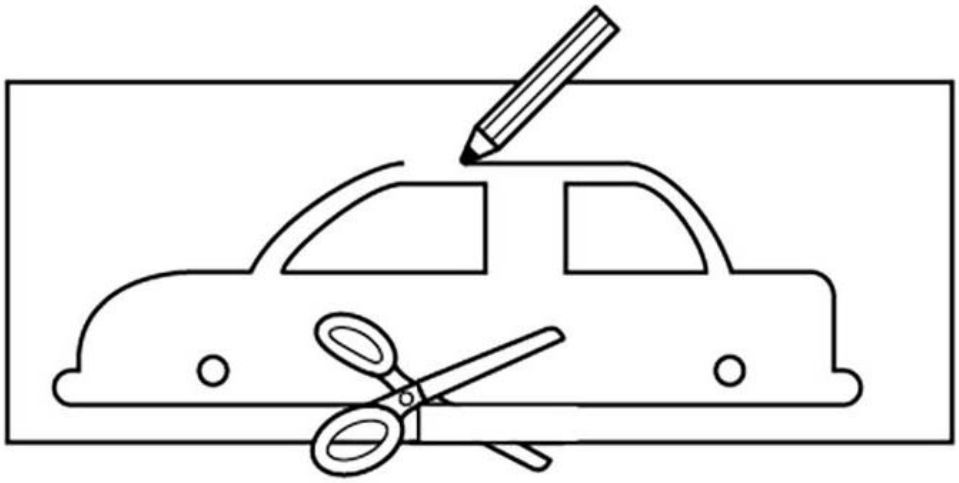
Gravity Racer was the most used activity in the space! We provided icon-based instructions (see next page). We saw visitors make many creative vehicles. Multiple access points (through instructions and play with example cars left behind) allowed families to participate with less barriers.



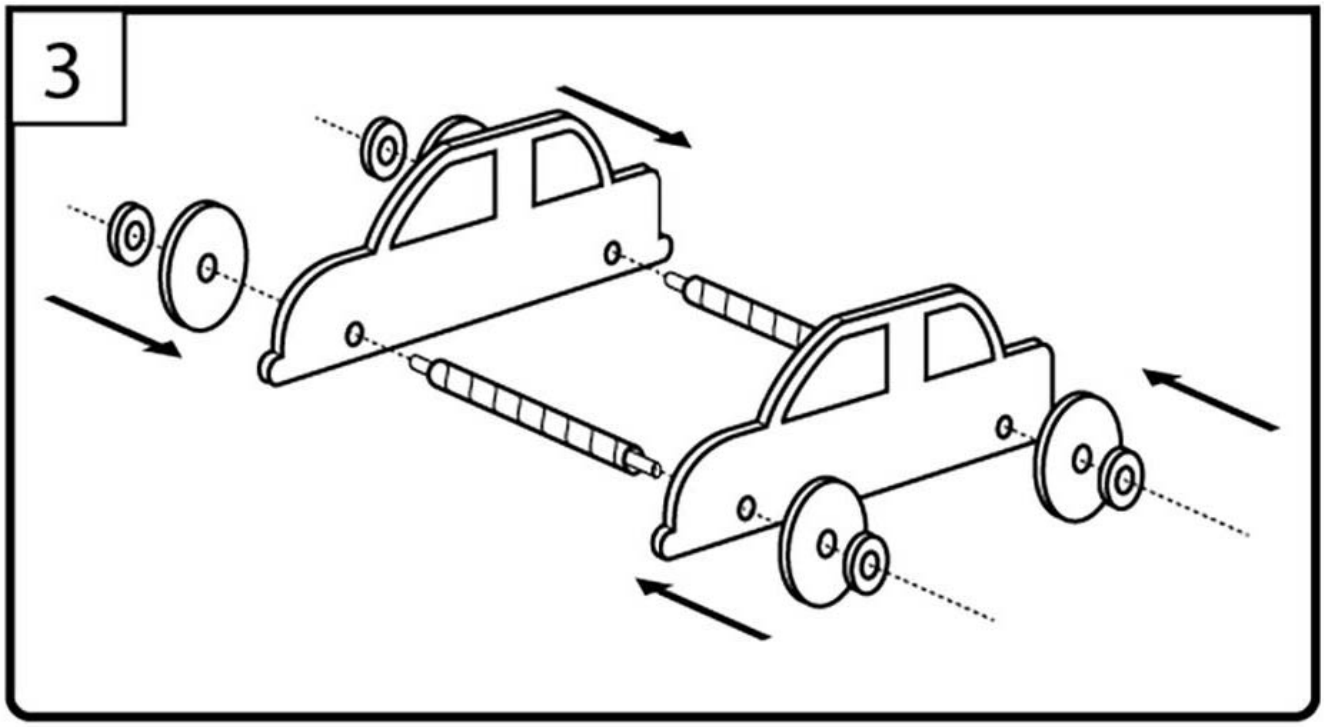
1



2



3



SHADOW PUPPET THEATER

Materials

Workstation:

- Colored masking tape
- Medical scissors
- Klever cutter
- “Pizza cutter” (perforating tool)
- Rulers
- Pencils

Additional Materials:

- Craft sticks
- Wooden skewers
- Light source
- Puppet stage with spaces for craft sticks and skewers

Examples

Example pieces — both those created by the museum and left by other visitors — let families start by playing with the shadow theater before deciding what new puppet to make.

Contribute to Something Larger

Many visitors used their own puppets and example pieces to create a story or “movie” with the shadow theater. Putting a creation into use is one way of contributing to something larger.

Prompts We Used

And then what happened?

You and your friends are strolling through the city when all of a sudden . . .
Who lives in this city? What happens here?
Create shadow puppets to help you share your story.

Make your city story

You and your family just moved into the city. One of the first things you notice is . . .
Create shadow puppets and share a story about life in the city.

Share a favorite story

Do you have a favorite bedtime story or fairy tale?
Make puppets to help you tell your story.

FACILITATOR NOTE:
Example pieces left at the theater ranged from laser cut fabricated pieces to a variety of visitor made creations. Visitors can make narrative play out of these pieces at the theater in addition to their own creation.

WEARABLES

Materials

Workstation:

- Colored masking tape
- medical scissors
- klever cutter
- “pizza cutter” (perforating tool)
- rulers
- pencils

Additional Materials:

- Yarn
- Shoe stays
- Mannequin bodies and heads
- Mirror for “catwalk”

Prompts We Used

Create something to wear, a tool to use, or a game to play. First imagine it, try drawing it, then make it!

Shoes for getting around

Design a functional yet stylish pair of shoes to wear in Cardboard City. Try them on. How do they fit? Check them out in the mirror. How do they look?

A hat that fits your mood

Make a hat for a special occasion or just for fun. Try it on and model it on the runway. How does it look? How does it fit? Does it stay on your head if you jump up and down?

FACILITATOR NOTE:
Making and wearing your own design is a great conversation starter and way to encourage others in the space!

Workstations

The workstations in the wearables section included additional items such as mannequin forms and a mirror for visitors to shape and test out their creations.

Examples

Staff made some amazing wearables to showcase on mannequins. They also made wearable creations like the airplane garment below that stayed in the space and was very popular!

STOMP ROCKET

Materials

Workstation:

- Colored masking tape
- medical scissors
- klever cutter
- “pizza cutter” (perforating tool)
- rulers
- pencils

Additional Materials:

- Variety of paper and cardstock
- Dowels to roll rocket body
- Stomp Rocket Launcher

Prompts Prompts We Used

Building a rocket

Rocket Body

- Roll a piece of paper around a dowel or PVC pipe and tape the edge
- Try different materials to find the best rocket body for you

Nose Cone

- Cover one opening of your rocket body
- Use to tape to secure it
- Check out different ways to make a nose cone

Fins

- Add fins to the open side of the rocket body
- How many fins?
- What shape or size fins?

Test out your rocket!

How far did it go?
Any changes you want to make?

Challenges:

Can you make your rocket:

- Go further than the last test?
- Change directions?
- Hit a target?

FACILITATOR NOTES:
Stomp rockets can introduce additional safety concerns. Use cones to block off the ‘launch zone’ if you can. Check for safety often, and use ‘cleared for takeoff’ to let visitors know when it’s safe to launch. Plastic rockets (purchased) or example rockets can be useful for engaging visitors that don’t want to build their own.

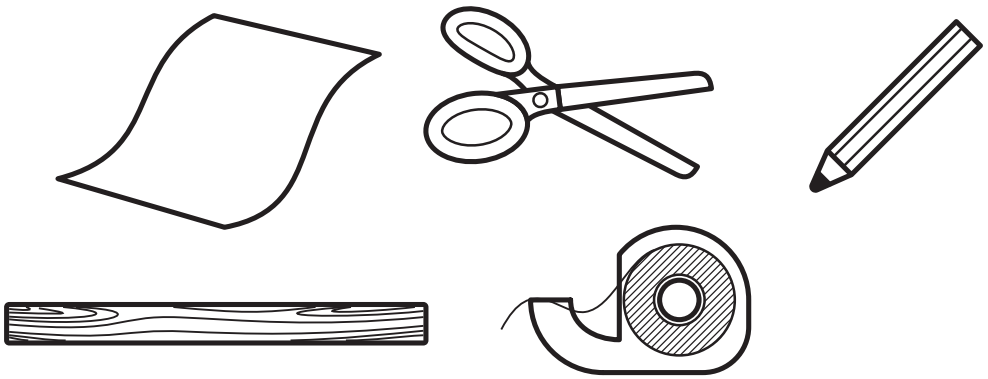
Rich Materials

We intentionally included a wider variety of materials — including paper and cardstock — because those materials afford rounded shapes easily compared to cardboard

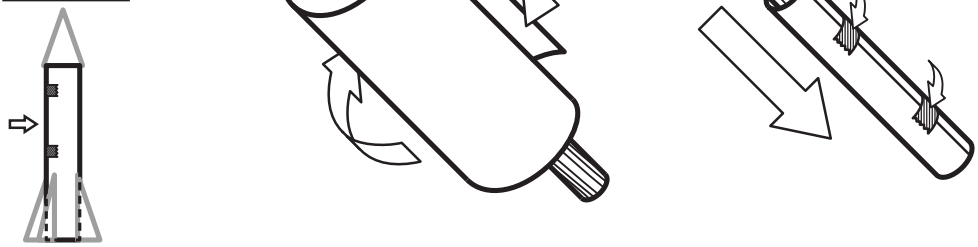
Icon Based Instructions

Icon-based instructions walked visitors through creating specific shapes including the tubular body and cone-shaped nose for the rocket.

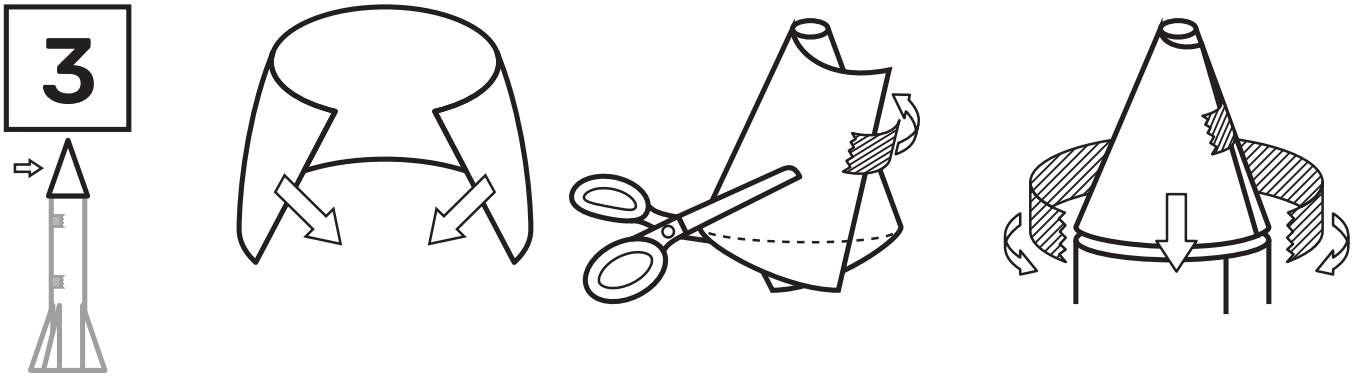
1



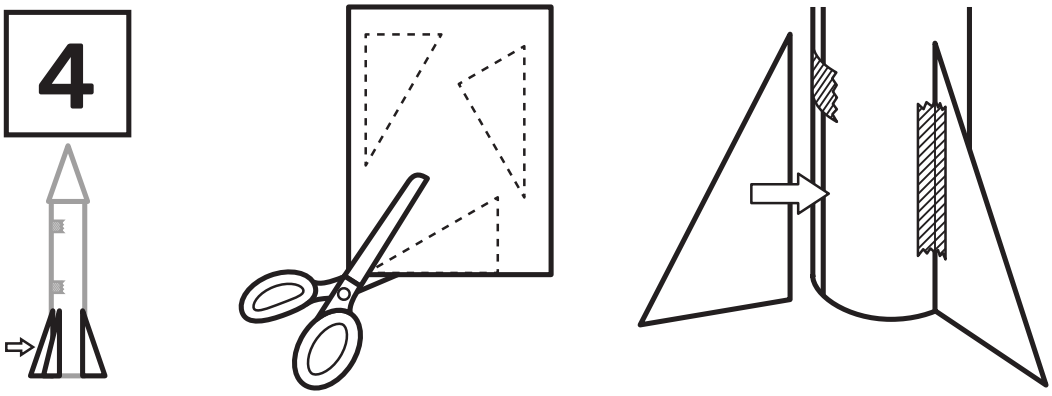
2



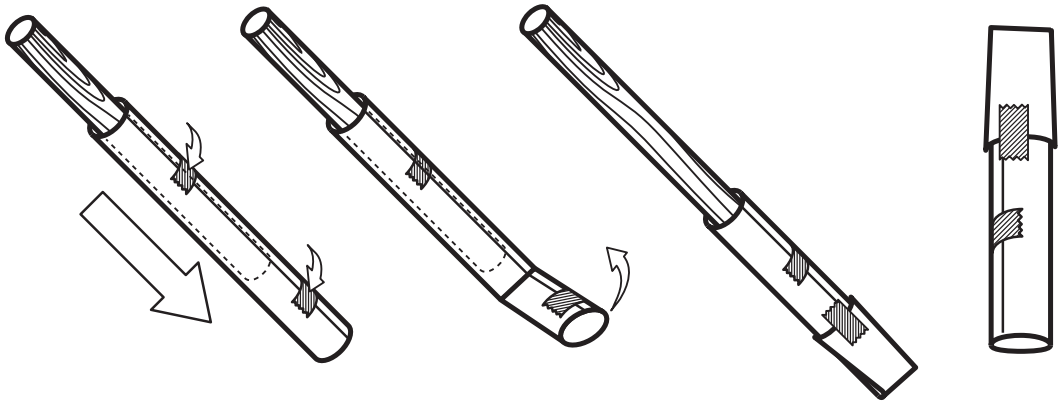
3



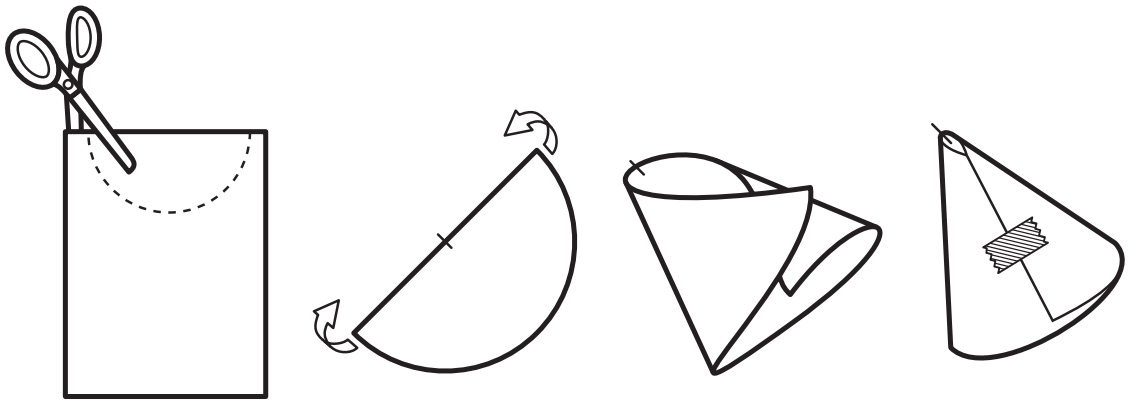
4



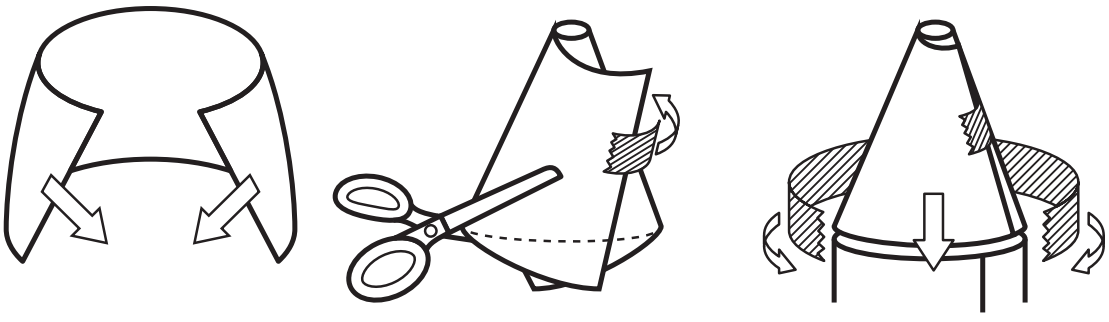
a.



b.



c.



INSPIRATION FROM OUR PARTNERS

Partnerships in Learning

After learning about making with our community partners and exhibition, we sought out museum partners to share our knowledge and learn from them. Our partners came from different regions, audiences, communities, and missions. Each partner identified topics of interest, challenges they were having, and goals for our time as a group. We met with each group separately in up to 10 meetings in April 2022, sent sample workstations their way, and a $5000 stipend to use to support making at their museum. Since the initial meetings, we have met to learn what they found valuable from our time together and to support their making endeavors.

Science Mill

Johnson City, TX | 16 Full Time Employees | Focus on STEM Careers in Rural Texas

Challenges: No municipal recycling

- Monthly making
  - Since Memorial Day 2022, Science Mill has facilitated monthly making activities on the floor. May's was focused on cardboard while June's focused on circuitry (with cardboard components). Each month has shifted themes encouraging STEM Careers.
- Pucks and sustainability
  - The Science Mill created Pucks, a cardboard connector, with their cardboard waste and a laser cutter. The Pucks are extremely flexible and adaptable to building needs. They have also been excellent tools of communication and team building. The Pucks have helped the Science Mill repurpose most of their cardboard waste into useful materials
- Rural Reach
  - The Science Mill reaches Western Texas by sending STEM content their way and training educators. They have added making and cardboard programming, as well as sent Pucks, across the state!
- Infused across the museum
  - Cardboard has become part of the Science Mill. They invested in a laser cutter and have been using it to create signage, name badges, and so much more.
  - When large groups are scheduled, floor facilitators plan additional making activities because of the low facilitation and high engagement

The Science Mill infused making into their daily practices and revolutionized recycling in their spaces!

Lewisburg Children's Museum

Lewisburg, PA | 3 Full-Time Employees | Audience: <8 year olds and their families

Challenge: Getting adults engaged in open-ending making

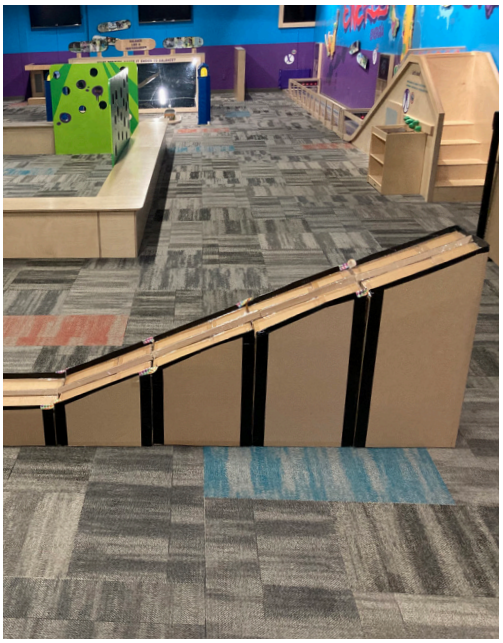
- MacGyver Camp
  - Lewisburg Children's Museum utilized the Making Design Principles to create a week-long making camp with daily challenges.
- Exhibition Space — Loose Parts
  - Their open-ended making space was not frequented by families and adults often and the team didn't know what to do.
  - LCM had plans to implement monthly themes and featured assembly-style activities to create starting points for folks who didn't identify as makers.

Makerspaces need people to restock, clean up, and sometimes facilitate. Implementing a makerspace requires staff buy in across the institution.

Iowa Children's Museum

Coralville, IA | 14 Full Time Employees | Audience: <10 year olds and their families

Challenge: Increase making in outreach



- Partnerships
  - The Iowa Children's Museum utilized their current partnerships to expand their making. They added making to their monthly activities with their local libraries.
  - Their current exhibit shop does not have a laser printer; they partnered with their local university to create cardboard pieces for assembly-style making.
- Adding to current events
  - Every month, the Iowa Children's Museum opens their doors for Family Free Night. Each month has a different theme and that is activated throughout the museum spaces. ICM utilized a cardboard theme for their Family Free Night in May 2022.
  - Move it, Dig it, Do it is the largest family event for the Iowa Children's Museum. It is a "truck zoo" where children can come see and sit in large vehicles and explore the careers associated with them. This year, they added the assembly-style car-building activity and had a foldable ramp for testing the cars. They were able to iterate off of our exhibit's model.

With an already established making program, ICM expanded offerings and extended partnerships!

APPENDIX A: REFERENCES

Anderson, A., Goeke, M., Simpson, A. M., & Maltese, A. V. (2019). Where should learners struggle? *Connected Science Learning*, 12(1). Retrieved from: https://www.nsta.org/connected-science-learning/connected-science-learning-october-december-2019/where-should-learners

Bequette, M., Causey, L., Schreiber, R., Pennington, R., Braafladt, K., & Svarovsky, G. N. (2018). Summaries of the Making Connections Project and Play Tinker Make Activities. Science Museum of Minnesota. Retrieved from: https://www.informalscience.org/making-connections-practitioner-guide

Bevan, B. (2017). The promise and the promises of Making in science education. *Studies in Science Education*, 53(1), 75–103. https://doi.org/10.1080/03057267.2016.1275380

Goeke, M., & Braafladt, K. (2019). *History of Cardboard at SMM* [Internal Report]. Science Museum of Minnesota.

Honey, M., & Kanter, D. (Eds.). (2013). *Design, make, play: Growing the next generation of STEM innovators.* Routledge.

Keller, C., & Keller, J. D. (1996). Thinking and acting with iron. In S. Chaiklin & J. Lave (Eds.), *Understanding Practice: Perspectives on activity and context. Cambridge University Press.*

Landau, K., Rohmert, W., & Brauchler, R. (1998). Task analysis. Part I - Guidelines for the practitioner. Part II - The scientific basis (knowledgebase) for the guide. *International Journal of Industrial Ergonomics*, 22(1–2), 3–35.

Lee, D. Y., & Shin, D.-H. (2012). An empirical evaluation of multi-media based learning of a procedural task. *Computers in Human Behavior*, 28(3), 1072–1081. https://doi.org/10.1016/j.chb.2012.01.014

Lukowski, S., Goeke, M., Schmit, B., & Bequette, M. (2023). Assembly-style making: How structured making serves as an onramp to creativity and engineering design. *Frontiers in Psychology*, 14. https://doi.org/10.3389/fpsyg.2023.1120186

Malamed, C. (2015). *Visual Design Solutions: Principles and Creative Inspiration for Learning Professionals*. John Wiley & Sons, Inc. https://doi.org/10.1002/9781119153801

Marsh, L. E., Kanngiesser, P., & Hood, B. (2018). When and how does labour lead to love? The ontogeny and mechanisms of the IKEA effect. *Cognition, 170*, 245–253. https://doi.org/10.1016/j.cognition.2017.10.012

Martin, L. (2015). The Promise of the Maker Movement for Education. *Journal of Pre-College Engineering Education Research (J-PEER), 5(1).* https://doi.org/10.7771/2157-9288.1099

Mayer, R. E. (2008). Applying the science of learning: Evidence-based principles for the design of multimedia instruction. American Psychologist, 63(8), 760–769. https://doi.org/10.1037/0003-066X.63.8.760

Michas, I. C., & Berry, D. C. (2000). Learning a procedural task: Effectiveness of multimedia presentations. *Applied Cognitive Psychology*, 14(6), 555–575. https://doi.org/10.1002/1099-0720(200011/12)14:6%3C555::AID-ACP677%3E3.0.CO;2-4

Norton, M. I., Mochon, D., & Ariely, D. (2012). The IKEA effect: When labor leads to love. *Journal of Consumer Psychology*, 22(3), 453–460. https://doi.org/10.1016/j.jcps.2011.08.002

Pavlus, J. (2015, October 28). How Ikea Designs Its (In)famous Instruction Manuals. *Fast Company*. Retrieved from: https://www.fastcompany.com/3052604/how-ikea-designs-its-infamous-instruction-manuals?partner=rss

Piehl, J. (2021). *Graphic design in museum exhibitions: Display, identity and narrative.* Routledge.

Wong, A., Marcus, N., Ayres, P., Smith, L., Cooper, G. A., Paas, F., & Sweller, J. (2009). Instructional animations can be superior to statics when learning human motor skills. *Computers in Human Behavior,* 25(2), 339–347. https://doi.org/10.1016/j.chb.2008.12.012