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**Research to Practice: Observing Learning in Tinkering Activities**

JOSHUA P. GUTWILL, NINA HIDO, AND LISA SINDORF

Joshua Gutwill (jgutwill@exploratorium.edu) is Director of Visitor Research and Evaluation at the Exploratorium, San Francisco. Nina Hido (nhido@exploratorium.edu) is Senior Project Evaluator, Exploratorium. Lisa Sindorf (lsindorf@exploratorium.edu) is Research Associate, Exploratorium.

**Abstract** As tinkering and making spaces proliferate in museums, many researchers, practitioners, funders, and policy-makers seek to understand what constitutes learning-through-tinkering. To support discussion of tinkering-based learning, the Exploratorium sought to articulate and refine a valid, evidence-based definition of learning in its permanent on-floor Tinkering Studio. We studied fifty learners and their companions in one of three tinkering activities in the Tinkering Studio. A team of researchers and practitioners used the videos to refine frameworks for learning and facilitation (initially developed in a prior project), leading to four Dimensions of Learning and three broad Facilitation Moves. We created a Tinkering Library of Exemplars that categorizes over one hundred video clips according to the frameworks. The Library may help articulate important aspects of learning and facilitation,

give voice to practitioners' values in defining learning-through-tinkering, and lay a methodological foundation for gathering evidence for such learning. The Library is available for download.

Making is the playful, learner-driven construction and deconstruction of objects or installations, usually in the context of exploring natural phenomena and generally using both high- and low-tech materials, such as sensors, cardboard, and hot-glue guns. In its ideal form, making involves creatively developing a personally meaningful idea, encountering roadblocks when physically realizing the idea, persisting, and experiencing breakthroughs as solutions emerge (Bevan et al. forthcoming; Vossoughi et al. 2013). Making differs from other forms of inquiry-based learning mainly in the high priority it places on the learner's authorship: learners pose problems or challenges for themselves, based on materials and other design constraints within a maker space (Martinez and Stager 2013; Petrich, Wilkinson, and Bevan 2013; Vossoughi and Bevan 2014). While the term "making" is widespread, we at the Exploratorium use "tinkering" to place greater emphasis on the process of making rather than on the final product of construction.

The Maker Movement has gained tremendous momentum in the past decade. Maker Faires—large gatherings where makers can show their creations and meet interested others—have grown since 2006 into a worldwide phenomenon, taking place in over a dozen countries (Maker Faire website  2013). Making has also become the darling of the science-education community, particularly in informal settings, such as museums, afterschool programs, and libraries. The 2013 annual meeting of the Association of Science-Technology Centers (ASTC) included five sessions, a pre-conference workshop, and a “Community of Practice” on the topic (ASTC 2013).

Museum staff, funders, policy makers, and other professionals may acknowledge that tinkering and making have the power to captivate people, but they often raise doubts about whether tinkering and making induce valuable learning. What, if anything, constitutes learning for museum-goers participating in tinkering/making programs? How do the designers and facilitators of these activities know when it is working, and how may they demonstrate success?

Our colleagues at the Exploratorium who develop, implement, and study tinkering activities have been wrestling with those questions for years. In their recent article “It Looks Like Fun, But Are They Learning?” Mike Petrich, Karen Wilkinson, and Bronwyn Bevan (2013) describe the varied elements of tinkering and make a compelling argument that tinkering activities do promote learning. Within the Exploratorium’s Tinkering Studio—a permanent on-floor environment featuring playful, collaborative design activities—they see people of all ages use their imaginations to develop and pursue an idea and to make something concrete, even if ephemeral, demonstrating “amazing focus, creativity, persistence, and pride” (Petrich, Wilkinson, and Bevan 2013, 51–52). Drawing on constructivist (Piaget and Inhelder 1969), constructionist (Papert and Harel 1991), and sociocultural (Vygotsky 1978) theories of pedagogy, they view learning as a “process of being, doing, knowing, and becoming” (Petrich, Wilkinson, and Bevan 2013, 53).

The wider field employs a variety of terms to describe the playful construction that blends science, technology and craft in maker activities. Martinez and Stager (2013) distinguish among making, tinkering, and engineering: making is the construction of a desired creation; tinkering is a playful mindset; and engineering is the practice of finding and applying general principles for building. For our purposes, the construction of making and the mindset of tinkering are combined into experiences that emphasize creativity, personal authorship, and improvisational problem-solving. This melded definition of making/tinkering is widespread in museum discussions, such as those found within the ASTC Community of Practice (CoP) on Making and Tinkering Spaces in Museums.

Although many posit that learning happens during making/tinkering, researchers are only beginning to investigate the nature of learning through such activities (Brahms, 2014; Sheridan et al. forthcoming; Vossoughi et al. 2013; for a review of the current literature, see Vossoughi and Bevan 2014). In 2011, we joined the Tinkering Studio practitioners to articulate and refine a valid, evidence-based definition of learning-through-tinkering. We spent the intervening years in a jointly negotiated exploratory study (Penuel and Fishman 2012), discussing and categorizing various aspects of learning we observed in the Tinkering Studio. Together, we produced a library of video clips that exemplify a new framework for learning and facilitation in tinkering. The results and products described in this essay represent another chapter in the Exploratorium's evolving story of how we understand the relationship between tinkering and STEM learning.

**Research Goals**

A team of researchers and practitioners set out to examine the nature of learning by drop-in visitors to the Tinkering Studio. We began with the tentative set of learning dimensions developed by the Tinkering team in 2010. With the goal of further specifying and authenticating these dimensions, we endeavored to

- define, document, and classify evidence-based examples of learning

- observe and categorize interactions between Tinkering Studio facilitators and learners
- explore connections between facilitation and learning

This pilot study was an initial, qualitative investigation of learning and facilitation in tinkering activities. In the end, we produced two frameworks—Learning Dimensions and Facilitation Moves—and created a Library of Exemplars containing video evidence in support of the frameworks and the connections between them. Our intent in sharing the frameworks and library is to help tinkering/making practitioners examine and discuss their work and develop new program directions. The frameworks have not yet been used to create rigorous and reliable coding schemes, the next step in our research. However, through the qualitative frameworks and library, we wish to contribute to the growing dialogue among researchers about the nature of learning during tinkering and making activities.

**Methods**

Watching learners make a whimsical marble track or connect a circuit of electrical components in the Tinkering Studio reveals a wealth of complex behaviors—activity is continuous, choices and intentions are often unspoken, and social interactions may be quick and inaudible. What in this buzzing commotion of experience constitutes learning? When do particularly important learning moments occur? Part of the work of research of this type is to develop "eyes" for identifying important dimensions of the process of learning (Frederiksen et al. 1998; Sherin and van Es 2005). To this end, we decided to collect video recordings of museum visitors in the Tinkering Studio and use the videos to (1) establish a shared language and understanding of learning among researchers and practitioners; (2) develop evidence-based categories for various dimensions of learning and facilitation moves; and (3) create a library of video clips for dissemination and professional development.

Our work builds on a previous project that explored aspects of learning and facilitation across a variety of informal STEM programs (Bevan and Dillon 2010; Bevan et al. forthcoming). That project, called Museums Afterschool: Principles, Data and Design (MAPDD), identified a tentative set of learning indicators for afterschool tinkering/making programs. We used these indicators as an initial frame for our investigation of learning in the Tinkering Studio. Ultimately, the context we studied—a drop-in museum environment rather than regular afterschool programs—demanded that we refine the initial indicators to create a valid framework of Learning Dimensions. Fortunately, the facilitation framework that arose in the MAPDD project applied well to the museum context; therefore, we adopted it as a lens for viewing and categorizing facilitation moves in the Tinkering Studio.

In our study, researchers and practitioners had equivalent power to pose questions, interpret findings, and share results (see Coburn, Penuel, and Geil 2013). Learning scientists concerned with the use of research in practice argue that without the meaningful involvement of practitioners, the results of research are likely to be limited in their reach and sustainability (Penuel and Fishman 2012). We anticipated that jointly negotiated research would have more relevance for practice, and might even shape the implementation of tinkering/making activities (Penuel et al. 2011).

**Data Collection**

To create our dataset, we audio- and video-recorded fifty participants within the Tinkering Studio as they engaged in one of three activities: Marble Machines, Wind Tubes, or Circuit Boards. See Figure 1 for images of each activity. Briefly, Marble Machines invites learners to create intricate and often whimsical marble runs on a vertical pegboard, using tracks, tubes, rubber bands, funnels, and other everyday materials. In the Wind Tubes activity, learners make a contraption out of cardboard, strawberry baskets, tape, and other materials that will float in a vertical air stream. Circuit Boards presents learners with a diverse set of individual components (battery packs, lightbulbs, switches, buzzers, LEDs, motors, and others) to connect in simple or complex circuits. During our data collection, only one of these three activities was offered each day in the Studio.

**<INSERT FIGURE 1 ABOUT HERE>**

To assemble a broad age range of learners, we employed purposive, rather than random sampling, recruiting visitors once they entered the Studio and began participating in the activity. We selected a “target” participant to follow, whether working alone or in a group. When others interacted with our target individual, we video-recorded those interactions, as well. We used hand-held cameras with attached mini-shotgun microphones in order to follow participants easily as they moved around in the Tinkering Studio.

Our recordings were made during the summer and fall of 2011. Participants were recorded in only one activity; we studied twenty participant groups in the Marble Machines activity, fourteen in Wind Tubes, and sixteen in Circuit Boards. Their ages ranged from 4 years to adult.

**Refining the Frameworks**

After collecting the audio/video data, we followed a multistep analysis process, leading to the development of our Learning Dimension framework. With Studiocode™ software, we noted any events in the videos that might be considered evidence of the Learning Dimensions (starting with indicators from the MAPDD project). We then reviewed the events and created short clips from the longer videos that seemed to illustrate one or more of the Learning Dimensions. Based on these short "call-outs," we revised the Learning Dimension categories to better align them with the evidence in the clips. These revisions included changing or adding to the text, or sometimes adding new subcategories, called "indicators," to the Learning Dimensions. We discussed the new categories with the practitioner team (seven staff from the Tinkering Studio), using the call-outs to ground the conversation in evidence. Periodically, we solicited comments from outside advisors, as well. Next, the research-practice team determined whether the revised categories reflected the types of learning that practitioners valued and whether the video call-outs sufficiently exemplified the categories. The team repeated this process until both the researchers and practitioners agreed on final language for the Learning Dimensions.

As mentioned above, the facilitation framework from MAPDD proved applicable to the Exploratorium Tinkering Studio; the "moves" that facilitators made were similar in afterschool and museum settings. With few revisions, we were able to utilize the existing MAPDD framework to catalogue video clips of facilitators interacting with learners.

**Library of Video Exemplars**

Once we finalized the Learning Dimension categories, we reviewed the video callouts we had already created during team discussions to determine those that best illustrated the Learning Dimension categories. We organized the video callouts in a searchable FileMaker™ database that we call the Tinkering Library of Exemplars. Each exemplar includes a link to the final video clip, an analytic description of the salient moment, as well as tags for various characteristics, such as the type of activity in the clip (Figure 2). The Tinkering Library of Exemplars, containing our full set of evidence in support of the frameworks, is available for download as a FileMaker™ database, and the video clips are accessible online.[1] The frameworks are not offered as rigorous coding schemes, but as tools for articulating valued forms of facilitation and learning in museum-based tinkering/making spaces.

**<INSERT FIGURE 2 ABOUT HERE>**

In a similar process, we created a set of exemplars for facilitation moves. We created call-outs by first finding instances when a facilitator interacted with the target learner on a subset of our videos. Then we categorized each call-out according to the MAPDD facilitation framework, and checked our categorization for face validity with the practitioners.

In the third and most exploratory part of our project, we sought to determine whether evidence existed in the videos of a connection between moves by facilitators and dimensions of learning. Rather than claim that certain facilitation moves result in particular aspects of learning, we wished merely to ascertain whether *any* link between facilitation and learning might be plausible. To answer this, we returned to the original full-length videos, located clips of facilitation moves, then continued to watch the video for about five minutes.[2] If the target visitor demonstrated a Learning Dimension within those five minutes, we excised the longer video clip.

The purpose in building the Library containing exemplars of Learning Dimensions, Facilitation Moves, and Links was to create a tool that practitioners could use for articulation, professional development, and dissemination. It was beyond the scope of this pilot study to quantify any features of the exemplars (frequency or length, for example) or to compare the effects of different facilitation moves. Future studies may pursue such goals.

## Four Dimensions of Learning

Starting with the framework developed for afterschool programs in the MAPDD project, we determined four different Dimensions of Learning: Engagement, Initiative and Intentionality, Social Scaffolding, and Development of Understanding (Table 1). The Dimension categories are described below, along with "indicators" and "descriptions" for each. An indicator is an aspect of a given Learning Dimension that might be visible in the videos; the description of each indicator offers more information about the learning interactions found within that indicator. Evidence in support of a Learning Dimension may come from one or several indicators. That is, a learner need exhibit only one indicator of a Learning Dimension for her or his interaction to illustrate that Learning Dimension. We also wish to note that a given video clip may demonstrate more than one Learning Dimension; we categorized the interaction in the clip based on the Learning Dimension our team believed was most apt.

**<INSERT TABLE 1 ABOUT HERE>**

## Learning Dimension 1: Engagement

Engagement—the act of participating in an activity—is a fundamental component of learning, sometimes identified as a prerequisite to learning, other times as a marker of learning itself (Renninger 2010; Blumenfeld, Kempler, and Krajcik 2006; Bransford and Schwartz 1999). The concept has long been identified as an important analytical dimension in both formal and informal educational settings (Hidi and Renninger 2006; Humphrey and Gutwill 2005; National Research Council 2009).

In the Tinkering Studio project, engagement means learners participate in tinkering activities over time, becoming emotionally invested and deepening their interest. The Engagement Dimension of Learning encompasses behavioral, emotional, and cognitive aspects of involvement (Fredricks, Blumenfeld, and Paris 2004). Though dwell time is a common behavioral measure for engagement, we were unable to use it for this study because our data-collection procedures necessitated that we recruit museum visitors after they had begun the activities. Consequently, we centered our attention on *investment in the activity*. We found call-outs in which learners demonstrated emotions such as pride ("I'm gonna tell my parents that I worked electronics all by myself!"), joy ("Yay!"), and frustration or disappointment ("So that's really a problem."). There were also several moments of investment in which a learner seemed to have completed his or her creation, appeared to come out of the activity, looked around for a few moments, and then dove back in, enhancing the creation or starting a new one. For example, after working for a few minutes with her father and younger sister on a marble machine, one girl announced, "My part works, so I'm done here," then began assembling a new independent machine in a different spot. We found that Engagement was widespread in tinkering activities. What was particularly interesting was the high degree of museum visitors' emotional investment in their work compared (anecdotally) to the lower investment often shown at exhibits. We observed some learners become so excited at their successes that they jumped up and down, clapped their hands, or made enthusiastic sounds.

**Learning Dimension 2: Initiative and Intentionality**

Developing and pursuing one's own goals is another key aspect of learning (Barron, Wise, and Martin 2012; Larson 2000; Lemke 2001; Zimmerman 2008). Empowering people to cultivate their own initiatives and motivations for learning is core to the Maker Movement (New York Hall of Science 2013). This fits well with the pedagogy of free-choice learning environments like museums, where intrinsic motivation tends to dominate (Falk and Dierking 2000). In order to support self-driven learning, some museum professionals have advocated shifting authority away from the museum, treating visitors as co-creators of their own learning experiences (see Hein 1998; Humphrey and Gutwill 2005; Ansbacher 2002; Simon 2010).

The Learning Dimension of Initiative and Intentionality expresses the freedom that learners have within tinkering activities to set and change their own courses within the broader frame of the activity (Martinez and Stager 2013). There were several indicators for this Dimension. The first is *setting one's own goals*, evident when learners simply begin working on something new or verbalize what they want to do next. One boy in the Marble Machines activity said, "I'm going to start building another one." Another participant in Circuit Boards remarked, "I want to plan out the design instead of just like aimlessly building." *Seeking and responding to feedback* encapsulates the abundant behavior of testing and retesting a creation to see how it works, making small tweaks, or sometimes developing an innovative solution to a problem. *Persistence in the face of setbacks* also denotes Initiative and Intentionality, as when we see learners continue to work with a creation that failed to function as intended or caused them frustration and disappointment. While three young people were co-constructing a marble track, the boy exclaimed when the track fell apart, "It broke. It broke. It broke!" One of the girls laughed, lightening the mood. "Maybe if we put this here instead of that place," suggested the other girl, "move that part of the machine up here instead, it'll hold up better." The boy seemed satisfied with that solution, responding, "All right." Finally, this dimension signifies what Duckworth (2006) calls the *intellectual courage* learners display when they continue to work and play despite a lack of confidence in their ideas or the skepticism of others toward their approaches. In the Tinkering Studio, a mother and daughter offered different explanations for why the daughter's contraption did not float out of the top of the wind tube. "I think it's just the shape," offered the mother. "Yeah," continued the daughter, "but it's also that there's nothing [on the contraption] to bounce off, so I'm gonna put more slippery pipe cleaner instead of sticky tape." The girl had disagreed, then proposed a solution based on her own view of the problem. Anecdotally, we found so many instances of Initiative and Intentionality that we struggled in our early discussions to tease it apart from simply "doing" the tinkering activity, the dimension we call Engagement.

**Learning Dimension 3: Social Scaffolding**

Many informal and formal learning settings seek to create a social environment in which learners help and inspire one another to persist and solve problems (see Scardamalia 2004; Vygotsky 1978; Pea 2009; Zimmerman, Reeve, and Bell 2010; Falk and Dierking 1992; Gutwill and Allen 2012). This is particularly important in museums, where most people visit in groups (ECSITE 2008; ASTC 2002). Collaboration among visitors has been found to improve investigative inquiry at museum exhibits (Gutwill and Allen 2010; Gutwill 2005).

The Dimension of Social Scaffolding reflects the value of mutually supportive collaboration within the Tinkering Studio. The design of the environment—with its open floor-plan, large workspaces that accommodate multiple learners, and shared materials—encourages learners to watch one another, interact with one other, even create together. The term "social scaffolding" echoes the well-studied pedagogy of cognitive scaffolding (Wood 2001; Collins, Brown, and Newman 1989), in which an educator uses questions, prompts, and other structured interactions as cognitive supports for learners during an extended investigation

(Samarapungavan, Mantzicopoulos, and Patrick 2008). In museums, people of different ages and experience levels (commonly, adults and children) often visit and learn together, allowing scaffolding to occur within groups. The Tinkering Studio supports learners in scaffolding one another through assisting each other, modeling for each other, or co-building.

During our analytic discussions of the videos, we developed three indicators of Social Scaffolding. The first is *requesting or offering help* in a direct way. On a day we featured Circuit Boards, a boy saw two other young people successfully turn on a lightbulb and asked them, “How did you light it up?” The second indicator occurs when one person *inspires new ideas or approaches* in another. Take this example from the Wind Tubes activity: a girl’s flying creation became stuck in the wind tube, so a boy used his kite-shaped contraption to bump hers free of the tube. The girl then fashioned her own kite object and used it to help release others’ creations that stuck in a tube. The third indicator of Social Scaffolding is *physically connecting to others’ works*, as when a boy decided to create a marble machine that would connect to his sister’s machine.

Although Social Scaffolding most often may ensue when learners are working together on the same assemblage, our Library of Exemplars focuses on the more unusual moments when learners are working on separate creations. In one clip, a boy silently noticed that the girl next to him cannot get one of her components to work in the Circuit Board activity. On her behalf, he asks the facilitator to get her a new component. Scenes like these are remarkable in that learners are helping one another despite having different goals for different creations. We called this “working across problem spaces.”

**Learning Dimension 4: Development of Understanding**

Although informal learning environments support varied aspects of learning, the development of conceptual understanding is often viewed as critical among them (see National Research Council 2009; Afonso and Gilbert 2007; Anderson and Nashon 2007; Falk and Needham 2011). Indeed, many educators who value tinkering wish to identify the kinds of STEM understanding learners are building during the experience (Petrich, Wilkinson, and Bevan 2013).

The Development of Understanding Dimension takes a broad view of understanding as both a process and an outcome. The four indicators range from more traditional notions of building understanding, such as offering explanations and rationales (Allen 1997; Hein 1998; Afonso and Gilbert 2007), to signs of meaning-making, such as proposing actions and drawing inferences (Gutwill and Allen 2010; Humphrey and Gutwill 2005), or struggling to resolve confusion (Duckworth 2006). Whether addressing process or outcome, our team was interested in the evolution, not the correctness, of learners' ideas and explanations.

The first indicator of Development of Understanding, *expressing a realization*, can manifest through affect (for example, widening eyes, a smile and a nod of the head, followed by renewed vigor in working on something) or utterances, such as when a young woman working in Circuit Boards said, "Oh, now it's all coming back. OK, that makes sense." The second indicator—learners *offering explanations for strategies, tools, or outcomes*—means verbal evidence of current understanding. One father working with his son on a marble track explained, "You still need to support the other end of the pipe. There's so much weight it's making this pop up. So, what if you put another pin under the far side?" The third indicator occurs when a learner *applies prior knowledge*. Sometimes that knowledge was clearly developed before the learner's experience in the Tinkering Studio, as when a young man in the Circuit Boards activity talked about series and parallel circuits: "If you [connect the batteries] in parallel then that's just increasing amperes, right?" Other times, the knowledge being applied was constructed earlier in the tinkering activity. A girl in the Wind Tubes turned from her own contraption to help her friend improve hers. "Was this sticking?" she began. "Yeah, kind of," responded her friend. "See what I did?" continued the first girl. "I put pipe cleaner, really soft and easy to slip, and had it poke up a bit and it worked out perfect. So if you want this one to fly better, maybe you should try something like that." The last indicator, *striving to understand*, may be observed when a learner struggles to understand something, but continues working with the materials to make sense of it. The Library has a video clip of a young girl at the Circuit Boards trying to grasp what would make a doorbell function. For a few minutes, she surmised that it might have something to do with the color of the wires, so she first attached a yellow wire, then a red one, and, finally, a white one. When changing the color of the wires failed to activate the doorbell, she wondered if the problem might lie with a lack of power in the batteries, asking, "Do you think I need another power system?" Her puzzling and her continued experimentation to resolve it indicate a development of understanding.

During the tinkering project, we had many discussions about learning, but also about facilitation. The practitioners spend a great deal of time and energy devising powerful ways to facilitate the types of learning realized in our Dimensions of Learning framework. Over the course of our conversations about facilitation, we decided to identify and categorize video clips illustrating the second component of the Tinkering Library of Exemplars—the Framework for Facilitation Moves.

## Facilitation Moves

Facilitation is a vital component of the Tinkering Studio, and has been a focus of tinkering practitioners for many years (Petrich, Wilkinson, and Bevan 2013). In a self-directed activity such as tinkering, facilitators must carefully balance offering enough support so that learners can actualize their ideas with maintaining enough distance so that learners truly drive the experience for themselves. Striking the right tenor can be challenging, forcing facilitators to question their own interactions constantly: *Should I intervene yet or allow that girl to be frustrated for a few more seconds? Should I offer a new idea or tool, or see if that boy comes up with a solution on his own?* In the MAPDD project, researchers and practitioners developed a framework for describing three different aspects of facilitation in tinkering: Spark, Sustain, and Deepen (Table 2). We adapted the framework to catalogue the video data in our Library. However, we caution that this framework, like that of the Learning Dimensions, should be viewed as a tool for discussion rather than a rigorous scheme for coding behavior.

**<INSERT TABLE 2 ABOUT HERE>**

**Facilitation Move 1: Spark**

The first type of facilitation move—Spark—orients learners to the Tinkering Studio space and its activities while establishing the safety needed for learners to take risks and unleash creativity. Sometimes this is accomplished by the facilitator tinkering with her own contraption, and other times it involves explicit invitations. Entering the Wind Tubes activity, a boy was intrigued by a creation and asked if he might take it home. In response, the facilitator encouraged him to make one of his own: "You can try and look at that, and see if you can make something like that." Boy: "I know but I want to make the exact same thing and I don't know how to." Facilitator: "You guys could try. You could look at how it works and see if you can, kind of reverse engineer it."

## Facilitation Move 2: Sustain

The Sustain facilitation move helps learners continue to participate when it appears they may be stuck or ready to withdraw. We filmed facilitators *offering new tools or ideas* to help learners move past frustration. “How’s it working?” asked one facilitator of a girl with her marble machine. “Bad,” she answered. After she explained the problems with it, he brought over two connected parts. “Can I show you one trick that I like?” he said, and then attached his “blocker” to allow the marble to turn a corner. This helped the girl progress with her marble machine. Another Sustain Move is to reinforce the safety of tinkering by *welcoming learners’ ideas*, even if they seem counterintuitive or unusual. In the Wind Tubes activity, a boy wanted to make his contraption float higher. His mother asked what could he add that would “grab the air.” He and the facilitator laughed as he came up with using a discarded plastic bag. As the boy began to work with the bag, the facilitator acknowledged, “That is a good tinkering spirit right there. Don’t let the trash go to waste. I like it.” A third means to Sustain learners is to try to *re-engage them as their interest wanes*. Another young girl working at Circuit Boards had difficulty making a lightbulb turn on. Disappointed, she rested her head on her hand and sighed. The facilitator noticed that her circuit had only one wire from the battery to the lightbulb, traced her finger along that wire, and gently prompted, “So, the electricity starts from here and then, you’re going to need . . . what?” Without a word the girl connected another wire and successfully lit the bulb. Facilitators may also Sustain participation by *re-voicing learners’ ideas* to help clarify the nature of a problem. In one case, a girl making a marble machine struggled to get the marble to drop down into a pipe, stating, “That’s the problem all right.” The facilitator asked, “Because it doesn’t go in there?” to which she responded, “Because it has too much speed.” “Too much speed?” continued the facilitator, “OK.” They then worked together for a few minutes to adjust the machine so the marble would slow down and drop into the pipe.

**Facilitation Move 3: Deepen**

In the facilitation move we call Deepen, facilitators help learners make more complex creations and develop their understanding of the natural phenomena within the activity (for example, electrical current, momentum, and aerodynamics). They may do this by *challenging learners to "complexify"* their work. When a boy in the Wind Tubes activity finished flying his contraption, the facilitator reminded him of a remark he had made minutes earlier, "Did you want to make a little passenger to go in there?" Her question was intended to deepen his exploration by asking him to make his creation more intricate. Another method to Deepen participation is to *foster reflection* by asking learners to make a prediction or offer an interpretation. A facilitator asked a learner in the Wind Tubes activity, "Do you think it's gonna fly with the basket up, or . . . ?" which prompted the learner to consider how she wanted and expected it to fly. In a clip of an example of *soliciting interpretations*, a facilitator asked, "Is it flying how you thought it was gonna fly?" which again triggered reflection. The purpose of a Deepen Move is to help learners take their tinkering to new levels, either through greater complexity in their work or more profound thinking about that work.

**Connections between Facilitation Moves and Learning Dimensions**

Once we had developed the Tinkering Library of Exemplars using the two frameworks, we set out to determine whether links exist between facilitation and learning. Our intent was to explore the terrain in preparation for future studies rather than use our data to gauge definitively the extent of any connections. To search for links, we revisited the facilitation clips and observed learners' interactions in the five minutes following the facilitation move. We found many instances in which a facilitator's move fostered learning. In just one example, a group working on a marble machine encountered incessant difficulty keeping their ramps on the wall. The facilitator made a Sustain move by offering them a new tool: "Have you guys tried using clothespins to help hold on ramps?" "No," replied a boy, "How do they work?" Instead of answering him, the facilitator showed them another group's work: "Well, if you want you can come around over here and see what these guys did. You can see, other people use different stuff to help hold it together. Just to get some ideas." "That's really great!" exclaimed the boy from the first group, then he launched into a conversation with members of the other group. Here, a Sustain facilitation move led to Social Scaffolding (inspiring new ideas or approaches).

Anecdotally, in our small qualitative sample, the type of Facilitation Move did not seem to lead to a particular Dimension of Learning: Spark moves led to Initiative and Intentionality as well as Social Scaffolding; Sustain moves supported all four Dimensions; and Deepen moves triggered Engagement, Initiative and Intentionality, and Development of Understanding. Clearly, many contextual factors affect how learners respond to facilitators, but the connections we found motivate us to articulate those links further and look for patterns within them in future studies.

**Discussion**

In videotaping groups in the Tinkering Studio, we found evidence of learning, examples of facilitation, and indications of links between them. Working together with the tinkering practitioners, we used the videos to refine frameworks for learning and facilitation, leading to four Dimensions of Learning and three broad Facilitation Moves. We created a

Tinkering Library of Exemplars that uses the frameworks to categorize over one hundred video clips of learning, facilitation, or links.

Why is this important?  We believe there are at least three answers to that question: (1) the Library and underlying frameworks help articulate aspects of learning and facilitation in tinkering that are difficult to describe; (2) they represent practitioners' voices in the broader discussion of how to define learning in tinkering; (3) they lay a methodological foundation for gathering evidence for learning in tinkering. Let us turn our attention to each issue.

As mentioned above, many stakeholders ask whether learning is really happening during tinkering or making activities. Recently, Hooley McLaughlin, Vice President of Science Experience and Chief Science Officer at the Ontario Science Center, convened a session at the 2013 ASTC conference entitled, "Is There Science in a Maker Event?" The session was structured as a debate, with Hooley arguing that making and tinkering are nothing more than crafts activities, devoid of STEM content and practices. Our Tinkering Library of Exemplars, however, supports the opposite view: the current tinkering/making movement goes much further than simply embracing crafts to increase the appeal of museums. Based on our qualitative data, we believe that the present movement is better described as an extension of the campaign in science centers and children's museums to design open-ended exhibits that engage visitors in collaborative scientific inquiry practices, rather than solely deliver information (see Ansbacher 2005; Humphrey and Gutwill 2005; Randol 2005; Borun et al. 1998; Allen 2004; Perry 2012). The goal of open-ended, interactive exhibits is to empower learners to drive the experience, to conduct their own explorations, to draw their own inferences. We believe the current trend to include tinkering and making in science centers continues that pedagogical trajectory, encouraging museum visitors to pose their own questions and solve their own problems, produce their own creations, and explore science phenomena along the way.

Still, the artistic or craft elements of tinkering and making remain—how important are they? While we have not yet explored this issue in our video data, we anticipate that artistic components may add important opportunities for personal connection, thereby increasing engagement. They may even augment the pursuit of conceptual understanding. After all, figuring out how to create a contraption that can spin clockwise in the Wind Tube may entail implicit comprehension of key aesthetic principles, such as balance and symmetry (Penny 2011).

The second benefit to refining the frameworks and creating the Library is that these efforts represent another step (started by MAPDD) towards defining tinkering-based learning in ways that are seen as valid and valued by both practitioners and stakeholders. In the Tinkering Studio project, the practitioners continued their MAPDD work to ensure that the exemplars allow colleagues, funders, policy-makers and other professionals to witness learning moments for themselves and draw their own conclusions. We hope that the effort will help align the views and concerns of practitioners and stakeholders. Without such alignment, learning in tinkering could be defined by stakeholders who have little experience with this pedagogical approach, which risks omitting or even denigrating aspects of tinkering prized by practitioners.

We also anticipate that our work will contribute to the ongoing conversation in research circles about what constitutes evidence of learning in tinkering/making spaces and in museums more generally. We engaged in a methodological approach that has advantages and drawbacks.

On the one hand, the collaborative nature of our discussions and data-review sessions profoundly affected our end products, and undoubtedly contributed to the professional development of everyone on the team. We succeeded in developing a shared understanding with practitioners who have a great deal of experience with tinkering. Together, we developed our “eyes” for observing and our “speech” for arguing about whether moments of tinkering activity constitute learning. On the other hand, we were limited by the approach for gathering these very same moments. We know virtually nothing about the learners we were studying, beyond what we could infer from the videos. (As this was a pilot study, we chose not to interview or survey participants.) In addition, we have video observations of our participants only during the time they spent in the Tinkering Studio; we have no repeat visitors and no information on how they used the museum before or after their tinkering experience. Still, the methods we employed enabled us to progress toward our goals. We trust that future studies will build on this work, but employ methods and explore issues set aside by the current pilot study.

We seek to serve three main groups with the frameworks and Tinkering Library of Exemplars: practitioners, stakeholders, and researchers. Tinkering/making practitioners in any institution may use them to explain the varieties of learning experiences that occur in their spaces. We expect they will be used in professional development trainings, conference presentations, and open discussions with colleagues. For stakeholders, the frameworks and Library may perform the critical function of making visible tinkering-based learning processes. Video clips may be shown in presentations for funders and policy makers interested in the tenets underlying tinkering. Finally, for researchers, we hope that the Library will invite critical questions that can be examined more rigorously in future studies. We plan to use the Library’s videos to develop a reliable coding scheme that can assist us to code new clips. We also plan to pursue outstanding questions regarding the nature of the connections between facilitation and learning, and between the design of the activities and environments and resulting learning experiences. In short, we hope to tinker with this Library for years to come.

## NOTES

1. The video clips within the database are hosted on a password protected server. To obtain the Library and necessary password, please follow the procedures outlined in the Tinkering Studio's website: http://tinkering.exploratorium.edu/learning-and-facilitation-framework.
2. Five minutes after the Facilitation Move seemed long enough to capture learners' responses, yet short enough to plausibly indicate a connection between Facilitation Move and Learning Dimension.

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