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The STEAM Dance Makerspace: A Context for Integration

An Investigation of Learning at the Intersections of STEM, Art, Making and Embodiment

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Abstract

This dissertation is an ethnographic study of the dance makerspace, a learning environment designed to support STEM engagement through making and embodied experience for a group of African American youth dancers. It looks at how participants in a 4-week summer camp program at an urban creative arts center-turned-makerspace, constructed embodied understandings as they developed projects that integrated STEM, dance, and making. Through a detailed analysis of the dance makerspace design, and of participant engagement in activities, I investigated what it meant to do science in an informal out-of-school context, where activities were guided by children's interests and ideas, and where learning science was not necessarily the ultimate goal. In this dissertation, I will share analyses from the perspectives of designer, facilitator, and participant researcher, the three roles I played in the study. I examine how factors related to design and facilitation influenced youth engagement with STEM. I also examined dance as an interest, a representational medium, and a tool for sense-making, using ethnographic descriptions to show how and what youth learned as they engaged in embodied sense-making practices; and the relationships between STEM, art, making and the body when dance was used as a representational medium. This work brings readers inside the making process and demonstrates the potential for conceptual learning outcomes in informal STEAM making spaces. The findings show how the design and facilitation of activities created opportunities for youth to engage meaningfully in STEM in ways that are nontraditional, utilize their bodies for sense-making, and integrate STEM and arts practices. These findings further our understanding of STEAM learning in makerspaces, and they have broader theoretical and methodological implications. First, the study lends empirical support to research on *making to learn* by demonstrating how STEAM making can lead to conceptual understanding. It also expands ways of perceiving the body's role in cognition and

sense-making, broadening definitions of cognition, and provides evidence to counter characterizations of cognition that separate mind and body. Further, the study provides methods for evaluating learning in informal settings where learning goals are not based on specific science content, and particularly when the products being evaluated are multimodal and non-verbal.

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Dedication

for colored girls who dare to dream…

"You don’t have to be awake to dream a dream,
but you have to be awake to follow one."
#dchampism

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Chapter 1. Introduction

In a summer STEM program, a group of five young people worked together to develop an explanation of the human nervous system, specifically, investigating how the brain communicates with the body. After reading through notes from their previous day of research, they stood up and held hands in a circle. Their sketchbook and notes sat on the floor, along with a host of other materials, a few tools, and an electronic device, an energy stick made with LED lights in a plastic tube that illuminated when both ends were held. Their conversation became a mix of talk, movement, and sound effects, taking on many different shapes and occupying different spaces as they moved fluidly around the room – running, jumping, spinning – as they made sense of their notes. At first glance, this composition of sights and sounds could easily be interpreted as chaotic and unfocused activity. Much of it resembles play, but the children were engaged in complex cognitive activity as they developed a multimodal embodied explanation that would include movement, music, visual art and electronic props. They were developing a project in the dance makerspace.

This dissertation is an ethnographic study of the dance makerspace, a learning environment designed to support STEM engagement through making and embodied experience for a group of African American youth dancers. It looks at how participants in a 4-week summer camp program at an urban creative arts center-turned-makerspace, constructed embodied understandings as they developed projects that integrated STEM, dance, and making. The type of exploration described in the short vignette above does not fit with how we typically think about science learning. Dominant and normative approaches to science learning might dismiss this type of experience as unscientific or unfocused fun; however, analysis of children's interactions as they worked to collaboratively construct dance representations of science phenomena shows that the youth dancers found ways to meaningfully engage with STEM content, tools, and practices, learned through embodied sense-making, and explored and expressed their understandings of science phenomena by fluidly integrating arts and STEM practices.

The STEAM dance makerspace was an informal learning space. *Informal* and *out-of-school* learning are terms that have been used broadly to describe structured or unstructured learning that takes place in settings other than formal schools and classrooms. In developing a set of best practices around assessing and documenting learning in informal settings, Lemke et al. (2015) described several categories of informal learning spaces, including informal learning institutions (e.g., museums, aquariums, zoo); after-school programs and community centers where youth interact in more flexible social arrangements with less structure and less hierarchical interaction with adults; short-term, focused out of school activities; computer-based online spaces; and learning in homes with families. The dance makerspace, while an out-of-school program, functioned as a semi-structured, interest-driven collaborative learning space (Cole, 2006; Stevens et al., 2016). In the dance makerspace, youth participants collaborated to create projects that combined dance choreography and electronic technologies. Their projects integrated making with science knowledge and technical and artistic skills. This exploratory study investigates learning at the intersections of making, STEM, art and the body, and specifically, what it means to make in an informal STEAM context where dance is a primary medium for representation.

Making and the Arts

There is somewhat of a natural connection between art and making as both deal with the production of creative artifacts. Art and making have been compared in research literature, which has pointed out similarities in art and making practices, makerspace and studio settings, and the habits of mind developed by participation (Halverson & Sheridan, 2014; Sheridan et al., 2014). Making activities are considered to be a combination of engineering, art and design practices (Wagh et al., 2014), and making blends aspects of arts and engineering through a learning-by-doing philosophy that is also common in studio arts. Like in art studios, participants in makerspaces work independently or collaboratively with materials to design and make products. In the learning sciences, researchers have begun to recognize an emerging domain of art that involves digital technologies as "new media" or "media arts." There are bodies of work emerging around the relationships between making and media arts. One strand of this research focuses on arts approaches to making and creativity and a second involves maker approaches to arts. Researchers are looking at art production in makerspaces or other out-of-school environments where youth are using new media tools and technologies (Peppler, 2016); how out-of-school arts organizations support making and digital art production (Halverson, 2013); and multidisciplinary design work in makerspaces (Sheridan et al., 2014). Peppler (2016) has suggested that contemporary arts education could be enhanced by considering it through a lens of making with wearable technologies. Research has also focused on the value of negotiating the tensions between technical, expressive and aesthetics aspects of making (Wagh, Gravel, Tucker-Raymond, Klimczak, 2014). However, studies have primarily focused on media arts, not on dance as a mode of expression or an art form with its own values and practices.

Making and STEM

There has been recent emphasis on the need to increase student participation, engagement, and interest in STEM disciplines in meaningful ways, particularly among populations underrepresented in STEM. Out-of-school STEM learning research has focused on finding ways to help children more closely identify with and meaningfully engage in STEM. This work has emphasized the importance of providing experiences that use interest-driven approaches to STEM engagement (Stevens, Jona, Champion, Echevarria, Hilppö, Penney, & Ramey, K., 2016; Larson et al., 2004; Barton & Tan, 2010; Cohen & Kahne, 2012), the value of acknowledging the overlap between science and children's everyday activities (Nasir et al., 2006), and the benefits of using culturally relevant educational approaches that foster personal creativity and ingenuity along with STEM knowledge and understanding (Blikstein, 2013). The idea of "making to learn" in makerspaces has garnered attention from those interested in the opportunities informal learning environments present for increasing interest and engagement among children who feel disenfranchised from STEM (e.g., Brahms, 2014; Sheridan et al., 2014; Bevan, 2017). There is both growing interest and opportunity in the use of informal spaces like makerspaces for STEM learning. Advocates argue that makerspaces offer chances to engage in STEM knowledge and practices in creative and playful ways and empower learners through hands-on, interest-driven activities (Sheridan et al., 2014; Stevens et al., 2016). The process of making has been said to afford opportunities for non-conventional thinking and to legitimize non-school based problem-solving practices, which may appeal to youth for whom schooling has felt marginalizing (Hetland, Winner, Veenema, & Sheridan, 2013; Martin, 2013; Buchholz, Shively, Peppler, & Wohlwend, 2014).

Research has shown that making links science learning to creativity and investigation when making activities have been integrated into formal learning settings, helps students engage with science curriculum units, and develops positive learning behaviors and practices, like remaining on task, engaging in task-related discussions with peers, and persisting with tasks through their completion (Bevan, 2015). In out-of-school spaces, making has been shown to support the development of 21st century skills, positive attitudes and dispositions toward STEM, design and engineering practices, problem solving, and spatial skills (Bevan, Vossoughi & Bevan, Ramey, 2017). This research, which has highlighted a wide range of skills, identities, and practices that can be developed through making activities, has led to excitement around the possibilities for making to learn among educators and some education researchers. However, there is still a limited number of studies that document conceptual learning in educational spaces, whether informal or formal (Bevan, 2015). There have also been several critiques of making and the makerspace movement that have made some researchers and educators wary of the movement and reluctant to identify wholly with it. These critiques include the frequent association of making with product-based narratives tied to consumerism, corporate values and American economic and political power (Vossoughi, Hooper, and Escude, 2016; Chachra, 2015) and the lack of diversity in activities that have come to be characterized as "making." The Maker Movement has been long criticized for the narrow ways that it has defined both makers and making. Make Magazine, the flagship publication for the Maker Movement, has been called out for its overwhelming over-representation of white boys and men (Buechley, 2013). The movement also focuses on a very narrow range of maker activities, usually those that include robotics and electronics (Halverson & Sheridan, 2014; Buechley, 2013). While makerspaces are beginning to attend more to diversity in the populations served, less attention has been paid to diverse forms of making that focus less on high-end technological tools, or the resources and practices that makers from non-dominant and lower-resourced communities can bring to the task of making. Instead of being positioned as sources of knowledge and skill, working-class communities of color are often positioned as targets of intervention who have more to learn than they have to offer (Vossoughi, Hooper, and Escude, 2016; Barton, Tan, & Greenberg, 2016). While researchers are beginning to think about how to create equity-oriented approaches to making, more work is needed to understand the experiences of non-dominant youth makers from strength-based perspectives.

STEM and the Arts

The separation of arts and sciences in education has been part of our cultural consciousness for so long that we have come to believe that a dichotomy truly exists between the two. This idea, planted by early (17th century Western) philosophers, blossomed into an imaginary divide that for hundreds of years has influenced how we think about what it means to "do science" and how we have shaped STEM learning opportunities. Dichotomous ways of thinking have historically privileged science over art, thinking over doing, the immaterial over body and matter, and logic over emotion or creativity (Brickhouse, 2001). Sociocultural and critical perspectives challenge these ideological separations which have led to narrow perceptions of science as disembodied, emotionless, purely objective, and lacking creativity (Bowman, 2004; Brickhouse, 2001) and to equally narrow perceptions of art as frivolous, irrational and non-cognitive. In actuality, both science and art require creativity and analytical thinking (Root-Bernstein & Root-Bernstein, 2013). Artistic and personal creativity play a role in scientific investigation and in designing science representations (Halverson, 2013; Azevedo, 2000; Calabrese Barton and Tan, 2004). Art-makers must visualize, gather and articulate information, analyze and solve complex problems, and scrutinize their creative work in order to achieve the quality, precision, and communicative power they desire. Both art and science are social forms of knowledge production, thriving on cycles of feedback and iteration and requiring practitioners to develop ways to clearly communicate ideas to an audience. Art and science are different interpretive lenses that both utilize a range of modalities to express ideas.

Opportunities for interdisciplinary, transdisciplinary, and cross-disciplinary thinking and work are becoming more and more prominent with the growing popularity of makerspaces as educational spaces. Understanding makerspaces as multidisciplinary contexts for learning, environments that allow makers to combine art and STEM in ways that are both creative and substantive, requires a better understanding of the relationships between art and science in learning. There is very little scholarship that addresses the overlap between learning through the arts and the sciences, but researchers are beginning to examine the possibilities for learning when STEM and arts are conceived as an integrated *ArtScience* (Root-Bernstein et al., 2011; Brown et al., 2011; Edwards, 2008; Heath, 1986; Jones & Galison, 1998; Root-Bernstein & Root-Bernstein, 1999; Siler, 1996). *ArtScience* highlights commonalities between the thinking and making practices used by artists and those used by scientists and builds on the theoretical philosophy that all things can be understood through art or through science but integrating the two lenses allows for more complete understandings (Enyedy et al., 2014; Root-Bernstein et al., 2011). More research is needed that explores the complexities and examines the potential learning opportunities at the intersections of making, STEM, and arts, and in particular, dance as an art form.

Embodiment and STEM Learning

How we theorize about learning has a great impact on the aspects of learning we perceive, acknowledge and attend to. Educational researchers and philosophers as far back as John Dewey have argued the importance of broader and more comprehensive ways of theorizing understanding and cognition. Sociocultural theories of learning challenge the notion of mind and body as separate entities and expand definitions of cognition and sense-making through theories that consider thinking, learning, and knowledge as situated in a context (Hutchins, 1995), consider the role of emotion, affect and aesthetics in learning (Dewey, 1938; Merleau-Ponty, 1962; O'Loughlin, 1998; Wickman, 2006), and consider the ways that knowledge is embodied.

There have been multiple theoretical attempts to characterize the body's role in cognition, which have led to many different schools of thought on embodied learning (e.g., ecological psychology (Gibson, 1977); dynamical systems theory (Spivey, 2008); grounded cognition (Barsalou, 2008); extended cognition (Clark, 2008); embodied cognition (Lakoff & Nunez, 2000)). Embodied cognition theories have put forth the idea that the body, movement, and gesture are resources for learning and communicating knowledge. Stevens (2010) has identified two distinct variant approaches – conceptualist and interactionist – to embodied cognition theory. Conceptualist theories (e.g., Lakoff & Núñez, 2000; Núñez, 2005) are rooted in cognitive linguistics and theories of conceptual metaphor and argue that understanding is grounded in everyday sensorimotor experiences and that world is experienced by a brain in a body. However, positioning the body's role in sense-making as no more than an interpretive lens for the brain makes it challenging to attend to the ways in which movement can be a cognitive act. Embodied-interactionist perspectives situate thinking and learning within interactions among people and materials in a cultural-material world (e.g. Stevens & Hall, 1998; Stevens, 2012; Hall, 1996; Goodwin, 2000; Streeck, Goodwin, & LeBaron, 2014). Embodied-interactionist research has shown that understandings are constructed through social and material interactions. It emphasizes the significance of the body's role in sense-making, however, it does not explicitly address movement as a creative, cultural, expressive, physical representational medium.

Black Youth and STEM

Even with the recent emphasis on issues of STEM engagement, interest, and achievement among underrepresented youth, low levels of achievement have persisted among youth of color and youth from low-income backgrounds. Researchers have documented the persistent gaps among children from historically marginalized communities even despite 20 years of science and math reform efforts in schools and out (National Center for Educational Statistics, 2012). The statistics are particularly distressing for black youth, and especially for African American girls, who have historically and consistently performed lower on academic measures when compared to girls more generally (Smith-Evans & George, 2014). Black girls, who are disproportionally concentrated in under resourced schools and less likely to be taught by highly qualified teachers, often have limited access to high-quality resources and inequitable exposure to quality instruction and out-of-school experiences (Margolis, Estrella, Goode, Jellison Holne, & Nao, 2005; Barton, Tan & Rivet, 2008; Brickhouse, Lowry, & Schulz, 2000; Carlone, 2004). They also encounter "deeply embedded racial and gender stereotypes, which lead to harsher disciplinary actions for non-conforming behaviors such as expressing their opinions and discouragement from participating in STEM learning opportunities" (Buck, Beeman-Cadwallader & Trauth-Nare, 2015). While these issues can create an infertile context for motivation toward and interest in STEM, the issue is not as simple as lack of exposure or stereotypes, and low performance on academic measures do not tell a complete story. Research on black youth and STEM has tended to view issues of motivation and achievement through a lens that characterizes minorities through the deficits in their STEM participation, college-level STEM matriculation and STEM career choice (Buck et al., 2015). This research, grounded in the underlying assumption the cultural values of black youth are aligned with the white, middle-class norms that position STEM as valuable, suggests that dominant and nondominant youth have the same motivations for participating and excelling in STEM activities. It also discounts the many creative ways Black youth engage in STEM activities in their everyday lives.

We have insufficient knowledge about how to engage diverse audiences in meaningful STEM-making experiences. The formal programming in many makerspaces is often structured in ways that appeal to predominantly white male audiences (Riegle-Crumb & King, 2010). The issue has been cited by researchers who have stressed the need for equity, however, much of the literature on making to learn in makerspaces limits conversations about equity and inclusion to increasing access and opportunities for minorities and girls to join these spaces and to participate in STEM-making activities and maker culture. Questions about how the values of underrepresented populations align and the driving forces for their participation and interest have not yet been adequately considered. The issue is not simply a matter of access, it is also, and perhaps more importantly, about opportunities to connect, to see the tools and activities as meaningful to their lives. While researchers are beginning to tackle this question (i.e., Barton & Tan, 2010; Litts & Searle, 2017), the issue of how to design and facilitate STEM making environments and activities that meaningfully engage underrepresented populations in ways that are responsive to their values, needs, interests and cultural practices is still an open question in the field.

The call for more STEM in education has the potential to shape future generations, drive new innovations and expand opportunities; however, its power has not been realized in many communities of color where children can feel disconnected from STEM and are often less likely to self-identify with STEM because the content and activities are not presented in ways that are meaningful, which can position STEM as removed from their everyday lives and experiences (Oakes, 1990; Barton, Rivet, & Tan, 2008; Simpkins & Jacobs, 2005; van der Veen, 2012; Newton

& Newton, 1992; Barman, 1995; Lederman et al., 2002; Simkins 2005). This work seeks to add to informal STEM learning literature by interrogating a designed informal making to learn environment that seeks to capitalize on interest and familiar practices, and more specifically dance as a familiar cultural practice for a group of urban youth; by exploring the roles of the body and expressive movement in making and sense-making and by examining closely children's work in the dance makerspace to identify the meaningful intersections between STEM and the arts and understand how STEM and arts practices supported their learning.

Questions Guiding the Research

In the STEAM Makerspace, youth engaged with STEM content, tools, and practices as they constructed dynamic embodied representations of science phenomena. They investigated their own questions about different science phenomena by moving, touching, tinkering, and playing with physical materials and choreographic tools. Their understandings were translated through multiple modalities and media and often expressed without words. They took a variety of different pathways of exploration and creation, setting their own goals for the tasks they wanted to accomplish, goals that often changed as they worked. Through a detailed analysis of the dance makerspace design, and of participant engagement in activities, I investigated what it meant to do science in an informal out-of-school context where activities were guided by children's interests and ideas, and where learning science was not necessarily their ultimate goal. The following questions guided my efforts to understand participation and learning in the dance makerspace:

1. What does the "making" of embodied, multimodal, collaborative dynamic representations entail?
    - How do choreographic representations get made?

  - How are ideas translated across different modalities and reshaped to create new embodied meanings and physical representations?
  - What understandings are built in the process?

2. How do participants experience the dance makerspace as a learning setting?
  - How do they understand the experience, its purpose, and its value?
  - How do they engage with and experience the relationship between STEM and dance?

I was deeply involved as designer, facilitator, and participant observer of the dance makerspace setting. In this dissertation, I will share analyses from those three perspectives. The next two chapters (2 and 3) focus on the design and facilitation in the learning environment and the impact of design iteration and facilitation on meaningful engagement. As a design-based researcher, it was critical for me to understand the design and to find useful and authentic ways to understand and describe learning as it was occurring. The remaining analysis chapters (4 and 5) bring the reader inside participants' experiences by looking at learning through the interactions, processes, and practices utilized by participants as they crafted their collaborative projects. In the remainder of this chapter, I introduce the context and participants in the dance makerspace program. I then lay the groundwork for how I understood engagement and sense-making as embodied and examined understanding as doing. Finally, I discuss my methods of data collection and analyses.

The Context: The STEAM Makerspace

The STEAM Makerspace was a 4-week summer program that challenged a group of African American youth dancers to combine dance-making and technology by working in groups to choreograph projects that explained science phenomena using kid-friendly electronic elements (i.e. LED lights, Arduino boards, conductive clay), and other tools and materials. The design intentionally privileged participants' familiar ways of knowing as dancers and positioned science content, practices, and technology as useful tools to help them engage in the creative work they were interested in doing. Participants attended the program 5 days a week, for each of the four weeks, from 9:00 am until 4:00 pm each day.

In this program, the children created group projects given the following prompt: *We all have big questions about the world and how things work. Like Why is the sky blue? or Why do bubbles float in the air? What are your big questions? Create a project with your group that answers your question or explains how something works. Your project must include a dance component and an electronic component.* In order to complete their projects, the children learned to build simple circuits, to design programmable circuits with Arduino boards, Lily pads and Makey Makey microcontrollers, to work with video and music editing software, and developed a host of other technology-related skills. Technological tools, science concepts, and dance composition tools were introduced through daily 45-minute modules and were framed for the youth as useful tools that could potentially help them to express their ideas. The program goals involved exploring science ideas, but because the Makerspace was a free-choice setting with no set content-based curriculum, goals and activities sometimes shifted based on the youth's emerging interests. Project groups were free to choose their own pathways to completion and decide on their own goals. They were guided through the making process by facilitators and mentors, but led by their own interests, researching topics and questions they wanted to learn more about. They were free to choose the directions they want their projects to take. They had the space and freedom to move, to make their own decisions, and to choose when their projects were complete.

Youth Participants in the STEAM Dance Makerspace

The program was implemented in the urban community where I grew up and where my creative arts center is located, a community that is predominantly African American (86%) with a relatively high poverty rate (more than 25% of residents live below the poverty line). However, the arts center program draws a diverse group of students from the region, extending beyond the city limits to attract children from neighboring cities. While the vast majority of children from those communities who chose to participate in the program are African American, it would be a gross oversimplification to consider them a monolithic group. Participants came from a wide range of socio-economic backgrounds, family structures, school types (public, private, and charter) and school experiences, and with a range of experiences with science, technology and dance.

The program participants ranged in age from 7-18 (teens, 15-18 served as mentors for younger participants). Youth or their parents signed up for the center's summer program based on interest, and participants for the study were recruited at the time of summer camp registration. The pool of participants, therefore, was biased toward children who were more than likely interested or experienced in dance. However, this was not always the case. The program also attracted children who were interested in science and others whose parents were just looking for summer activities for their children. While the children came from different schools, neighborhoods, and family situations, they did share a set of experiences around coming to this studio in this city and other commonalities around their life experiences growing up in the same region in the Midwest. This includes school experiences in a city with a crumbling infrastructure and “failing” school district. In this district, schools are typically hyper focused on state test prep, which means there is a heavy emphasis on drilling basic reading and math at the expense of science learning experiences. Many programs also emphasize discipline, requiring children to sit still for long hours and not allowing them to talk while in school. There are limited opportunities for quality STEM experiences in school and out of school, which has made it more difficult for the children to see pathways to future STEM careers.

My Role as Designer, Facilitator, and Researcher

I came to this work through my own personal experiences with STEM and the arts. Born and raised in a low-resourced African American community, I developed an early love for math, science and dance. As I learned to make sense of the world through these various lenses, falling in love with each, I also began to experience tensions between my life as a dancer and as a scientist, tensions that were not internal but eternally imposed. The literacies, skills, and ways of knowing I had developed as a dancer were not welcomed in science and math learning spaces, and the literacies, skills, and ways of knowing I had developed through math and science were not understood in dance spaces, even though I always experienced these different ways of knowing as related. This tension ultimately led me to choose a path, and I pursued a career in the "more serious" sciences, with a focus on chemical engineering. However, the artistic and embodied lenses that I brought to sense-making remained. As I worked as an engineer, I often tried to make sense of the ways that dance had helped me understand science and the ways that science had helped me understand my dancing, and I began to study the relationships between somatic learning and cognition. I eventually returned to my community to develop a creative arts education program with a curriculum that infuses science, math, and literacy learning into dance activities.

My background and experiences have allowed me to bring a multidimensional perspective to my research on learning and cognition and have shaped the ways that I understand math and science to be accessible through creative problem solving and embodiment. The dance makerspace is a design-based research project that grows out of that multidimensional perspective. It is an attempt to better understand how to design environments that welcome all of the tools and practices from the different ways that we think as resources in the task of problem solving.

Taking up the multiple roles of designer, facilitator and participant researcher uniquely positioned me to understand the complexities of making in the setting. My role as designer and researcher provided rare access to the intentions, understandings and concerns of the design. As a participant researcher, I approached observation from an insider's perspective, using my own disciplined perception (Stevens, 2010) as a dancer to understand the dynamic processes involved in dance-making, and I experienced the context with participants, which allowed me to construct rich descriptions of engagement, learning and making in setting.

Theoretical Foundations

Learning through making aligns with the long history of perspectives in educational research and philosophy that argue for learning grounded in experience. The underlying argument for experiential learning was John Dewey's belief that learning happens in interaction, and understanding is transactional. In his writings on education and experience and art as experience, Dewey defined learning in terms of continuity and change. As summarized by Ostman & Ohman (2010):

> "In a learning practice, th[e] *continuity* aspect is understood as the prior experiences the students re-actualize in order to make meaning in a new situation. …The *change* aspect is understood in the way the students relate the recalled experiences to what is experienced in the current educational practice. In this establishment of new relations, students' previous experiences take on a different or extended meaning" (p.12).

Dewey theorized that knowledge and understanding are continually transformed by transactions that take place between individuals and the other people and things in their environment (Dewey, 1934; Dewey, 1938). In other words, learning happens through interaction with materials and people in a context. This idea has been taken up in pragmatic and sociocultural literature and in the design of learning environments in many ways (e.g., materials-based approaches; inquiry-based, problem-based learning approaches; hands-on activities and field trips; constructionism). I have drawn on these ideas in my theoretical stance toward analysis of learning in the dance makerspace. In this work, I consider sense-making through the lens of *meanings constructed through action and interaction*, drawing on pragmatic, practice-based and embodied-interactionist approaches in my efforts to understand how participants made sense of ideas and information. As described later in this chapter, I used practice-based and transactional approaches that focus on understandings enacted in interaction to examine engagement, conceptual understandings, and making practices.

Data Collection and Analysis

This design-based research project had four iterations, which took place in the summers of 2013, 2014, 2015 and 2016. In all, there were 48 youth participants, including program participants and teen mentors, 47 of whom consented to participate in the study. There were also four adult facilitators. The different camp activities required participants to work together in a variety of arrangements. However, the primary focus of the analysis was on group activity in the moments when youth were working in their stable project groups. There were 14 of these project groups in all – three groups in 2013, three groups in 2014, four groups in 2015, and four groups in 2016. Data were collected from all groups and data from the group with the non-consenting participant were eliminated.

Table 1.1. Number of Participants for Each Iteration of the Camp

	Number of Participants	Number (and %) of Returning	% of participants with prior Dance Training/Experience		
			0 years	1-3 years	3+ years
Iteration 1 (Summer 2013)	14	-	36%	-	64%
Iteration 2 (Summer 2014)	15	6 (40%)	6%	27%	67%
Iteration 3 (Summer 2015)	24	9 (38%)	8%	21%	71%
Iteration 4 (Summer 2016)	27	17 (63%)	18%	26%	55%

I collected more than 300 hours of video process data, which was supplemented with participants' reflections about specific moments of interaction and about their dance-making processes, more distal reflections from parents and from participants regarding related practices and experiences, photos and group design journals (which included artifacts like concept maps, writings, drawings, and notes about choreography), and my own field notes and memos.

Part 1: Design Research Data

I began investigating RQ1, how do choreographic representations get made, from the perspective of the designed environment. In order to understand the perspectives of participants, facilitators, and designer across all four iterations of the dance makerspace program, the data used in this analysis included field notes and video of participant interactions, facilitator notes and daily memos, and documentation of design and activity changes for each new iteration of the camp. Participant interactions were video recorded across all camp activities. At the end of each camp day, after a quick facilitator and mentor debrief, the researcher wrote a brief analytic memo that documented emerging understandings about how the camp was functioning and how participants were engaging in the various activities. As is customary in design-based research (Wang & Hannafin, 2005), I engaged in simultaneous data collection and analysis. Design and activity changes were carefully documented, as were the activities that led to specific changes and the reasoning behind those changes.

Video Data. To understand STEM engagement and the aspects of design and facilitation that may have impacted it, I engaged in an analysis of the video data. I looked at facilitator/child interactions across iterations and activity types, specifically attending to tensions that may have led to design changes. I also looked at interactions when there was no facilitator present. These moments were identified through video content logs (Jordan & Henderson, 1995). Through this process, I identified 13 hours of relevant video. From this data set, videos clips of group project work were selected from three different points (near beginning, middle and end) of each of the four iterations (Summer 2013, Summer 2014, Summer 2015, Summer 2016) based the quality of video. I chose to use only clips that included at least 90% of group members in interaction because I wanted to account for engagement across all group members as much as possible in each moment.

Facilitator Memos and Design Documents. I juxtaposed the video data with notes that documented design and activity changes and with facilitator memos to get a better understanding of the moments that led to design changes, facilitation intervention, and their impact on engagement. The notes and memos, initially collected to inform subsequent design changes, served as supplemental data that provided facilitators' perspectives on what was happening in the critical moments that often led to changes in facilitation or design. The notes and memos also allowed me to compare the design intentions with what actually happened in the space.

Part 2: Video Ethnography and Participant Observation Data

For the second part of this study, ethnographic data in the form of video, field notes, and participant artifacts and interviews, were analyzed to understand the process and experience of making embodied, multimodal, dynamic collaborative representations, as well as the sense-making it involved.

Video Data. A second set of video data was analyzed to make sense of participant experiences in the dance makerspace. Participants were recorded in groups as they designed and constructed projects and participated in the other activities of the camp. A whole room camera was used to capture the entire studio space and the children wore point of view cameras (mounted on visors) as they worked together at the tables in the Makerspace. This method of data collection was necessary in order to understand the richness and complexity of their language, as well as their movements, gestures, gaze and other interactions in context. Video recordings were the primary source of data collection, allowing me to capture the "in the moment" details of each group's actions and interactions as they moved through their process of creation, and to effectively record the simultaneous activities of multiple moving children as they constructed their choreography. It was critical for capturing multimodal details that would have otherwise been nearly impossible to describe in notes (especially in the case of youth-generated dance movements that did not necessarily have a corresponding vocabulary to describe them).

For this part of the analysis, I reviewed 36 hours of video data collected from the project work of ten groups (40 participants), their individual interviews and group interviews, along with other representational artifacts across three iterations of the program. Video data were treated in accordance with the methods of interaction analysis (Jordan & Henderson, 1995). All video was content logged based on initial viewing and any available field notes and memos written during data collection. These logs were used in conjunction with field notes and memos to identify moments where children were engaged in sense-making around an idea or concept. These moments were transcribed using a process of multimodal transcription and coded for moments of continuity, and the gaps and relations that were present and an analytic memo was created for each episode. Synoptic representations of the group's process and understandings were created to make sense of shifts in understanding in the moments of sense-making, to allow for comparisons across groups that would reveal patterns and disconfirming evidence.

The video data were also analyzed to trace the different practices that were present in the children's creative problem-solving processes as well as to determine how those practices and other factors influenced their representational choices. I began by looking at the content logs created during and after each iteration of the camp. The logs provided a rough summary of the events on each video. Reviewing the content logs along with video data from interviews and group discussions across the corpus of data allowed me to identify moments of decision-making, negotiation, and conflict as groups engaged in the dance/Making activities during *Make Time*, the time set aside each week to work on projects.

Focal Groups. After content logging, three focal groups were chosen for in-depth analysis. Data from the focal groups was reviewed in order to reconstruct their full project-making processes. Moments of understandings enacted, decision-making, negotiation and tensions that were identified through content logging were analyzed for these three focal groups and compared across a random sample of data from all ten groups from the 2nd-4th iterations. The focal groups were selected based on amount of consistent data available, and each group comes from a different iteration of the camp. Each focal group also has a mixture of new and returning participants. The focal groups selected were: *Fast on Our Feet* (from Iteration 2, Summer 2014), *Kiwi* (from

Iteration 3, Summer 2015), and *Stardust* (from Iteration 4, Summer 2016). Each analysis chapter uses one of these focal groups as an exemplar. Data from all groups across iterations of the camp were used in the analyses. However, because each group worked on a different project, chose their own pathways for project completion, and explored many different ideas on their own individual timelines, using examples from multiple groups would make it difficult for readers who are unfamiliar with the context to keep track of groups and their corresponding projects and ideas. The findings are presented in this format to make them easier to follow.

Design Journals, Field Notes, and Memos. Each group kept a design journal where they were encouraged to take notes, make sketches, and keep track of their developing ideas as projects evolved. The design journal was full of blank pages (half white unlined paper, half graphing paper). The last several pages of each design journal had Share Card templates for the group to fill out each day. The design journals were collected at the end of each iteration and used to supplement video data analysis along with field notes and facilitator memos.

As a participant researcher, I spent most of my time directly engaging with youth in some capacity. Field notes were taken during *Make Time* when activities were not facilitator directed when possible. Each day, the facilitators and teen mentors wrote memos to keep track of progress and needs. These memos were discussed at end of the day briefings and collected as supplemental artifacts.

Individual and Group Elicitation Interviews. Analysis began with data collection. As clips of group work were reviewed, children were asked periodically to participate in either individual or group elicitation interviews so that they could explain different choreographic choices or interesting moments in collaboration. The short (10-15 minute) interviews took place during make time and took the form of quick conversations between researcher and group members as they worked. These interactions were video recorded on a small, handheld device. During the interviews, selected clips were shared with participants who were asked to describe what was happening, to explain what certain movements meant, or how they came up with specific ideas. The elicited response interview (Harper, 1987; Jordan & Henderson, 1995; Stevens & Hall, 1997) not only served as a way of member checking, they allowed dancers to make explicit their choreographic choices, how certain ideas were represented, and what was happening in moments that were unclear to the researcher or that warranted further investigation.

Methodological Tools for Analyzing the Process

Practical Epistemology Analysis. Practical epistemology analysis (PEA) is an embodied interactionist approach to understanding sense-making, as its focus is on the meanings people make as embedded in their practices. It is also transactional. Transactional approaches to understanding regard knowledge as something practical, not something in the minds of human beings, but as something that we do, often in a context in which we are interacting with others (Almqvist & Quennerstedt, 2015). Practical epistemology analysis is a method for studying learning in action by describing the actions people use to deal with events and to pursue their goals. It uses continuity, gaps/relations, and transformation to describe how decisions and relationships are constructed in interaction. Continuity, as defined by Wickman (2006), occurs when actions and language are not questioned but allowed to stand fast in interaction without question or hesitation and an interaction can proceed. An example of this would be if two people are working together to build a cardboard model and one asks to other to score the cardboard. If the second person responds by reaching for a blade and making a light incision down one side of the cardboard, her actions allow the interaction to proceed and are evidence of her understanding. If the second person responds with a confused look or a question about which tool to use or what it means to score, this would be evidence of a gap in understanding. An interaction cannot continue when there is a gap in understanding. In order to fill a gap in an encounter, people must find relations whose use in the encounter stand fast. In this example, the first girl would need to take the time to explain what she meant by scoring in this context in order for the interaction to proceed. Her explanation would allow the second girl to incorporate a new understanding of the word *score* into her vocabulary and to continue with the interaction, demonstrating a transformation, or new understanding, by scoring the cardboard. Transformation is defined as evidence of how experience and what we know is changed as situations are made continuous.

PEA is a discursive analysis that focuses on how people proceed with activities and the consequences this has for what they learn. It was developed as an analytical tool for characterizing the meaning-making process in science classroom discourse and has been used to analyze student meaning-making in socially shared processes (Lidar, Lindqvist, & Ostman, 2006) and to understand the role of aesthetic experience in science learning. It has also been used to understand how teacher practices interact with student learning, how students produce meanings, and what meanings are produced by what practices (Ligozat, Wickman, & Hazma). I applied the framework to video data in order to examine how STEM engagement was constituted in action and interaction of the project groups; to understand how youth constructed, enacted, and interpreted the information they were learning about the science phenomena they studied; and to understand how their chosen practices helped support sense-making.

Mediators and practices. Dance-making as a form of art-making, is a creative process that involves the production of external representations (Halverson & Sheridan, 2014). Dancers use their bodies in relation to space, music, props, and other dancers to create images that represent ideas or symbolize some aspect of the observable world. In this way, dances are representational artifacts (DeLoache & Burns, 1994). Dance has its own form of literacy, with vocabulary (locomotion and gestures in dance), grammar (rules in different languages and dance traditions for putting together the vocabulary and justifying how one movement can follow another), semantics (meaning) and its own set of practices (Hanna, 2008). Making dance is essentially about using a movement vocabulary to create representations. To understand how youth learned from dance-making in this context, I analyzed their making processes through the lens of representational mediators and practices. Studies of students' representational practices have looked at the relationships between representational actions and various mediating factors (Danish & Phelps, 2007). Representational actions are the observable acts that students engage in as they create representations, such as drawing a line, adding a turn or jump to a dance, or an LED to a model, asking a question about a representation, or asking for feedback. Mediating factors are those features of the activity setting that enable or constrain actions. Representational practices are identified by looking at talk and actions as learners create, debate, and modify their representations (Enyedy, 2005; Hall & Rubin, 1998).

Methodological Tools for Analyzing Creative Products

Multimodality/Semiotics. In addition to a process-based approach to this research, I also examined each group's representational product from a multimodal or semiotic perspective. The literature on multimodality has shown that representational choices have consequences for how and what is learned (Jewitt et al., 2001; Jewitt, 2008; Wright, 2003). Semiotics provides a framework for making sense of representational products, "from words, symbols, narratives, symphonies, paintings, and comic books, to scientific theories and mathematically theorems"

(Danesi, 2007, p.3-4). In this study, the representations created were analyzed for both content (what was represented) and form (how it was represented). The multimodal analyses were examined in conjunction with analyses of each group's project-making process.

Conclusion

This dissertation examines the STEAM dance makerspace as a learning environment. The findings presented in the chapters that follow show how the design and facilitation of activities created opportunities for youth to engage meaningfully in STEM in ways that are nontraditional, utilize their bodies for sense-making, and integrate STEM and arts practices. In this introductory chapter, I described my rationale for engaging in this work, the theoretical principles that guided my investigation, the data and methods of analyses that I used. In the chapters that follow, I seek to articulate what learning looked like in the STEAM dance makerspace by presenting the findings from my analyses. In Chapter 3, I share aspects of design and facilitation that were critical for creating opportunities for STEM engagement, the various ways in which participants chose to engage, and the drivers of engagement. Chapter 4 offers rich descriptions that explain the ways that children developed embodied understandings. Chapter 5 examines the multiple lenses participants brought to their work and how those lenses mediated their representational choices and thinking. Each analysis chapter focuses on the experiences of one of the three focal groups as an exemplar of the findings related to engagement, sense-making, mediators and practices and are representative of the work that was done across groups and across iterations. To set the stage for understanding the dance makerspace as a learning environment, I begin with a description of the program design.

Chapter 2. Design of the Dance Makerspace: A Responsive Approach to Design and Facilitation

The STEAM Dance Makerspace

On a warm summer day in July of 2013, fourteen young dancers walked through the doors of an arts center in the heart of their urban community and into a new type of learning environment. Although many had taken dance classes at this school before, today they were beginning a different type of summer dance program, a dance makerspace summer camp, and no one was sure what to expect. The concept of a makerspace was foreign to the pre-teen and teenaged camp participants, and they had certainly never heard of a dance makerspace. The dance makerspace was part dance studio, part makerspace. Like a makerspace, it was filled with materials, tools, and technologies, including drills and screwdrivers, LED lights and wire, bread boards and circuit boards, craft materials, recycled and found materials that were placed on shelves within their reach. There were also work stations with access to tablets and electricity where groups could collaborate. However, in this space, participants also had access to open floor space in the dance studio to develop ideas through movement, music and art. The goal was to use making as a way into STEM for this group of young dancers. Upon their arrival, the children were met by me and another facilitator who introduced this new program. The experience was new to all of us; we were venturing into uncharted territory. "Making" itself is not necessarily a new phenomenon, particularly for people from marginalized communities like this one who often have to make to make do (Vossoughi, Hooper, & Escude, 2016; Eglash, 2004; Nelson & Hines, 2001). However, the idea of working with no set curriculum, expecting youth to engage in design and construction work that they hadn't done before with no idea how things would turn out was both exciting and a little unnerving.

Over the course of the initial three-week program, the children designed and constructed projects that creatively combined their science interests and developing skills in dance with new sets of tools—soldering irons and electric circuits, music editing and programming software— that helped them bring their ideas to life. The children engaged in brainstorming and research, designed sketches and built prototypes of their project ideas.

Figure 2.1. A group working in the makerspace to create life-sized remote-controlled dance sculptures that would perform choreography with them and one of the final sculptures with a sketch of the designed circuit (iteration 1)

The children immersed themselves in their projects, learning about the tools of the space by using them to bring their creative visions to life. Given the space and freedom to create, to make their own design decisions, they chose the directions they wanted their projects to take. They also ran into setbacks and dead ends, moments of frustration and confusion. With the help of facilitators, who were challenged to find ways to build on their interests, help them achieve their visions while constraining their ideas, and do this without taking over control of their projects, these young dancers went from not knowing where to begin to the presentation of finished products. Through the process they discovered that their bodies were conductors of electricity, used their bodies in conjunction with conductive materials and technology to express their ideas, and constructed many different ways of communicating with their bodies and technology. Their experiences brought to light important issues in designing for learning in these spaces, as well as tensions around facilitation, engagement, and the relationships between moving and making to learn.

The next two chapters explore how opportunities for STEM engagement were created, cultivated, and constrained in a makerspace program that was designed to flexibly respond to the emergent needs, ideas, and interests of its participants. In this case, participants were African American youth, mostly girls, who did not enter the program with explicit initial STEM interest but with a shared interest and in many cases prior experience in dance. Drawing on data from multiple iterations of the camp, I discuss issues of designing for their meaningful engagement from the perspectives of multiple roles I played as designer, facilitator, and researcher. Specifically, I address the ways that the program goals and activities were designed to capitalize on youth interests and familiar practices, the characteristics of the design that allowed for flexible facilitation and iterative changes in response to interests and needs; the aspects of the design and facilitation that led to meaningful STEM engagement for the youth; and the unanticipated and emergent themes and tensions that opened up opportunities to re-design for meaningful engagement.

Designing the Dance Makerspace

Sheridan and Halverson (2014) describe makerspaces as “informal sites for creative production in art, science and engineering where people of all ages blend digital and physical technologies to explore ideas, learn technical skills, and create new products” (p. 505). These spaces bring together “tools, projects, mentors, and expertise” (Hlubinka et al., 2013, p. 1) which together, support a diverse range of making activities, learning and disciplinary practices that include “play, design, the arts, science, tinkering, collaboration, informal and hands-on learning” (p. 1)." There are many ways of defining and configuring a makerspace. The makerspace design explored in this study was not meant to be an exemplar of a makerspace or of an informal STEM-learning environment. It was treated as a design experiment (Cobb, Confrey, Disessa, Lehrer, & Schauble, 2003), where the idea of designing a context for exploring STEM content and tools through familiar dance practices could be examined in order to better understand how children learn and engage in STEM in structured informal settings.

Design Principles

The design process focused on identifying principles that would support novice engagement in making. The initial pilot was designed through a process that began with identifying what the learning goals for participants should be, what things were important for participants to know, understand, and be able to do by the end of the program. The primary goal was to get participants engaged in a process of making that would allow them to apply both scientific and creative thinking tools, to learn the process of making while learning through the process of making. Once the goal was identified, I conducted interviews with both expert and novice makers in order to identify differences in how they thought about and engaged in processes of making and the key ideas that new makers would need in order to engage successfully in projects in the makerspace and move from novice to more expert making practices.[1] Five principles were identified through this process: (1) immerse learners in an engaging environment that provides hands-on opportunities for learning and opportunities to construct their own ideas by playing with ideas, materials, and tools; (2) provide opportunities not only to learn component skills, but to practice integrating them, and then make choices about how and when to apply what they have learned; (3) provide lots of opportunities to iterate in an environment in which failure is embraced as a part of the process; (4) create a community of co-learners, where facilitators and participants can collaborate, pooling their skills and knowledge and sharing the tasks of teaching and learning; and (5) make the learning relevant to students interests and practices.

Making the environment engaging. The dance makerspace was designed to provide opportunities for learning through meaningful play and experimentation, for children to solve problems and construct their own ideas using a variety of media and tools. A key feature of the design was that the environment would immerse youth in the activities of making. The space was inviting, there were many opportunities to touch and do, and lots of time and space to play.

The dance makerspace program took place in a dance studio with large mirrored rooms for dance-making. In the makerspace area, a large carpeted room with table and chairs, tools and materials were readily available and easy to reach. Unlike the industrial-looking environments of many makerspaces, the dance studio had a layout and feel designed to be welcoming for girls; the

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[1] The entire design document is in Appendix A.

materials included familiar craft materials, the tools were small enough for them to use, and the walls were covered with pictures of sample projects and design ideas that were made by and were interesting to girls, including images of projects that featured girls engaged in making. While I looked specifically for images that featured Black girls engaged in making, they were difficult to find. It also included images of projects that featured conductive craft materials (conductive thread, paint, fibers), artistic ways of circuit-building, like electronic "sketches" and paper circuits (Buechley, 2013), and projects that featured human interaction and combined familiar everyday materials (like fruit, pencil lead, paper) with electronic technologies. The pictures represented both products and processes of making (sketches and diagrams of projects in progress). The environment was intended to make the children feel like it was their space, like their ideas would be welcomed, and like creativity should be a part of the process.

There were also ample opportunities to touch and do. The space was filled with inexpensive, recycled and found materials (i.e. cardboard, string, wire, paper, felt, glue) along with other tools, allowing for multiple entry points for exploring ideas. Activities were designed to invite participants to learn by doing. For example, to introduce the young makers to the tools in the space and to electronic technologies, the earliest making activities for newly formed project groups involved taking apart old electronics equipment to explore what was inside and deconstructing old toys and using the parts to create new toys. We started with these types of hands-on exploratory activities, in which there was no right or wrong way to proceed, to allow youth to develop skills and learn about the tools they would be working with, many of which were new to them. In module activities, which are discussed in more detail in the next section, facilitators made sure there were plenty of opportunities for all participants to have hands-on experiences with the materials, tools and technologies that were being explored. The children were able to jump right into projects that required them to use the skills, content and technology they were learning. Children were also given time and space in the makerspace to play.

Figure 2.2. (a) Materials, (b) groups working in the downstairs makerspace area and (c) the upstairs studio space

Providing opportunities to develop and apply component skills. The process of making often requires the application of prior knowledge and as well as new knowledge and understandings. Research has shown that it is beneficial for learners working toward domain mastery to develop "key component skills, practice them to the point where they can be combined fluently and used with a fair degree of automaticity, and know when and where to apply them appropriately" (Ambrose et al., 2010). The dance makerspace program provided opportunities to not only learn component skills, but to practice integrating them, and to make choices about how and when to apply what was learned through modules that were designed to give students opportunities to develop and reinforce relevant component skills in a simpler context. These daily morning mini-workshops took on different organizational structures, including small group work, moments of direct instruction, peer problem-solving and share, and open exploration, but were always facilitator guided. The modules served as an introduction to important content, concepts, tools, and technologies and provided early opportunities for success with activities that required using these concepts. For example, in early modules, participants learned about what causes conductivity through a conductive clay-making activity. Facilitators began the 45-minute session by engaging participants in a quick discussion about electricity and circuits to provide some context for the activity. In the discussion, they provided information about the concept of energy flow and invited participants share things that they knew and their experiences with electricity. Facilitators made connections to the conductive materials that were available in the space, shared things they thought might be interesting to do with them and also found out what youth thought might be interesting. After this brief set up, they began the clay-making activity. In this particular activity, they worked as a whole group to make a big batch of clay. However, facilitators found ways to get every participant involved. For example, one student was asked to read the directions while another wrote down the group's emerging questions as they came up. Other students measured, added and mixed materials and made observations about what was happening as the ingredients were combined. Everyone shared in the work of kneading the dough. Facilitators encouraged youth participation, calling them "mad scientists" and responding to their observations and questions with excitement. We engaged in a discussion about which of the ingredients might make the clay conductive and researched to find some answers. To end, we reflected on the process and the things that were discovered, and then created a space in the materials bin to add the conductive clay.

Other examples of module activities included: exploring different types of circuit components with littleBits electronic building blocks, making a live body instrument orchestra using the Makey Makey and a laptop, learning choreographic composition tools, playing dance brainstorming games, or learning practical skills like how to use the soldering iron. While each module began with an introduction to a concept or a tool to provide context and generate excitement about the day's activity, the module activities took on different forms. At times, as in the example above, facilitators led the whole group in an exploration or activity. In these activities, one or two children would often act as the hands for the groups and follow the directions of the other participants as they tried to complete a task. The other participants would observe, give directions, and ask questions. This explorational arrangement was utilized when materials were limited or when facilitators wanted to focus attention or particular aspects of an exploration. In a second type of module activity structure, facilitators set up multiple stations around the room, each with a different set of tools and technologies (i.e., littleBits, Makey Makey with laptop and different conductive objects), and allowed youth to circulate to find something they were interested in exploring further. While these explorations were often more independent (explorations at each station were not facilitator led), they were guided by a prompt that usually asked youth to try to make something or figure out how and why something worked. The goal of these explorations was to get them immediately engaged in doing, to encourage youth to pick up, open up, and utilize to tools in order to learn about them. Module activities always ended with time to share and reflect.

Figure 2.3 Examples of module activities: (a) littleBits exploration (from iteration 1), (b) conductive clay making and (c) Makey Makey human body instruments (from iteration 2)

In order to complete their projects, children were asked to build simple circuits, to design programmable circuits with Arduino boards, Lily pads and Makey Makey microcontrollers, to work with video and music editing software and, in general, to develop a host of technology-related skills. But instead of positioning exposure to technological skills as the obvious takeaway, the dance makerspace program positioned technology as a useful tool for helping participants engage deeply in their own interests. For example, microcontrollers like the Makey Makey and Lilypad were not introduced as programmable technologies that would help youth learn to code, but as tools that they could use to make music for a dance piece or to enhance an idea for a costume design. Science, technology and dance were framed as tools for expressing ideas. The modules were designed to introduce important concepts and tools and help children develop useful skills. Groups could choose to integrate the skills they deemed relevant into their projects during Make Time. During Make Time, they had access to guidance and assistance from facilitators, mentors, who were older and slightly more "knowledgeable peers" (Cole, 2006), and from the other camp participants who were learning along with them.

Providing opportunities to fail productively. Research on making to learn has suggested that failure can be an important part of the learning process (Kayler, Owens, & Meadows, 2013, Stevens et al., 2016). Researchers have also raised tensions as to whether "failure" is an appropriate term for the process of iteration (Martinez & Stager, 2013; Ryoo et al., 2015). Fostering a safe space for experimentation, exploration and play is a key aspect of idea generation. It allows makers to take chances and supports the process of trial and error that leads to innovative thinking and discovery. The dance makerspace program sought to foster an environment in which iterative play, experimentation, and revision were embraced as a part of the making process by allowing time to play and lots of opportunities for iteration and feedback. Work in the dance makerspace was not completely focused on designing an end product. An equally important goal was to discover through the process – to learn how things worked by playing around with ideas, to think and learn by doing and make something creative in the process. While each group worked toward a final presentation, the presentations were framed as works in progress, which allowed the children time and freedom to take more circuitous routes to completion. The young makers were encouraged to test out even their wildest ideas and to discover through their mistakes. They were also encouraged to share in a knowledge exchange. The dance makerspace design included a daily *Share Time* during which each group could share not only their progress, but frustrations, obstacles, and any open questions they were struggling with. This open space for sharing issues and "failures" was designed to create opportunities for strategy sharing and investigating new ideas. The context was designed to situate frustrations and obstacles and setbacks as important parts of the learning process. The word "failure" was not used in the space.

Figure 2.4. A group shares their progress and gets feedback during Share Time (iteration 4)

Creating a community of co-learners. The dance makerspace was designed to be a collaborative space where facilitators, mentors and young makers could pool their resources, share their skills and knowledge, and share in the tasks of teaching and learning. In order to create the feel of a collaborative community, it was important to create shared values, practices, and expectations, and shared excitement about participating in the process of making. Materials and tools had to be shared in the space, creating opportunities for cross talk between groups. Groups worked on projects simultaneously, in the same space and because they were working on different things, they were able to develop different skills, which allowed them to be resources for each other. Even though they were working in project groups, they were not limited in who they could approach, talk to, or work with at any given time. Youth were free to ask anyone for support. They could go to the adults in the space, the slightly more knowledgeable peer mentors, or other children for help, and offer their knowledge and assistance to others. This approach made it possible for knowledge and skills to be shared freely across groups. It also created a cooperative energy in the space, as shown by this excerpt from a facilitator memo from the first iteration of the program:

> "The kids had a lot of frenetic energy today. There was a lot of loud talking and playing even though they were getting a lot of work done. At one point, they had the music going, and they were singing together as they worked ("You look so much better when you smile!"). They were also asking each other questions and sharing their ideas for one another's projects. The mood in the Makerspace was great. There was an [energy] that was contagious. I was concerned that they were getting a little too rambunctious though. (concerned with safety... didn't want them to get hurt because someone was not paying attention or playing). I tried to settle them down at the end of the day by doing a little meditation. They calmed down a little, but still had a lot of energy... It was cool though. It was the end of the day. I sent them home."

Children were also invited to bring in their own materials to contribute to the makerspace and to share their knowledge, skills, and intellectual resources. It was important to move away from the hierarchical structures between adults and children that are typically present in educational spaces. While the role of the facilitator was to lead the training modules and guide the students toward project completion, facilitators were primarily responsible for “creat[ing] the conditions for invention rather than provid[ing] ready-made knowledge” (Papert, 1993). They were not expected to have content or technical expertise but to engage in the process of making and learning with youth makers. Mentors, facilitators, and youth makers were learners in the space, each with different valued skills sets and knowledge to share. During *Share Time*, every participant was invited and encouraged to contribute ideas and suggestions to presenting groups. Everyone's ideas were to be taken seriously, but groups had the freedom to decide whether or not to incorporate feedback, even facilitator feedback. Each person who wanted to, had an opportunity to ask a question or make a suggestion. Each person was responded to by the presenting group, each idea was noted. Facilitators reinforced the idea that there are no bad questions. Participants (particularly younger children) were not shamed for asking "silly" questions or repetitive ones although they may have been reminded that a question had already been asked. This also served as a way of modeling how groups should work together and the things to think about as they worked on their projects. In this context, learning was a negotiation and collaboration between participants, where different perspectives are valued and respected.

Figure 2.5. A participant in the presenting group recognizes another youth participant who wants to give feedback during share time

Making the activities relevant to learners' interests and practices. The dance makerspace sought to provide authentic, relevant challenges that connected to children's interests and required complex problem solving. A primary goal of the program was to get participants to engage in making in a way that acknowledged and utilized their interests, skills and practices as substantive resources. The design incorporated children's interests in two ways: it combined interest in dance with exploration of science phenomena and electronic technology, and it allowed the young makers to choose their own project themes and pathways to completion.

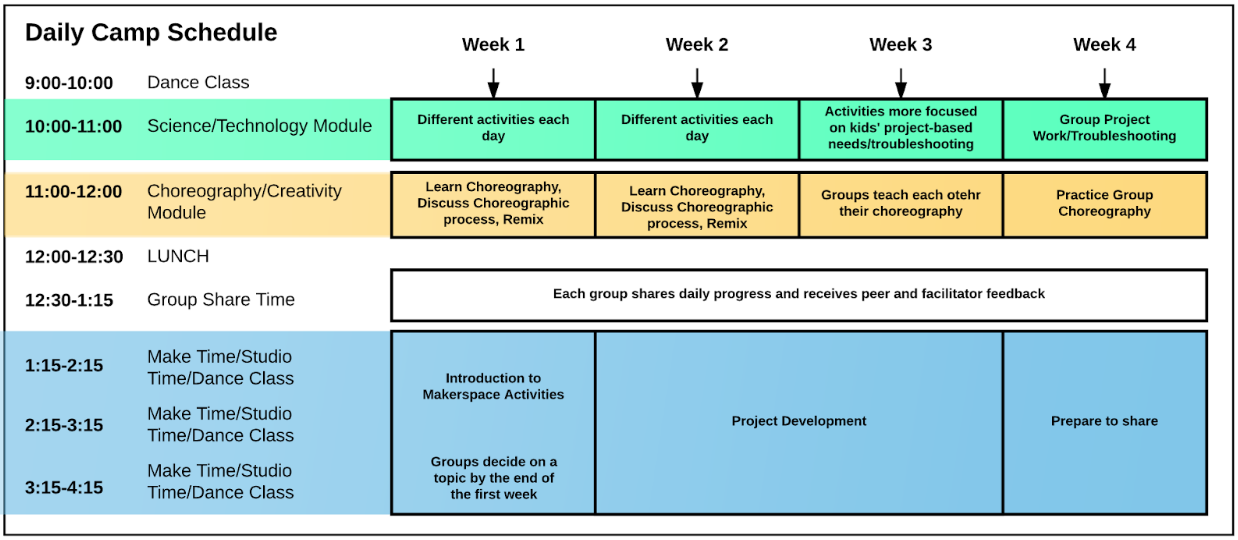
Project and Prompt. The activities and projects in the dance makerspace recruited the children's interest in dance and knowledge of dance and dance-making practices to engage them in STEM exploration. Project groups were given a prompt that asked them to choreograph using electronics, to create a project that combined dance with electronic technology (in iterations 2-4 they were also asked to use their projects to explore a question or phenomenon of interest). The prompt was intentionally open-ended, and the nature of the task required them to learn information and develop technical skills in order to use them to accomplish a goal that was interesting to them. In order to bring their ideas to life, they needed to understand the technology, which required troubleshooting and authentic problem solving. They also needed to understand the science in order to create a dance that explained it. By integrating the science and technology into something they were already interested in and identified with, STEM was positioned as something valuable that they could use and do. They would engage with the technology because it served a purpose for them.

Choosing their own pathways. The design also allowed each group to chart its own course. The prompt provided makers with an open-ended task, and then, along with their groups members, the children decided on a topic to explore, what they would create, and a plan for achieving their goals. Makers were encouraged to seek out information, help and guidance as they needed it, to include ideas and materials that reflected their interests, and bring their projects to completion through their own chosen strategies. The open-ended framing of the task allowed them to bring in their dance experiences, and other experiences, skills and practices as equally valued resources. This learning environment situated STEM as relevant and meaningful while treating young people as knowledgeable and capable, allowing them to participate, contribute, and develop as members of a STEM making and learning community. This need is particularly great amongst girls and youth from low-income communities who are disproportionately treated as less capable in STEM (National Research Council, 2009; Grossman & Porche, 2014).

Integrating Familiar/Cultural Practices. Another key aspect to the design of this learning environment was to find the overlaps and draw on the similarities between making and youth familiar or cultural practices. Sociocultural perspectives on designing for equity for underrepresented populations have attuned us to importance of recognizing, respecting and recruiting children's practices in order to create equitable learning environments, particularly for children from marginalized communities (Nasir et al., 2006; Barton & Tan, 2008; Halverson & Sheridan, 2014). The youth participants come from multiple communities with varied practices. The focus of this design was on dance practices. The dance makerspace design draws on participants' knowledge and practices as dancers through activities that build on and utilize their prior dance knowledge and skills; by foregrounding dance as a tool for exploring STEM, asking youth to draw on their ways of knowing as dancers to explore; and by framing activities in the context of dance-making so youth know how to participate.

Program Activities

The STEAM dance makerspace summer program was initially designed as a 3-week summer intensive program for children ages 9-14. Participants attended camp 5 days a week, for 7 hours each day. In iteration 1, the design focused on creating opportunities for participants to develop skills and efficacy around making. The goal of the program was to immerse children in a creative environment that would expose them to tools and problem-solving strategies so that they could use their developing skills in the arts and sciences to solve an open-ended problem. They were challenged to work together to use kid-friendly electronic elements and other available tools and materials to create group projects that included choreography and an electronic component. At the end of the program, they presented their projects to an audience of parents and peers. In subsequent iterations, the program expanded to 4 weeks and the children created group projects to answer a question or explain how something worked, a science phenomenon.



Daily Camp Schedule

		Week 1	Week 2	Week 3	Week 4
9:00-10:00	Dance Class				
10:00-11:00	Science/Technology Module	Different activities each day	Different activities each day	Activities more focused on kids' project-based needs/troubleshooting	Group Project Work/Troubleshooting
11:00-12:00	Choreography/Creativity Module	Learn Choreography, Discuss Choreographic process, Remix	Learn Choreography, Discuss Choreographic process, Remix	Groups teach each otehr their choreography	Practice Group Choreography
12:00-12:30	LUNCH				
12:30-1:15	Group Share Time	Each group shares daily progress and receives peer and facilitator feedback			
1:15-2:15	Make Time/Studio Time/Dance Class	Introduction to Makerspace Activities Groups decide on a topic by the end of the first week	Project Development		Prepare to share
2:15-3:15	Make Time/Studio Time/Dance Class				
3:15-4:15	Make Time/Studio Time/Dance Class				

Figure 2.6. Sample daily schedule of camp activities with a breakdown of the focus of each week of the program.

Framing Activities in the Context of Dance-Making. Each day of the summer program began and ended with a dance technique class in either ballet, tap, modern, hip hop, or African dance. This helped to ground the summer making experience in dance. Technique classes focused on developing and practicing the technical dance skills required for dance-making and performance. Dance classes were intended to help keep participants immersed in the language of dance, their expressed interest, as they developed new skills and competencies as makers. The morning dance class was followed by two 45-minute workshops. The first was a choreography module that exposed participants to different choreographic elements and composition tools in order to better understand the dance-making process. The second was a STEM module, during which facilitators introduced the youth makers to science concepts like electrons, energy flow, and circuits, and to technologies like microcontrollers, LED lights and the programming software scratch. Modules were intended to present potentially useful choreographic and technological tools that groups could incorporate into their projects if they desired. They took place in the dance studio space and were modeled after dance classes, providing lots of opportunities for immediate feedback, opportunities for participants to work together and see each other's work and progress, and multiple opportunities to attempt the skills they were learning, individually and in groups.

After lunch each day, participants worked in stable groups to develop their choreographic projects. The making process included things that dancers do (i.e., improvisation, choreography, integration of props, choosing music). It also included another process that was familiar to dancers, the process of sharing work and getting feedback. There was a formal time to share before groups went to work on their projects for the rest of the afternoon. During *Share Time*, each project group (4-6 participants) shared their progress from the day before, specifically attending to what they accomplished, what they learned, and what they still needed to know. They took feedback and questions from other makers, mentors and facilitators during this time. The feedback and questions pushed groups to think deeply about the media and modalities they would use to represent their ideas and the scientific accuracy of their representations. Through this process, youth came to care deeply about getting the science right; however, that accuracy was not just about the science. It was also about the dance. An important value that emerged through *Share Time* discussions was that a dance about something has to look like that thing. Youth held each other to this standard when it came to their dance representations. Groups had two hours (split between the makerspace and dance studio) to work on their projects each day, while facilitators circulated, checking in periodically with each group. At the end of *Make Time*, each group filled out a share card, a page in their design journal that helped them keep track of their progress and emerging questions.

Building on and utilizing prior dance knowledge and skills. Because the project required them to create a dance, participants were expected to apply dance and dance-making skills to engage in the work. The nature of the task required participants to utilize their developing dance technical skills, vocabulary, and choreographic composition skills to communicating science ideas. Dance-making is a process that requires connecting and integrating ideas and knowledge from diverse sources, making choices about which ideas and relationships can be represented and how. In order to communicate ideas, choreographers use different *symbolic devices* (i.e., stylization, metaphor, and icon) and *spheres of communication* (i.e., specific movements, sequencing of movement, patterns of performance, intermeshing movements with other communication modes) (Wright, 2003). The process of dance-making provided a foundation for thinking, planning, revising and iteration on ideas, as well as collaborative problem solving (Lai & Hunt, 2006; Fournier, 2003).

Figure 2.7. Youth in dance technique class, learning choreography as a group, and thinking through how to represent phenomena (iterations 3 and 4)

Foregrounding dance as a tool for exploring STEM. Participants were also invited and encouraged to use dance to investigate science ideas, concepts, and phenomena. Space was provided for them to move in order to work through their ideas, and they were challenged to explore new ideas and science concepts by using moving bodies in space. For example, in iteration 1, an activity called *Take Apart Tuesday*, during which children in their project groups worked together to disassemble electronic equipment, led to an emergent discussion and inquiry about resistors and their function in a circuit. A lack of clarity about the function of resistors prompted facilitators to organize an activity in which youth worked together to choreograph a movement phrase that explained the role of a resistor in a circuit.

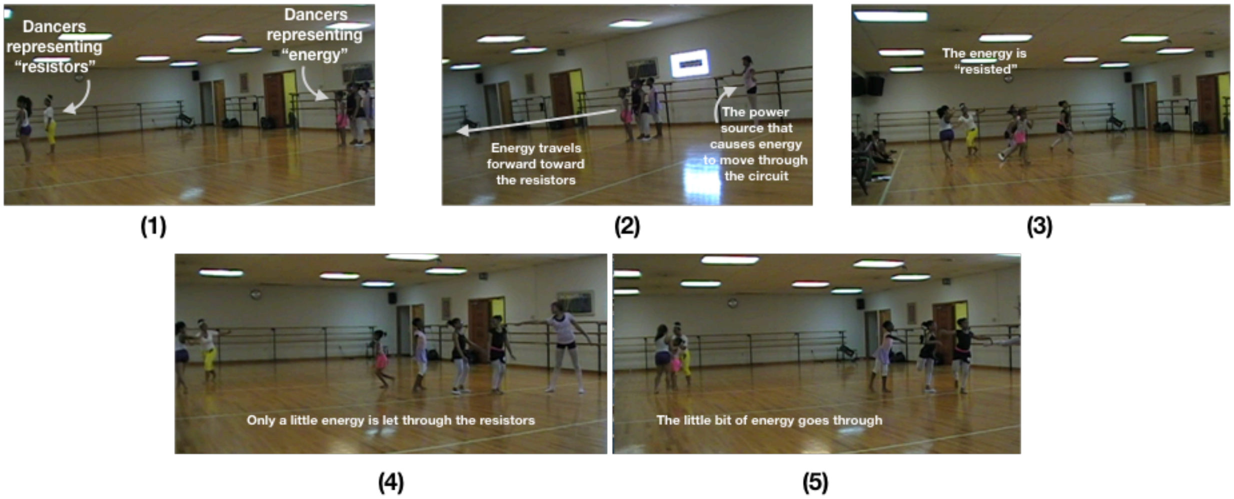


Figure 2.8. Moments from the *Resistor Ballet* choreography annotated with youth's descriptions of what the movements represent.

In this activity, youth were split into two groups, each with slips of paper with information they had written down from the "homework" they were assigned as a result of the previous day's emergent discussion on circuit boards and resistors. Those who had not done the homework at home were given an opportunity to look some things up before we started the full group conversation about it. This was important for a few reasons: it gave everyone an opportunity to contribute to the discussion; to let youth know that we would follow up on engaging their interest in resistors and circuit boards; and to send the message that they need to do the work, but also that if they don't have the resources at home, there would not be negative consequences, they could use the makerspace resources to do it. Each group worked for about ten minutes to develop a quick movement phrase, a rapid prototype that allowed them to think through their ideas about the phenomenon. Then, we engaged in a cycle of feedback, reflection and revision. Each group shared their dance and the observers tried to explain what they saw. The dancers then presented what they thought their dance meant. We talked about how many of the ideas got across and potential other ways to get them across, and they made some revisions. The idea of exploring science concepts and phenomena through choreography was incorporated into subsequent iterations of the dance makerspace program.

A Responsive Approach to Facilitation, Iteration and Design

In order to truly design based on interest, to support youth interests, needs and practices as they developed projects in the dance makerspace, both the design and its implementation had to remain flexible. In this type of environment, where there were no explicit content-based curricular objectives, needs and interests were likely to shift based on what youth were learning, how their projects were advancing, and the decisions they were making. It was important to be able to follow their lead, to allow them to follow their ideas, and to attend to emergent ideas, issues and pathways of exploration. Both the program design and its facilitation had to be responsive. I am defining *responsiveness* as an approach to design that is participant-centered, grounded in a commitment to attending to the needs and interests of those for whom a program is designed as those needs and interests shift and emerge. It is a dynamic form of design-based research.

The process of design-based research involves formulating and iteratively testing conjectures about how designs support learning and involves revising and refining designs through iterative cycles (Barab & Squire, 2004). Because of the nature of this process, DBR designs are interactive, iterative and flexible; initial plans are intentionally left somewhat open so that designers can make deliberate in the moment changes when necessary. However, DBR can also be rigid, too linear, with revisions only taking place on larger timescales. In a responsive approach to design, the design remains open and subject to revision (Gutierrez & Vossoughi, 2010). Researcher and facilitators attend to what is happening in the space, focusing on the experiences of participants and what youth need to remain engaged, and redesign the learning ecology as needed. Changes can be made within and between iterations.

The idea of responsive design and facilitation, while grounded in design-based research, also borrows from culturally responsive pedagogies and design practices intended to engage children of color by affirming their cultural experiences, practices and ways of knowing, and positioning them as knowledgeable and capable doers of STEM. In prior research, affirming children's experiences has taken many different forms, including creating space for and attending to different cultural perspectives (Gay, 2000), valuing different forms of meaning-making (i.e., Nasir, Rosebery, Warren, & Lee, 2006), and building on prior knowledge and ways of knowing (i.e., Tsurusaki, Calabrese Barton, Tan, Koch, Contento, 2013; Moll et al., 1992; Emdin, 2010; Lee, 2001). Another approach has been to situate STEM as relevant and meaningful, attending to children's interests by enriching science lessons with content that highlights sociocultural issues or having them investigate real-world issues that impact their lives (i.e., Laughter & Adams, 2012; Barton & Tan, 2010). Responsive design in this informal learning environment, allows for consideration and inclusion of children's cultural practices by leaving it open for them to decide which practices are most relevant to bring into the learning space, a learning space that is intentional in welcoming youth to bring their whole selves. The goal is to create and examine the impacts of a design that, while structured, is flexible enough to follow their lead, their interests, the ideas they want to investigate. This requires attention and responsiveness on the spot and between iterations.

Responsive design and facilitation in the dance makerspace. There were multiple iterations of the dance makerspace summer camp. While some things remained consistent, the design changed over iterative cycles. Even though some of the program activities shifted, the overarching goal remained the same, to get youth to engage in STEM through dance. It was important to create an environment in which youth felt comfortable bringing their dance backgrounds and knowledge to STEM exploration. The design also had to be flexible enough to allow room for changes when necessary but still provide the structure the youth dance makers needed to engage meaningful in the work of making that integrated STEM and dance.

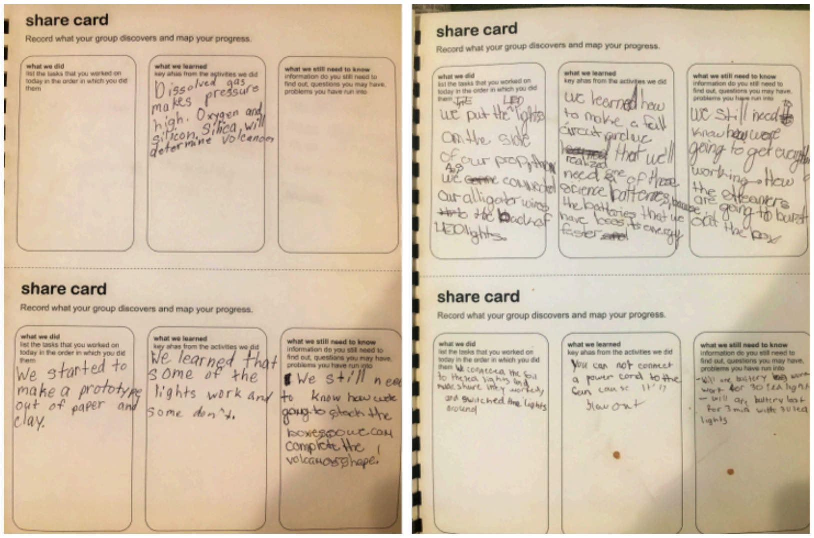
Welcoming Whole Selves. It is possible that many of the youth participants already felt comfortable bringing their whole selves to the dance center space, particularly those who had previously been dance students at the center, because community-based school already functions as a learning environment in which students' whole selves are welcomed. Instructors show an interest in their students' their lives outside of the studio, students bring in their homework for help, science and math are often talked about in relation to the activities of dance class as are issues of the world and issues that they are dealing with in school. They participate in decisions about the kinds of topics that are explored through choreography. There is a permeable line between their lives and their dance lives, and maybe no line at all. Facilitation in the dance makerspace utilized many of these same practices. We asked youth about life outside of camp, we asked them to bring in things they wanted to use or spare materials that they thought be might useful, we shared our own personal stories, triumphs and trials and the children in turn did the same. We shared practices from many different cultural styles of dance (ballet, tap, African, hip hop, modern), talked about the values of dance from different cultural perspectives, and invited them to use their own cultural dance styles to create. We defined dance very broadly, not as ballet or any other specific technique, but as expressive movement that could be whatever they made it. We emphasized the idea that there was no one right way, and that learning was a process that involved putting your ideas out into the world, receiving feedback, and making decisions to revise to move your work closer to what you want it to be. These practices created the space for youth to bring their wholes selves to their work in the dance makerspace.

Three Types of Activity Structures. The dance makerspace design included three types of activity structures that represented different levels of flexibility in the design – an open activity structure, in which activities and participation were driven by children's decisions; a fixed or stable activity structure, in which participants were expected to follow directions and participate in ways that were predetermined; and a flexible structure, in which activities, though loosely planned, remained open to change.

Open. Making time was a completely open structured time. As groups engaged in project work, they made all of the decisions about what they would do and how they would do it. Activities shifted from day to day and sometimes from moment to moment based on the type of work that seemed most relevant or what became interesting as related to their projects. Facilitators and mentors played a supportive role during this time, available to answer questions, give advice, or provide encouragement. Open activities allowed lots of room to take risks to approach problem solving in different ways. While much of the focus of the program was on dance practices, the open activity structure allowed youth to decide which other practices they felt were most relevant to bring into the learning space. They could bring in whatever resources, use whatever strategies, take whatever pathways, and include whatever practices they desired. Each group had their own project goals, and they could use make time to do or make whatever they wanted. Youth were accountable to the members of their group for the work they decided to do. Each group shared their project progress each day, including what they worked on the day before, during *Share Time*.

Figure 2.9. Different ways that making looked in the dance makerspace

Fixed/Stable. Dance classes, on the other hand, had a more stable or fixed activity structure. Dance instructors taught technical skills and grammars, choreography, and conditioning in a format that was typically direct instruction. The structure of *Share Time* was also relatively stable. It was led by either a facilitator or teen mentor and run the same way every day, so that participants could get used to the process of talking about their work, asking questions and making suggestions, identifying issues they were running into or anticipating issues that other groups may confront. There was a standard format for how to report their daily progress, and a template included in the back of each group's design journal to help guide their *Share Time* presentations. A filled-out example of the template, called a *Share Card*, can be seen below in Figure 2.10.



share card

Record what your group discovers and map your progress.

what we did list the tasks that you worked on today in the order in which you did them	**what we learned** key ahas from the activities we did	**what we still need to know** information do you still need to find out, questions you may have, problems you have run into
	Dissolved gas makes pressure high. Oxygen and silicon, Silica, will determine volcanoes	

share card

Record what your group discovers and map your progress.

what we did list the tasks that you worked on today in the order in which you did them	**what we learned** key ahas from the activities we did	**what we still need to know** information do you still need to find out, questions you may have, problems you have run into
We started to make a prototype out of paper and clay.	We learned that some of the lights work and some don't.	We still need to know how we're going to stack the boxes so we can complete the volcano's shape!

share card

Record what your group discovers and map your progress.

what we did list the tasks that you worked on today in the order in which you did them	**what we learned** key ahas from the activities we did	**what we still need to know** information do you still need to find out, questions you may have, problems you have run into
The LED we put the lights on the side of our prop, then 4,9 we ~~came~~ connected our alligator wires ~~into~~ the back of LED lights.	we learned how to make a full circuit and ~~learned~~ realized that we'll need one of these science batteries, because the batteries that we have loses its energy faster ~~and~~	we still need to know how we're going to get everything working. How the streamers are going to burst out the box

share card

Record what your group discovers and map your progress.

what we did list the tasks that you worked on today in the order in which you did them	**what we learned** key ahas from the activities we did	**what we still need to know** information do you still need to find out, questions you may have, problems you have run into
We connected the foil to the led lights and make sure they worked, and switched the lights around	You can not connect a power cord to the can cause it'll blow out	-Will one battery work for 30 led lights -will one battery last for 3 min with 30 led lights

Figure 2.10. Filled out Share Cards from a group constructing a dance about volcano eruption (iteration 2)

Flexible. It was important to create an environment that was structured without feeling too rigid, so that children would be encouraged to generate new ideas and explore uncharted territory (that was often uncharted for both the youth and the facilitators) while they learned skills that would be necessary for successful project completion. With this in mind, there were activities that were designed to be flexible and open to change. The choreography and STEM workshops were both structured and open. They were loosely planned, but not bound to the plan. Not only could the activities within each daily module be tweaked, but the modules themselves could be added or removed based on facilitators' responses to what participants needed. As project developed, shifted and changed, facilitators had to stay in communication with groups to make sure that they would have the materials and tools they needed, that their ideas remained reasonably scoped and scaled, and they were making connections to important information and resources.

Facilitators recognized the needs of each group by paying attention to questions that came up during *Share Time* or during group check ins, the designed mechanisms for feedback; the directions that projects took (i.e., a project idea that required using a technology that children were not familiar with required training on the new tool); and issues or struggles that groups were having (i.e., noticing that a lot of groups in iteration three were getting stuck on figuring out choreography that expressed a mechanism in their phenomenon led to a module on three different ways to express an idea). While facilitators had general goals in terms of what tools to introduce during the morning modules, the modules themselves were often structured as a guided time to play, making it easy to introduce new tools or make adjustments regarding which tools to share based on children’s emergent interests or needs.

Activities in the choreography and science/technology workshops were designed to introduce ideas that might potentially be useful to youth as they developed their projects. While it was clear that they would benefit from playing around with composition tools, the practice of expressing ideas through movement, learning about how circuits work and possible materials they could use or the electronic components, what was most useful often became clearer as their projects developed. Therefore, workshop activities remained flexible and responsive to what was most useful, often evaluated and re-evaluated in situ, which led to adjustments. As researcher, I was careful to track changes in the design as I went, documenting the changes made, the activities that led to specific changes (whether in the midst of one camp iteration or between iterations), and the facilitator or designer reasoning behind those changes.

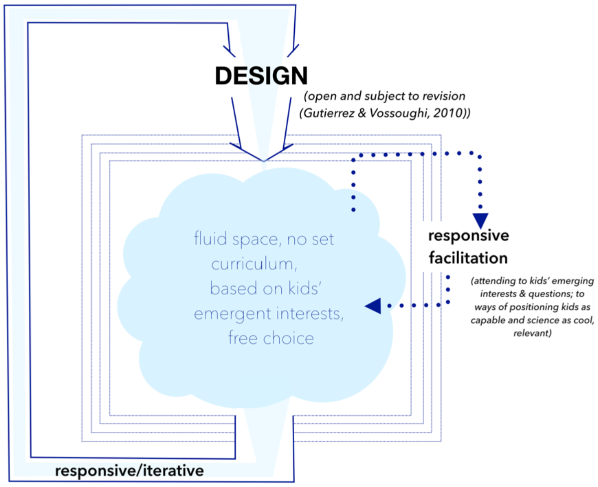


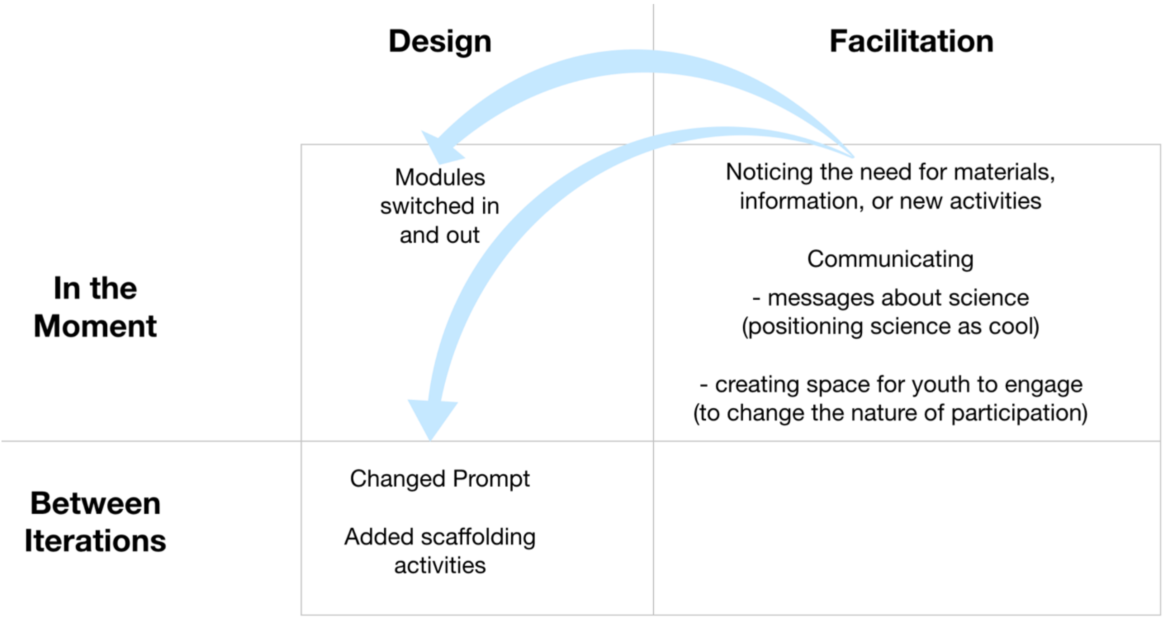
Figure 2.11 Responsive Facilitation and Design of the STEAM Dance Makerspace

There were three types of iterative changes. Facilitation changes that happened in the moment shifted the nature, the purpose, or the content of an activity. Modular changes, in which an entire activity was traded out for a different one, were not instant, but still fairly flexible. These changes could take place within or between iterations. More substantial design changes took place between iterations. One example that incorporates the various types of changes was mentioned earlier in this chapter, the *Take Apart Tuesday* activity that led to in the moment changes prompted by facilitator noticing, modular changes, and iterative changes.

The original goal of *Take Apart Tuesday*, which occurred during Make Time on the second day of the first iteration of camp, was to give participants an opportunity to get familiar using the different tools in the Makerspace in an activity that was low risk – that they literally could not mess up or get wrong. Participants were instructed to take apart the equipment, VCR and beta max machines, a laser projector, anyway they could. They tore into the equipment and began removing pieces. This process raised several questions from the youth. They shared their emergent questions during *Share Time* the following day and circuit boards and resistors became a reoccurring theme of the conversation. Because of the emerging interest in understanding resistors and circuit boards, facilitators sent the youth dance makers home that day with an assignment, to find out as much as they could about what either a circuit board or a resistor was and to bring back information the following day. Facilitators took their inquiry seriously. They could have let the conversation about resistors and circuit boards end with the deconstructing activity, which would have been a perfectly reasonable thing to do, especially because there was a schedule and the facilitators did not have any of the content knowledge required to answer the children's questions. Instead, they went along with the inquiry. The schedule of activities was adjusted the following day to create space for the children to share the information they found.

As that discussion proceeded, facilitators noticed that many were still struggling to grasp how resistors and how circuit boards functioned in a circuit. They decided to make a change in the planned activities for the choreography module to allow participants to continue exploring their developing interest in resistors and circuits boards. The new activity challenged youth to work in two groups to choreograph resistor and circuit board ballets, dances that showed how either the resistor or the circuit board worked, using all the information they had collected. Reflecting on the richness of the children's experiences learning about the function of circuit boards and resistors through choreography resulted in a design change for the subsequent iterations, a new project prompt that used challenge youth to use dance as a way of investigating science phenomena of interest.

In moments of responsive facilitation in the dance makerspace, facilitators noticed the need for information, materials or new activities, which often led to design changes either in the moment or between iterations. They also attended to children's emerging interests and ideas, sought to draw connections between those interests and the dance makerspace activities, and used interests and ideas to elicit excitement around the activities and to position youth as knowledgeable contributors.



	Design	**Facilitation**
In the Moment	Modules switched in and out	Noticing the need for materials, information, or new activities Communicating - messages about science (positioning science as cool) - creating space for youth to engage (to change the nature of participation)
Between Iterations	Changed Prompt Added scaffolding activities	

Figure 2.12. Types of Iterative Changes

Adjustments were made to the types of activities in the modules, the way that the prompts were presented, and the activities that grounded group project making. These changes were based on observed student need rather than on predetermined ideas about what factors might impact learning, participation and engagement. In order to systematically make decisions about what to change and track the changes made as we moved forward, facilitators shared their observations in daily debriefs at the end of the camp day. These debriefing sessions focused on the activities of the day, what we didn't do and why, what we noticed about issues that participants may have had, and how to best address them moving forward. Specific moments brought up during the debrief sessions were tagged for video review. Changes in the schedule were documented and then discussed with youth participants through quick check-ins at the start of the next day. The check-ins provided an opportunity for the youth participants to hear about the changes and the reasoning behind those changes as well as ask questions and make suggestions of their own. Meeting notes from the debrief sessions as well as the tagged videos were reviewed in order to understand shifts in participation and engagement and to make between iteration changes. The following table shows design changes that were made between the first and final iteration of the dance makerspace program.

Table 2.1. Responsive Design Changes Made Within and Between Iterations

	Responsive Design Changes	
	Within Iteration	*Between Iterations*
Iteration 1	• Replaced share time with discussion of circuit boards and resistors • Changed choreography module to circuit board and resistor dance making activity	
Re-Design		• Added activities to choreography modules • Added time for groups to work specifically on project choreography • Paired with other groups in the dance space to give each other feedback
Iteration 2	• New Prompt with a focus on exploring questions of interest • Added Idea Remixing to choreography modules • Added New (project specific) materials added to the makerspace	

	• Groups were encouraged to work on choreography during Make Time	
Re-Design		• Left make time open for groups to decide what aspects of the projects they worked on (choreography or electronic components) • Added all-camp choreography project in the first week • Adding activities that involved playing around with ideas for each groups' choreography to choreography module • Set aside time in technology workshops for prop building and technology troubleshooting
Iteration 3	• Added New (project-specific) materials to the makerspace • Adjusted time spent on all-camp project	
Re-Design		• Constrained the scope and scale of the all-camp project • Added brainstorming activities • Added Choreograph/ Deconstruct/ Remix activities to Choreography Workshop
Iteration 4	• Repeated previous day science module activities at participants' request • Shifted afternoon activities were to allow more time to work on projects • Added opportunities for groups to troubleshoot specific choreography issues during choreography module • Added relaxation exercises and morning reflection time to dance warm up • Abandoned technology module activity with e-textiles because it was not relevant for project work	

The table highlights the types of things that facilitators noticed and reflected on to make within and between iteration changes. For example, it shows that in the first iteration, facilitators noticed both interest and confusion about the role of resistors in a circuit board. They made the choice in the moment to create space for an emergent discussion about the functions of resistors and circuit boards. The discussion led facilitators to add a module activity in which dancers would work in group to choreography circuit board and resistor ballets to help them get a better understanding of resistors and circuit boards. Reflection on these activities led to a new project prompt in the next iteration of the program that used dance as a way of investigating science concepts. Activities were added to the choreography modules that would give youth opportunities to practice explaining science concepts through movement. As groups engaged in their project-making activities in iteration 2, facilitators noticed that many groups were struggling with choreographic idea generation and added an "idea remixing" module as a way to provide strategies for thinking beyond an initial idea. Facilitators also noticed that the schedule, which designated different times to work on the choreography and electrical components, seemed to encourage some groups to think about these aspects of their projects as separate. Facilitators encouraged groups to work on both choreography and their technology elements during Make Time, and reflection on these issues led a re-design in iteration 3. Activities were added to model generating and developing ideas, working together, and explaining ideas through movement and to provide strategies for concept representation and idea development. *Make Time* was left open for groups to work on both choreography and technology. One of the activities added in the third iteration was an all-camp choreography project that was meant to model how to develop dance representations around science concepts. Facilitators worked with youth to brainstorm ideas for the dance project, and participants decided to create a piece that featured many current events, including the Black Lives Matter movement. Facilitators responded to youth excitement about and commitment to the project by creating more time in the schedule than was initially allotted to work on it.

This chapter has laid out the design of the dance makerspace as a learning environment. The dance makerspace was designed to engage youth dancers in a process where they could be creators and STEM problem solvers using their own voices, skills and practices. As designer, the goal was to help participants experience the ways that technology can be useful and see that science can be interesting and that taken together, science and technology can help them to expand their craft. As one of the facilitators, I focused on attending to emerging interests and questions, staying open to new activities and being willing to learn with the participants.

This research is concerned not only with understanding the design, but also with the development of theoretical understandings of learning and engagement within the setting, how changes in designed activities both within and across iterations impacted engagement and learning in the dance makerspace. The next chapter will look at the impact of responsive facilitation and design on engagement. The subsequent analysis chapters will address what and how children learned as they engaged in their dance/making projects.

Chapter 3. Engaging Youth who are Typically Underrepresented in STEM through Responsive Facilitation and Design

This chapter examines how opportunities for meaningful engagement are created and constrained when design and facilitation are responsive. In a responsive approach to design, the design remains open and subject to revision (Gutierrez & Vossoughi, 2010). Researcher and facilitators attend to what is happening in the space, focusing on the experiences of participants and what youth need to remain engaged, and redesign the learning ecology as needed. The focus on responsive design and facilitation relates to research question 1, how do choreographic representations get made, from the perspective of the designed environment. Specifically, I seek to understand what aspects of the dance makerspace as a learning setting supported youth in their making activities.

This chapter will show how attending to the interests, needs and ideas of participants, in the moment and over time, created opportunities and tensions that led to meaningful engagement with information, tools, and practices related to science, math, engineering and technology. I begin by defining meaningful engagement in the context of the dance makerspace. I present examples that show how participants utilized STEM content, tools and practices in their project group work, examining how and why youth made the choice to become or remain engaged in STEM talk and activities. I then examine the aspects of responsive design and facilitation that were critical for creating opportunities for STEM engagement in the various ways in which participants chose to engage. I argue that engagement was a choice made by youth from moment to moment (not a characteristic of certain types of children) by highlighting the ways that the children, facilitators, and the design of the learning setting influenced the choice to engage with STEM.

Meaningful Engagement in the Dance Makerspace

Much of the research on engagement as it relates to STEM has focused on understanding the relationships between student engagement and STEM achievement. Studies have sought to measure how cognitive and motivational factors impact engagement, the relationships between engagement, achievement and future STEM careers (Lau et al., 2002; Singh, Granville, Dika, 2002), and how changes in attitude and engagement affect STEM learning (Martin, Way, Bobis, Anderson, 2015). Engagement in the literature has been loosely and broadly defined. At times, definitions have included: classroom behaviors, attention in class, participation in science activities, homework completed, persistence, involvement in extra-curricular activities, expressions of emotion during interactions at school, self-perceptions and beliefs, and involvement in self-regulated learning activities (Azevedo, 2015). Fredricks, Blumenfeld & Paris (2004) have categorized these various types of engagement as behavioral, cognitive, and affective. Researchers have recently begun to take issue with the divergent interpretations of engagement in the literature, citing this as one of the definitional and conceptual issues with how we talk about the concept, also raising concerns that engagement is often positioned as an individual construct (Ryu & Lombardi, 2015), and often as one that is non-variable, mostly assessed through self-report and studied primarily in the context of schools and classrooms (Azevedo, 2015; Greene, 2015).

Socio-cultural researchers have argued for the need to understand the behavioral, cognitive, emotional and social aspects of engagement not as different types, but as related yet distinct dimensions that are dynamically embedded in environment, content, and activity (Wang et al., 2016). While socio-cultural studies consider engagement as it is influenced by context, sociocultural factors, and educational ecologies (Eccles & Midgley, 1989; Connell, 1990; Skinner & Belmont, 1993, Ryu & Lombardi, 2015; Martin et al., 2015), they still often position engagement as a characteristic of individuals, framing their questions around understanding factors inside and out of school that lead students to be more engaged with STEM in the context of school.

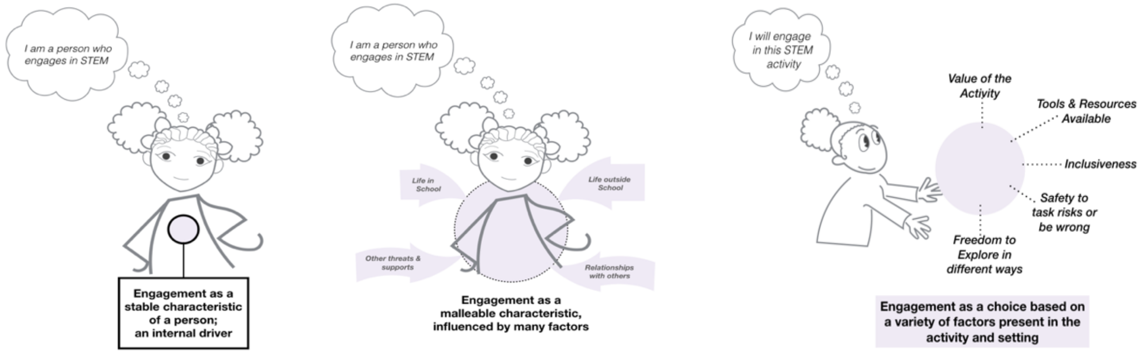


Figure 3.1. Three different ways of thinking about youth engagement in STEM

This analysis presents a shift in thinking about engagement by focusing on STEM engagement through moments of interaction. Where past research has relied on self-reports, which frame the choice to engage in STEM as an individual construct or stable characteristic of a person (e.g., Lau, Shun, Roeser, & Kupermintz, 2002; Ryan & Deci, 2000; Martin, Way, Bobis, & Anderson, 2015), this analysis will show that STEM engagement is a choice enacted from moment to moment, in relation to certain qualities of the environment, activities and interactions. From this perspective, understanding engagement becomes not a question of whether or not a child seems likely to have an inclination for STEM participation, but a question of what aspects of an environment or interaction allow engagement to occur or to continue.

As an out-of-school learning environment, the dance makerspace offered unique opportunities to better understand the driving forces behind children's engagement in STEM activities. In this context, participants had the freedom to make choices about what they would do and how. This offered the opportunity to understand how children engaged when they were involved in self-regulated and self-directed STEM-related activities and were making the choice to be involved and participate in the ways they saw fit. Looking at aspects of engagement in an informal context also offers an opportunity to understand engagement with STEM ideas, content, questions, practices as separate from engagement with school, potentially helping to illuminate and identify ways of increasing STEM engagement, particularly for children for whom school can be a marginalizing experience. It provides an opportunity to look at how STEM engagement can be grounded in creative exploration, as well as how engagement may shift and change from moment to moment. Using video data to investigate engagement this space offers the opportunity to provide rich descriptions that capture what engagement can look like in real time. Understanding the moments that lead to, deepen, or constrain engagement can help to better understand the factors that lead to participation in science.

I have defined meaningful engagement in this context as sustained attention, reflection, or problem solving that involves interaction with STEM content, tools, or ideas and that draws on, connects to, questions, or interprets knowledge and relationships. In this context, engagement was both an individual and a group accomplishment, identified by looking at individual body language and talk as I analyzed the process each group went through to develop their projects and bring their creative visions to life. Given my interest in understanding the fluid and dynamic properties of STEM engagement in this context, what meaningful STEM engagement looked like, and how it was shaped in the moment (influenced by activity structures, relationships, etc.), I focused my analysis of the data on children's encounters with tools, ideas, and STEM content in various activities and group interactions. The literature on engagement provided an orienting frame for which to begin making sense of these moments; however, the analysis was a dialogue between the theoretical ideas and the evidence present in the data (Ragin, 2011). I began by coding the data for three dimensions of engagement (behavioral, cognitive, and affective), but also engaged in a round of open coding and memo-ing to see what themes emerged from the data. I held these two sets of codes in conversation with one another to develop a representation of what was happening in the space. I identified five characteristics that were present in the data across interactions when youth were demonstrating sustained attention, reflection, or problem solving related to STEM:

1. The freedom to choose their own ways to investigate;
2. Opportunities to be creative and iterate on their ideas;
3. Opportunities to use one another as just in time resources;
4. Opportunities to make meaningful contributions or support others in making meaningful contributions to the activity; and
5. A shared/common goal that creates a need and value for the exploration of STEM content.

In the remainder of this chapter, I elaborate on these factors and highlight the aspects of facilitation and design that impacted them through a series of analytic episodes that feature one group's project work during *Make Time*. The episodes are representative of the kinds of interactions seen throughout the data across all ten project groups included in the analysis. During the course of analysis, I identified these factors in project-making work across groups and did not find disconfirming evidence in any other group's work. I am sharing the findings through examples that feature one group because as each project group worked on a different topic of interest, at a different pace, and chose different pathways of exploration, using examples from multiple groups would be confusing to follow. This group was chosen as an exemplar because their work captured in brief excerpts many of the factors that influenced meaningful engagement.

Freedom, Facilitation, and Feedback: The Factors that Influenced Meaningful Engagement

Freedom and the Open Activity Structure

As discussed in the previous chapter, the activities of the dance makerspace were designed as either fixed, flexible, or open structured activities. These three activity structures provided opportunities for participants to learn new and potentially useful information, allowed the freedom for participants to make their own decisions about what activities they would engage in to complete their projects, and provided opportunities for feedback that would help to scaffold their progress. The open activity structure during *Make Time* allowed freedom for groups to take their own creative approaches to research and problem solving. Participants could decide on their own processes for completing their project tasks – what to work on, who to work with, when, and how. As a result, groups often engaged in multiple simultaneous and overlapping activities. As the following analytic example will show, having the freedom to make their own decisions about how to proceed allowed participants to become and remain engaged in research and exploration of their chosen phenomenon.

Episode 1: Kiwi learns about heart attacks. Krystle, Nirvana, Laura, Portia, and Erykah were members of group *Kiwi.* This group of five girls, who ranged in age from 10-13 during the third iteration (Summer 2015) of the dance makerspace camp, set out to understand and create a dance that explained why people have heart attacks. To complete their project, the girls researched the circulatory system, what causes heart attacks, and what happens to the heart during a heart attack. They drew diagrams, built foam models of arteries with plaque build-up, and used their bodies to develop movement phrases. They ultimately created a choreographic project about a man who suffers a heart attack. Their dance combined information about constricted blood flow and the changing rate of speed of a heart in cardiac arrest with images of a person dramatically falling to the ground, while experiencing feelings of fear and pain. Along with their choreography, they integrated music, an Arduino-programmed LED-illuminated beating heart, and a video projection of a man going into cardiac arrest.

This episode takes place during the open activity structured *Make Time* as group Kiwi began the third week of camp. In the previous week, Kiwi used *Make Time* to work on choreography and to develop ideas for an electronic component for their project. They brainstormed multiple ideas for the construction of a beating heart for their dance and went through two rounds of iteration on their choreography, changing the movements they wanted to use to demonstrate the role of the arteries during a heart attack. They changed their minds about their project direction several times and had decided at the start of *Make Time* on this day, day twelve of the camp, that in order to proceed, they would need more information and a better understanding of what actually happens inside the body and to the heart during a heart attack.

Choosing their own ways to investigate. The girls began day twelve by compiling a collection of tools and materials which they spread across the table, including a laptop computer, multiple cell phones, their design journal, loose sheets of paper, foam blocks, scissors, box cutters, and other cutting tools, and modeling clay. As they sat down together at their station, they began working immediately. They chose different approaches to begin investigating the phenomenon, simultaneously exploring multiple aspects and different questions about heart attacks. Portia began making a foam model of the arteries to understand what the blockage would look like. Erykah searched multiple websites to find out if the heart beats faster or slower during a heart attack. Krystle searched on her iPhone and wrote down the information she found on the difference between veins and arteries. Laura shifted between several different activities. She started by making a list of materials needed to make their giant beating heart then volunteered to start making a blocked artery as a comparison to Portia's unblocked one.

Figure 3.2. Group Kiwi engaged in multiple simultaneous activities as they develop ideas for their project on Heart Attacks; (a) Erykah looking up information about the rate of the heart during a heart attack on the internet; (b) Krystle is writing down information from her phone about arteries; (c) Laura and Portia are carving foam; (d) Nirvana is helping Laura and Portia paint the foam arteries.

Kiwi's collective work on this day included many different activities including internet searches for websites that explained different questions they had about heart attacks, cutting, carving, and painting foam, mixing paint, drawing, looking at and comparing images of heart and arteries to their own constructed models, measuring and estimating, and discussing choreography. Each member of the group was actively working in some way, but with the freedom to choose their own ways to investigate, they found multiple entry points into thinking about the phenomenon. The following excerpts show how engagement was supported even as the girls worked on different things, how the freedom of the activity structure and their talk and actions created opportunities for new and continued engagement, gave them ways in to exploring and the phenomenon, and raised new questions.

Excerpt 3.1

Day 12 [BLUE: 00:08:20]

Portia is cutting a foam block with a small hacksaw when Laura returns from the materials bins to their work station with her chosen piece of foam.

1	Laura:	So, are we making two arteries or just the one ‘cause I can start making a second one?
2	Portia:	I need fat- I want some fat
3	Laura:	Huhn?
4	Portia:	I need-
5	Laura:	We could just draw it in
6	Portia:	Yeah but it’s… I want it like 3D
7	Laura:	Okay, let me see how you did yours... can you like flip it over (she wants to see the side that Portia drew on)
8		(Portia flips it so that Laura can see the lines she drew on her piece of foam)
9	Laura:	Okay you did that?
10	Portia:	I'll just trace it
11	Laura:	Yeah you just trace it (she passes her foam piece to Portia)
12		(Portia takes a black marker and makes black lines down the side of the foam)
13		(As Portia is tracing, Krystle holds her phone up to Laura and Portia)
14	Laura:	Where should I put the fat? (looks at a sketch in the deisgn journal)
15	Krystle:	This is an artery
16	Laura:	Let me see it... Whoaaaaa
17	Portia:	We gonna do [ours] like this
18	Laura:	Ours looks like the kid- kids' kind of artery
19	Laura:	(struggles to carve the inside of the foam) Portia, can you help me?
20	Portia:	(looks at Krystle who has put her phone on the table) Hey Krystle, can you carve out the middle, but not that deep?
21		(Portia makes two marks inside the black lines she had already drawn on her foam, then hands her piece of foam to Krystle and asks her if she can carve out the middle...)
22	Krystle:	Like what
23	Portia:	Like carve out some to make a dent… Do we really need to carve it out though?
24	Laura:	Yeah it needs to represent-
25		(Krystle picks up a pair of scissors and uses them to puncture perforations in the foam)
26	Erykah	Okay So I looked up some more information on heart attacks
27	Laura:	You should write it down...
28	Krystle:	I'm 'bout to in a minute (she is still helping Portia carve out the artery)
29	Laura:	I can do it... I can do it...
30	Laura:	Try to make it flat (*meaning carve out the foam until the surface is a flat as possible)
31	Portia:	O: It's not gonna get flat. But it's good because the fat in the arteries-
32	Laura:	Alright

Figure 3.3. (a) Portia carving out foam with a box cutter; (b) Krystle showing Portia and Laura the image of an artery on her phone ("This is an artery")

Communication and opportunities to use each other as just in time resources. The girls were involved simultaneously in different aspects of research and modeling related to their investigation of heart attacks. Although they had independent starting points, they communicated across their various activities in order to support each other as just-in-time resources. For example, at the start of this excerpt, as Laura joins Portia in modeling arteries using foam, she offers Portia an idea for how she can represent fat in the unblocked artery she is making (line 5) but also asks for Portia help in getting started on her own model of a blocked artery (line 7). Portia supports Laura's engagement in the modeling activity first by flipping her model over so that Laura can get a better view of the lines she drew (line 8) and then by offering to draw the lines herself on Laura's foam block (line 10). Portia's support allowed Laura a way in to the modeling activity. Later, Krystle acted as a resource for Portia and Laura by showing them new images of arteries she discovered during her internet search (line 15) and again when she helped Portia carve out her foam artery at Portia's request (lines 20, 21, and 22).

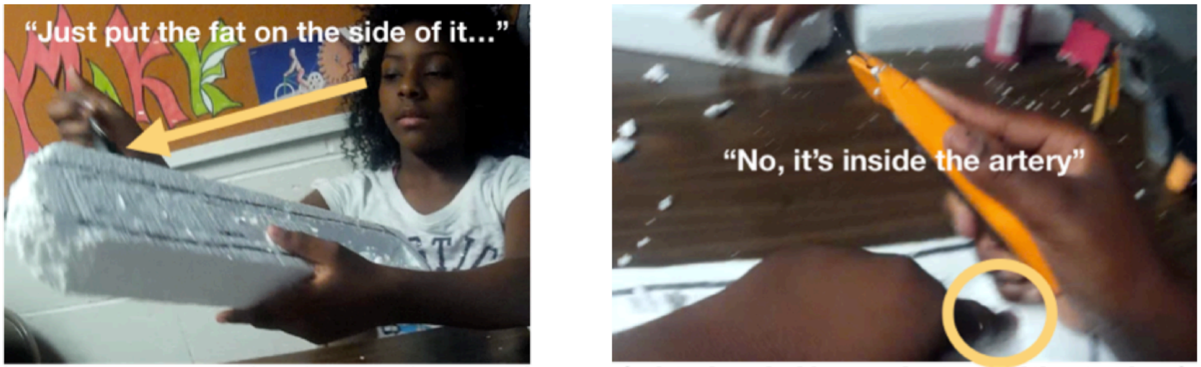
The open activity structure provided the girls the freedom to shift activities, ask for help and get support when they needed it. Opportunities to offer each other help with what to do allowed the girls to start new activities or to continue to work with confidence. The freedom to shift roles to help each other do the work allowed them to continue working without getting frustrated when they found things difficult. When they could get their questions answered, and get the support they needed, they were able to continue the activities of their investigations and move forward and into deeper exploration. In this case, Portia's offer to draw the outer lines of the artery on Laura's piece of foam (in line 10) after also showing her how she made her lines (in line 8) allowed Laura to move beyond thinking about how to get started making her artery and to begin thinking about where the fat should go in her model. Portia became a resource for Laura to help her move beyond what could have been a potential point of frustration. In addition to asking for help, the girls communicated about what they were working on, their intentions and interpretations, the progress they were making, and about how the available materials could be used to best represent the phenomenon. They directed, advised and delegated work to each other (Lines 20, 21, 30) and provided one another with new information (Lines 15, 26). Their open communication and use of one another as resources as they explored the phenomenon supported their behavioral engagement, or active participation in activities involving STEM content or practices.

Finding ways to make meaningful contributions. The girls engaged both behaviorally and cognitively in STEM as they researched and modeled the heart and arteries for their project. Their behavioral engagement was supported as they found ways to make meaningful contributions to the research and modeling processes. The girls not only found ways to position themselves as useful, but also to position each other to make useful contributions to the work that was being done. They did this in a few different ways: by asking for help, by asking to help, or volunteering to do important things for the group. For example, in line 1 Laura volunteers to make another artery. Again, in line 27 Laura points out the need to write down the information Erykah has discovered about heart attacks then in line 29 positions herself to fill the need by volunteering to write the information down because Krystle, who had been scribing for the group, was occupied with helping Portia. The girls also found ways to engage one another by positioning each other as useful. One example of this is in line 20 when Portia, seeing the Krystle has set her phone down, asks her to carve. There were also moments when the girls who were making the models would request more information from the researchers about aspects of the phenomenon and then use the new information to change their approach to modeling or re-evaluate their thinking about a concept. The open activity structure during *Make Time* allowed the girls the freedom to engage by finding ways to be needed, to make meaningful contributions to the group's work. The girls found ways to be included in the work and to include each other as they engaged in research and modeling to explore the phenomenon.

Creative freedom. Opportunities for creative freedom also allowed members of group Kiwi to engage and remain engaged in exploratory STEM activities related to the phenomenon of the heart attack. Portia and Laura began modeling as an activity for their own inspiration, to explore the kinds of things they might do for their project, to begin thinking about how to translate the 2-dimensional drawings in their sketchbook and the information they collected about heart attacks into a 3D-dimensional representation. Their exploration was a negotiation between materials, representations, and their understanding of the phenomenon, which was still developing. Within that exploration, they applied creative interpretations of the phenomenon. One example of this is in line 15, when Krystle showed Portia and Laura an image of an artery she found on her iPhone as they were modeling. Portia's and Laura's responses in lines 17 and 18, "we gonna do ours like this" and "ours looks like the kids' kind of artery", show that they did not feel constrained by the representation that they saw in the image on Krystle's iPhone. They were not hindered by a feeling that they had made a less accurate representation or intimidated by the more complicated image that Krystle showed them. They continued to work on their foam models and embraced their representation as a kids' version of an artery. While this could be interpreted as a lack of attention to detail or an "I don't care" attitude, it is clear from the effort that they put into the project that the girls did care about making a representation that reflected what is happening in the arteries. In lines 23 and 24 Portia and Laura discussed the need to carve the foam, which they had discovered was a difficult task, in order to make an accurate representation. In lines 30 and 31 they related the clumpy texture of the carved-out foam to fat in the arteries, evidence that they were thinking about how the materials they had could best help them represent the phenomenon. As the next excerpt will show, they referred to their own sketches made as part of their research the previous day to support their decisions about where the fat should be placed in their model arteries.

Excerpt 3.2

Day 12 [BLUE: 00:20:09]
1 Laura: I'm gonna cut this out like you are and I'm gonna put something in it to represent the fat...
2 Portia: Just put the fat like on the side of it 'cause that's how it is on the picture
3 Laura: No, I mean this is the part where the fat goes
4 Portia: Yeah but in the picture the fat is on the side
5 Laura: No, it's inside... it's inside the artery
6 Portia: Oh
8 Nirvana: I thought it was on the side in the picture
9 Laura: Uh uh... it's on the side- it's like right here ‘cause it blocks up the artery



(gestures down the outside of her styrofoam artery) (points down inside carved out part of the styrofoam)

(traces finger down the inside of her black line)

Figure 3.4. (a) Portia traces down the outside of the foam with her blade to show where she thinks the fat should go; (b) Laura points with her finger to show where she thinks the fat should go; (c) Laura traces her finger down the inside of the black line drawn on the foam.

Finding ways in to engagement. What began as a way to play around with ideas for their dance project led to a discussion about where fat is located in the arteries. The girls' choice to build foam models of arteries provided opportunities for them to clarify their thoughts and ideas and to make their interpretations visible, helping them to reach a consensus about their understanding of the phenomenon. Activities like carving and painting provided important entry points for additional thinking and raised new questions about aspects of the phenomenon. This included questions about the nature of fat in the arteries (i.e., where it is located and whether it moves); questions about the effects of plaque in the arteries on the blood (does it get infected, should it change color); and thinking about the visible details of the veins and arteries. The next excerpt is an example of how the painting of the foam arteries becomes a way into thinking about the details of the arteries for Nirvana.

Excerpt 3.3

Day 12 [BLUE: 00:22:28.17]

1 Portia: Oooh this some pretty blood. We just need to mix it in with some black for the...
2 Nirvana: We need black to make it darker?
3 Portia: Yeah 'cause if it's dark enough, then it's like isn't it some kind of blood infection too?
4 Krystle: We need to find that out.
5 (Nirvana goes to get black paint. Portia starts painting with the red paint. Laura starts setting up materials to paint. Krystle looks up heart attacks and infection.)
6 Nirvana: Can I help you [paint] it?
7 Laura: Yeah… You can sit over here, 'cause I'm putting it over… on the… (sits it to her left)
8 (Nirvana comes around to Laura's left side to help her paint)
9 Nirvana: (Picks up paint brush and holds it over the red paint)
Is there any details in the artery?
10 Laura: No
11 Nirvana: Look up pictures of arteries
12 Portia: We did that
13 Nirvana: Are you sure?
14 Laura: Ask Krystle
15 Krystle: What
16 Laura: Did you look up pictures of- did we look up pictures of arteries?
17 Portia: Let me look it up
18 Nirvana: I feel like we are building science

Nirvana's entry into the modeling activity began when she went to get black paint for Portia. With the freedom to choose to participate in the ways that felt most comfortable for her, Nirvana had mostly chosen up to this point to contribute to the group's work by fetching materials as they were needed (as she does in line 5). Though she was behaviorally engaged, participating in the activities of the group, her participation was mostly peripheral. Her engagement with thinking about the phenomenon was limited during the foam carving and in the discussions when decisions were being made about where to put the fat. However, when she returned from the materials bin, she asked to help the girls paint the arteries (line 6) and Laura invited her into the activity, creating an opportunity for Nirvana to engage more deeply in thinking about the details of the arteries. This moment is the first time she actually engages with the science. Participating in the painting of the models led her to think about her own questions, to interrogate what she thought she knew about arteries. When she began participating in the process of model-making, which involved deciding which materials to use and why, using images that they found in their research to create the models, asking questions of each other to make sure that their models were "accurate" or true to the images and the information they were finding, in in Nirvana's case, thinking about which colors to paint use for the representation, she got excited about the science. Her questions led the group to do additional research. Her new level of engagement in the research and modeling activities allowed her to feel like she was participating in "building science."

Allowing room for change and iterating on ideas. In the moments that followed, as Erykah brought the laptop over to Portia and Nirvana to look up more information on arteries, she disclosed to the group that her own research had revealed issues with how they had been thinking about their choreographic representation of the heart attack.

19 Portia: Are you done with the computer? Can I see it?
20 Erykah: I'm done with the research
21 (Erykah brings computer to Portia)
22 Erykah I looked up some more information on heart attacks. I think we need to change the dance altogether
23 Laura: Okay
24 Krystle: What now?
25 Laura: We're changing the dance altogether
26 Erykah: What we have to show the heart and arteries right now doesn't make sense
27 Krystle: We need to get in a group chat over text message and discuss some stuff [at home tonight]

Erykah's research led to a demand for thinking about their choreography differently in order to develop a more accurate representation. At that point, their choreographic representation included: four dancers working together to play the role of the veins and one dancer who represented fat in the arteries. They were using movement and spatial formations to show that as the fat (Nirvana) moved through the arteries, the arteries narrowed. Then, they had a series of movements in which they would hit and kicked their heart prop to show the arteries "attacking" the heart. Questions raised as they explained their piece during *Share Time* prompted Erykah to research what happens to the heart and the heart rate during a heart attack. Through her research, she found that size of the arteries does not change as fat particles move through, but that the fat sticks to the artery walls allowing less blood to travel through. She also found that the heart rate decreases because of the shortage of blood, then increases drastically at the point of heart failure. Once she discovered and recorded this new information, she suggested that they would need to change their dance entirely.

When presented with the suggestion that they change the dance altogether (line 22), Laura's response to Erykah (line 25) shows that they were fine with starting over. There is no evidence that they felt like they had failed because their initial ideas were problematic, just quick agreement that they had to make changes. They did not express any frustration and did not seem upset or intimidated by this notion. Erykah's statement was accepted and they began to come up with a plan to proceed. Having the freedom to choose their own pathways for completion of their project allowed them the room to iterate and make changes without feeling pressure to get it right the first time or worrying about setbacks. They came up with a plan to work outside of camp in order to continue to make progress.

A shared common goal that created a need and value for the activity. In this episode, the girls demonstrated sustained interest in STEM activities. Their goal was STEM-related – to understand aspects of a science phenomenon – however, the value of the scientific investigation served a greater purpose for the group. They needed accurate information to inform their choreography. Their common goal, to complete a project to present to an audience, was an important motivator and gave a shared value to their activities. Their activities in the makerspace on day 12 not only helped them to develop ideas for the props that they planned to use in their dance, but also helped them to think more deeply about the phenomenon they wanted to understand. The girls became deeply involved in research and exploration of content related to heart attacks, continuing without prompting from facilitators or mentors, working on their own for more than an hour, communicating with each other and attending to one another's activity. They even showed a willingness to work outside of the program hours in order to make progress on their project.

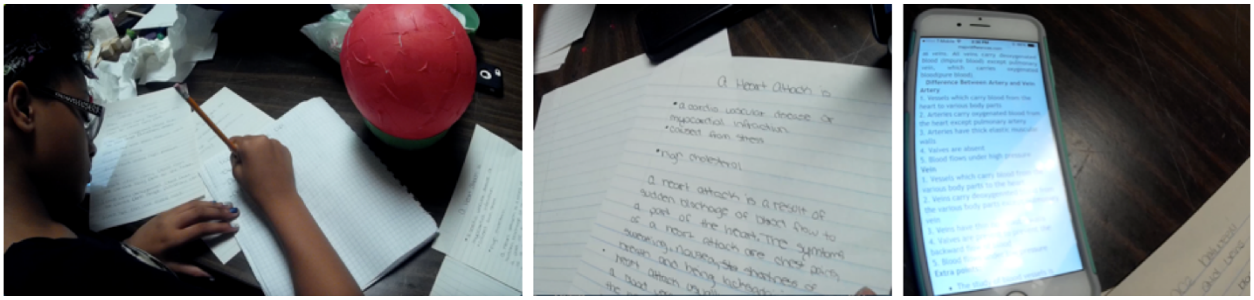


Figure 3.5. Krystle recording her research on heart attacks and arteries.

Summary of Episode 1. Given the freedom to choose their own ways to investigate, group Kiwi engaged in multiple simultaneous activities that were complementary and supported each other’s engagement. The girls took different routes to gather information and insights about heart attacks and worked on different parts of the project as they decided what they were going to do for their dance. They figured out how to use each other as resources and found ways to make meaningful contributions. Their engagement was also supported by their common goal. Their work in the makerspace informed their choreographic decisions.

The open structure of *Make Time* allowed youth the creative space to decide on their own individual and group goals and the freedom to change their minds about how they needed to proceed. They could change goals, make decisions about what was most useful in the moment, and shift activities as they worked. As a result, not only did groups decide to explore different phenomena, but they also had different starting points for their explorations and took different pathways to engagement with STEM content, tools, and practices. Some groups began exploring their chosen phenomena by engaging with materials and tools to help construct their understandings. Others began exploring by using their bodies and choreographic tools to co-construct models of their phenomena. Given the freedom and space to make choices about how to explore ideas that were interesting to them, they often found ways to bring in the things they liked (i.e., clay, glitter, paint, certain dance movement or styles) and pulled from a variety of resources, including experiences from school and home and information from books, friends, songs, and the internet. They also engaged in STEM practices like estimation, measurement, modeling, comparison, and critical examination of their work as they figured out which essential ideas needed to be represented. The opportunity to choose their own adventure as a group but also as individuals within a group, along with other aspects of the design which I will explore below, allowed everyone to jump in and participate at their own level of comfort.

Facilitation and the Open Activity Structure.

In the previous episode, the girls in group Kiwi jumped right into research and modeling as exploratory activities. It is easy to assume from their levels of consistent engagement throughout the episode that members of group Kiwi were youth who were likely to engage in STEM. The next episode shows that STEM engagement in the makerspace was not necessarily consistent within groups or among individuals. Though minimal during *Make Time*, facilitator[2] interactions with project groups influenced engagement in STEM-related project tasks.

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[2] Facilitators in the context of this discussion is meant to include adult facilitators and the teen mentors who were tasked with supported group project work.

During *Make Time*, facilitators entered into interactions with groups in one of two ways, either by invitation or by check in. Sometimes groups would seek out facilitators and mentors with questions, requests, or concerns. At other times facilitators would initiate an interaction by checking in with a group to monitor their progress as they circulated through the makerspace. Facilitator interactions ranged anywhere from a few seconds to several minutes and took on different forms, including quickly answering clarifying questions or filling requests for resources, listening to groups share their progress without providing any input, sitting down and working with youth to brainstorm and develop ideas, working with youth to troubleshoot technical issues, and mediating conflicts between group members. The composition of groups, the complexity of project ideas, and the amount of progress determined the level of support needed by a group. For example, groups that were comprised of younger members or youth who were newer to the camp often needed facilitators to help mediate their discussions. Groups that chose more complicated topics like "how an iPhone works" needed more support in interpreting the information they found in their research and conceptualizing their representations. Facilitators were not STEM content experts, but they made themselves available to provide support as needed. As they circulated through the makerspace, facilitators made judgements and decisions that supported or constrained engagement. Through this next episode, I will identify three different ways that facilitators interacted with group Kiwi and examine the consequences of those interactions on Kiwi's engagement. The examples highlight how facilitator talk and actions positioned youth to be more or less engaged. They also highlight the different ways that facilitators entered into interactions, how they recognized engagement and made decisions about when to leave groups to work on their own.

Episode 2: Making a Heart and Heartbeat. This episode takes place on day sixteen, at the beginning of week 4, the last week of camp. At this point, Kiwi had decided to use Arduino-controlled LED lights for their electronic component. The cornerstone of their piece and a critical part of their representation, the lights would rhythmically illuminate a large (36-inch diameter) papier mâché heart. Days away from their final performance, the girls had yet to begin building the circuit that would control the LED lights to represent the beating heart. They had not figured out how to hook up to the Arduino and they still needed to finish their choreography. Presenting a finished project was still a common goal that they all cared about; however, on this day, they were not engaged in the work that was needed to complete their project tasks. Nirvana and Erykah sat on the floor of the makerspace area, Nirvana singing and kicking her legs while Erykah fiddled with the Arduino board in her hands staring at an Arduino tutorial site on the iPad. Erykah sat silently trying to figure out the Arduino, not talking to any of her group members, while two teen mentors, Kiara and Destiny, applied a mixture of water and glue to a large balloon that was sitting on the table nearby.

"Working for" and "Telling." The teen mentors had been working with the group to papier mâché the 36-inch balloon for their heart for the last two days. When group Kiwi entered into the makerspace on this day, Destiny and Kiara, the teen mentors, were already working on their project. Kiara and Destiny did not look up or acknowledge the girls as they entered and sat in a space on the floor near the table. They did not make eye contact with any of the members of group Kiwi or say anything to them at all. They did not communicate about their progress and did not include the girls on decisions or position them as useful or needed. They continued in their own conversation, which was unrelated to the project or the work they were currently doing. Because the actions and interactions of the mentors were not inclusive, the girls in the group did not feel welcomed to participate in the task. This lack of opportunity to make a meaningful contribution stifled their engagement. When Kiara and Destiny finished one coating on the balloon, they celebrated with one another and finally invited Krystle into the activity, leaving the other girls unsure of what to do.

Excerpt 3.4

Day 16 [GREEN: 0:30]

1 Kiara & Destiny: We did it! Woo hoooo!
2 Destiny: Krystle!
3 Krystle: Yes?
4 Destiny: Come here
5 (Krystle goes over to the table where Kiara and Destiny are working)
6 Krystle: Yes?
7 Laura: I can help
8 Portia: (sitting at a different table with her head down, picks her head up to say) She did not say Laura... She didn't say Laura
9 Nirvana: She didn't say um... Laura Thomas

Kiara and Destiny's actions are an example of facilitator talk and action that position youth to be less engaged. *Working for* group Kiwi, Kiara and Destiny made progress on the project, but the progress did not lead to behavioral or cognitive engagement from the girls who they were helping. There is a tension that can exist for facilitators of open-ended project work between helping in ways that ensure that projects are ready for sharing and helping in ways that enhance meaningful engagement for youth. In this case, the mentors and youth participants worked separately on different aspects of the project, papier mâché and Arduino, without communication between them and some group members were left out entirely.

When Kiara and Destiny did invite Kiwi into what they are doing, their invitation was exclusive. They called only Krystle to come over to their table (line 2 and 4). This moment of exclusivity obstructed the opportunity for others in the group to feel they could make a meaningful contribution to the work. The girls handled this is different ways. Erykah left the group to go and find someone who could help her figure out the Arduino set up. Laura chose to invite herself into the papier mâché activity, even though she was not personally invited. In line 7, when Laura said, "I can help", she took the necessary steps to get herself engaged by positioning herself as a useful contributor. Portia and Nirvana did not feel the same sense of agency in that moment and made a point to tell Laura in lines 8 and 9 that she was not invited. Because those girls were not positioned to feel included, they did not recognize Destiny's invitation as an opportunity for them to make a meaningful contribution and did not engage in the activity of the mentors at the other table. They were left idling. With no direction, they struggled to figure out where to begin working and they disengaged from any project-related activity to play games on their mobile devices.

Excerpt 3.5

Day 16 [GREEN: 01:29]

10 Nirvana: Can I see and play on your tablet
11 Portia: (looking at the tablet): No
12 (Laura walks by and goes to the materials bins)
13 (Nirvana follows Laura to the materials bins)
14 Nirvana: (to Laura): Can I see your phone? Please?
15 Laura: Yeah
16 Nirvana: Yes!
(goes into the dressing room and gets Laura's phone out of her bag... excited maniacal laugh... she picks up the phone and starts walking with it back into the makerspace area... She enters in Laura's passcode and opens a game on her phone)
17 Nirvana: Can I play with your Sims?
18 Laura: (still at the materials bin) Yes... make sure they eat, sleep, and... take a shower
19 Nirvana: Okay (opens the Sims app on Laura's phone). You just earned two hundred and twenty-one dollars

Teen mentor Franklin noticed by their talk and actions that Nirvana and Portia did not seem to be actively engaged in constructive project work as he walked by to check in on group Kiwi. He attempted to get the girls to re-engage through another facilitators interaction strategy, *telling*.

20 Franklin: (to Nirvana): What are you doing?
21 Nirvana: Oh it's Laura's phone
22 Franklin: So, what other part of the project y'all gotta do?
23 Portia: I don't know
24 Nirvana: unuhun (I don't know)
25 Franklin: Ask your group, where's your group?
26 Franklin: Well ask your group what to do
27 Nirvana: We could do some choreography

28 Franklin Yeah do that (starts to walk away)
29 Portia: (does not looked up): That's supposed to be upstairs doing that with the whole group

In this excerpt, Franklin suspected Portia and Nirvana were feeling disengaged from the project activities and made the decision to intervene. He entered into interaction with the girls by asking questions about what they were doing (line 24) and what they still needed to do (line 26). This was common practice among facilitators and mentors as they circulated between groups during *Make Time.* When the girls expressed uncertainty about what they should be doing, Franklin told them to ask their group. When Nirvana attempted to create a meaningful task by suggesting that they could work on their choreography (line 31), Franklin tells them to "do that" but leaves the interaction while there is still some uncertainty between the two girls about whether or not it is appropriate to do choreography without the entire group. By telling them to ask their other group members about what they should be working on, Franklin presented a them with a potential strategy for moving forward; however, his *telling* did not provide the girls a way into working, did not engage them in thinking themselves, or provide the resources or tools needed to support their participation or engagement.

Working with. A more effective way of supporting engagement was when facilitators *worked with* youth to investigate, troubleshoot, and figure things out, positioning them as knowledgeable co-contributors in inquiry. *Working with* in this context did not mean taking on ownership of a project. It meant discovering answers and solving problems alongside youth participants and creating space for them be equally knowledgeable contributors to the process of investigating, troubleshooting, or inquiry. It meant working in parallel to figure things out, using their ideas and giving them ideas to try, openly sharing with them personal knowledge and the struggles, questions and confusion. Working with was not a matter of feigning ignorance or pretending to not know important information but setting up interactions so youth had opportunities to pull from their own knowledge and positioning them as peer contributors. This meant letting them take the lead but also suggesting things to try; asking them for help, not only help doing, but help in understanding; modeling how to get help and also following their strategies for getting help. This next excerpt shows how *working with* the same girls helped them to re-engage in project-related activities.

Excerpt 3.6

Day 16 [GREEN: 00:08:18]

While Krystle and Laura were working with Destiny and Kiara, Erykah came to get me for help figuring out how to connect the Arduino to the LED lights. She had read the website but was confused about how to hook it up. She had stuck the legs of a single LED light in ports 13 and ground. She invited me into the group to help them figure it out.

1	Me	What are **we** trying to figure out?
2	Erykah	How do we connect it?
3	Me	**Let's** figure it out. Portia, Nirvana come here… Do you remember what we said about a circuit?
4	Erykah	(stares at me but says nothing)
5	Portia	It's a complete uh- It's a complete circle (gestures a circle with her pencil)
6	Me	Okay so maybe we should have a circle. What else do we know about? What are the components? What else should be in our circuit?
7	Erykah	holes
8	Me	Holes? What do you mean, holes?
9	Erykah	(Erykah reaches again for the Arduino board)
10	Portia	Negative and positive energy?
11	Me	Okay... negative and positive- there's negative and positive in there... what else? Let's write some of these things down... and draw a picture
12	Erykah	I don't know
13	Me	Krystle and Laura... come over here please...
14	Krystle and Laura	Okay (they walk over to the table)
15	Me	**We** don't know what a complete circuit looks like. Do you know what a complete circuit looks like?

At the point when I joined the group, the girls were at a stuck point. Erykah's body language showed signs of frustration. Nirvana and Portia had dropped out of any project-related activity. My goal as facilitator was not only to help Erykah figure out how to connect the LED light to the Arduino, but also to help the three girls re-engage in the work they needed to do in order to make progress on their project. In this excerpt, I made several moves to position the girls as co-contributors in the process of figuring out how to connect the LED to the Arduino. Like Franklin in the previous example, I entered into the interaction by asking a question about what the group was trying to accomplish (line 1). However, unlike the previous example, I used language that signaled to the girls that this was a problem for us to solve together, asking the girls what **we** are trying to figure out. This inclusive language is also found In line 3 ("**let's** figure it out"), and in line 14 ("**We** don't know what a complete circuit looks like"). The language of "we" set up the interaction as a collaboration, signaling to the girls that we were in this together.

Working with the girls also meant helping them engage in thinking as we worked to figure things out. Instead of telling them what I knew about how to proceed, I asked questions that created opportunities for them to pull on their prior knowledge, helping them remember, think through, and apply things they had been learning, showing confidence in their knowledge base. When they reached the limits of their own knowledge, I enlisted their other group members to support (line 12), showing them that it okay not to know and to ask for help, and supporting their communication with each other, modeling the values that would encourage engagement. At this point in the interaction, *working with* still looked fairly didactic, which was an acceptable strategy for engagement at points when youth did not have enough knowledge or skill to move forward on their own. My work as the facilitator was not only to provide the needed information but to seed and lay the ground for deeper engagement. As the girls got more engaged, I backed off, always trying to position them to take over, and the girls became more vocal, more involved, and began working with each other.

15 Me **We** don't know what a complete circuit looks like. Do you know what a complete circuit looks like?
16 Laura Yeah so, we have a battery (picks up a battery) and some wires...
(goes to the materials bins to get wires...)
17 Me Mmhmm.
Does this light work? (pointing to the light in the Arduino board)

		Have you tested all of these lights?
18	Erykah	Yeah they work
19	Portia	The red and the...
20	Erykah	This one work (pointing to one of the lights)
21	Nirvana	The red and yellow, this yellow and this... yellow work... it turns into red... cause when I did it, it was red
22	Erykah	Don't that mean it's too much energy
23	Laura	(returns from materials bins) So, we have a battery… This is the... negative side (hooks the wire to the battery)… Negative to the long side? …and then, the shorter side... to the positive side?
24	Me	Try it both ways and see what happens
25	Krystle	(points at that alligator clip connected to the battery) It’s not gonna work because the clip is touching both wires
26	Laura	(adjusts the alligator clip)
27	Laura	(switches the connections and the light illuminates)
28	Laura	See it's a full circle... circuit... circle... a full thing
29	Me	So... this is a complete circuit... what makes it complete? It's in a circle...
30	Erykah	OHHHHHHH! That's what a circuit- I remember it now (starts to smile and laugh)
31	Nirvana	The yellow light is glowing red
32	Erykah	It's too much power
33	Portia	It's too overpower- it's yeah

Recognizing the change in engagement. Inviting Laura into the LED-circuit and Arduino activity provided an opportunity for her to make a meaningful contribution and be a resource for her group. She grabbed the materials immediately and began to share her knowledge. When she walked away from the table to get more wire, I asked the other girls questions about the LED lights that were relevant to the success of the activity, giving them an opportunity to meaningfully contribute to the activity as well (line 17). The fact that they had already tested the lights gave them useful information to share, they knew which lights worked and which ones didn’t. Asking the question provided an opportunity to share what they knew as well as their previous observations, and to make a connection to previously learned information about what happens to LED lights when too much energy flows through.

Shifts in their engagement occurred as the interaction proceeded. I positioned myself not as the expert, but as someone who was trying to figure it out just along with them. In line 24, instead of telling Laura what I thought was the correct way to connect the lights to the battery, I suggested that she try it both ways, so she could have the experience of seeing which way works. The girls began to talk more to each other as I talked less. Not only did they share their observations and hypotheses about what was happening with the LED lights (lines 21-22, 31-33), but they also supported one another by helping to troubleshoot, as in line 25 when Krystle points out to Laura that her circuit would not work because the wires were touching. This moment led to a discussion about the need for a resistor in the circuit as we attempted to set up the LED circuit on the Arduino board. In next excerpt, the girls are more fully engaged in the activity. They begin to answer each other's questions, and chime in to finish my sentences. They offer suggestions about what to do and begin to use resources without prompting.

34	Me	So I guess if we have to connect into these two ports like this-
35	Portia	We could take some alligator clips and find a way to like make it a complete circle- circuit
36	Me	You were in 13 and ground, right?
37	Erykah	13 makes it blink
38	Portia	Mmhmmm
39	Krystle	Does it matter which leg is in 13 and which leg is in ground?
40	Portia	Wait, it's gonna matter
42	Erykah	The long leg has to be in 13 and the short one has to be in ground
43		(Erykah asks Portia if she can borrow the iPad which Portia is looking at... they look it up on the iPad and I connect the LED light to the Arduino) (Erykah pulls up a picture of an LED light connecting to the Arduino on the iPad and holds her LED light up to the picture to see which is the long and short leg)
44	Erykah	The long leg has to be in 13
45	Me	Wait... the long leg of the LED to the other end of- so the long one gets connected to the resistor…
46	Laura	you have to twist the- the... (does a gesture with her hand) this leg of the resistor goes with that
47	Me	Mmhmm... You have to twist the resistor onto this leg (repeating what Laura said as I do what she said)
		You could also solder it so that it stays...
48	Laura	Yeah
49	Me	and then this... goes in here like that... now you're connected in a circle right? Do you see that?
50	Kids	Yeah
51	Krystle	See It's blinking already...
52	Erykah	Oh
53	Portia	We could use that for the- can't we use that for the um... heart?
54	Erykah	That's the whole point!
55	Portia	Ohhh (laughing)
56	Me	So now...
57	Portia	we need to dim it to make it faster...
	Nirvana	Can we connect it to ladybug light circuit?
		(they start looking for the batteries)

This moment is a shift in their engagement in this activity, particularly for Portia and Nirvana who went from initially not even being involved in the problem to being engaged only behaviorally, following the directions they were being given, to beginning to think through logical answers and next steps. At this point, we are participating together as they talk me through what they know. Engagement was evident not only through their talk, but in their body language which changed as we worked. The first noticeable shift was in attention, and gaze as we talked through how to connect the LED to the Arduino.

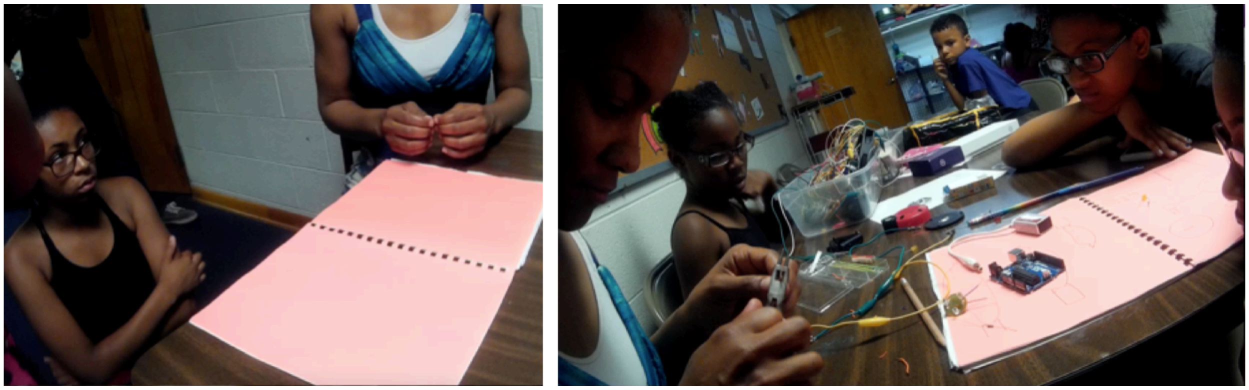


Figure 3.6. Contrast between body language in group Kiwi at the start of interaction with facilitator and toward the middle of the interaction (a) Erykah's arms are folded and gaze is distant; (b) Nirvan (left), Krystle (center) and Erykah (right edge) are focused on the facilitator's hands

They moved from observing to participating in the process of stripping wires to connect the microcontroller to a circuit that had been removed from a ladybug nightlight earlier that day. At that point, each girl was eager try stripping her own wire.

57	Nirvana	Can we connect it to ladybug light circuit? (they start looking for the batteries)
58	Me	Sure, you have to strip the wires. Do you know how to connect it?
59		Yes!
60	Me	Okay I'm leaving
61	Portia	I'm 'bout to cut the wire... I can see it right now (cuts through the wire)
62	Nirvana	Let me try it (picks up wire and wire cutters)
63	Krystle	(picks up another wire and pair of wire cutters): Let a pro do it
64	Erykah	I peeled it, but... there's not wire in it
65		(they laugh)
66	Erykah	It's all naked... I took its clothes off

Summary of Episode 2. This episode highlights the impact that facilitation can have on participant engagement with STEM ideas, tools and practices. In this set of examples, facilitators and mentors engaged in three different ways – *working for*, *telling*, and *working with* (investigating/troubleshooting/ learning) – that had different consequences for engagement. When mentors took over the work of the group, participants did not feel included and were less likely to engage. They either had to take extra steps to include themselves or did not find a way to contribute. The mentors' choice to work on parts of their project without group Kiwi limited the girls' freedom to direct their own path, to make creative choices, and to use each other as resources. As a result, they disengaged from the activity. This aligns with Vossoughi's and Escude's (2015) work on interaction dynamics between youth and facilitators in makerspaces, which shows that opportunities for learning and shared problem solving can be missed when facilitators take over youth projects. When provided with opportunities to raise questions, make decisions, and get their hands dirty, youth in this setting were more inclined to participate and there were shifts in how they participated. When they could not find the support they needed, the same youth struggled to find ways to remain engaged.

Working in a responsive environment required that facilitators attend to each group's progress and to their questions, to notice or recognize when groups or individuals needed support, and to make decisions about how to support activities, individual participation, and engagement. This episode highlights the different ways that facilitators entered into interaction as well as the choices they made to influence engagement as they interacted with project groups. In the telling example, Franklin's initiates the interaction with group Kiwi as he circulates through the space. My own interaction with the group moments later was the result of a direct invitation by Erykah. In either case, both Franklin and I had to assess engagement as we made decisions about how to proceed with the group. Although we both began with a question to the group about their current activities, Franklin's question ("What are you doing?") was more of a check-in to question whether their current activities were constructive. It positioned Franklin as an authority figure to whom they needed to report their progress. My question ("What are we trying to figure out?") positioned me as a co-learner or co-investigator.

Across group/facilitator interactions, telling and working with took on many forms, which are listed in the table below:

Table 3.1. Different Forms of Facilitator Telling and Facilitator Working With

Facilitator *Telling*	- Telling youth to do something (giving a direction) - Telling youth what to do (providing information) - Telling youth what you think they should do (Facilitator interests take over)
Facilitator *Working With*	- Questioning from a place of genuine inquiry - Supporting youth needs (helping, directing, advising) - Positioning yourself as a peer in the process (sometimes more knowledgeable, sometimes less knowledgeable)

Telling can be productive and necessary in situations where facilitators have useful information that can that support group progress. Telling and working with were most productive when facilitators positioned themselves as peers in the process because it opened the door for youth to do the thinking. They became less helpful when facilitator interests and goals took precedence over the interests and goals of a group. Often, facilitators and mentors made moves to hedge on their own ideas or remove themselves from group activities when youth tried to position their thoughts and ideas and more valuable than their own. These examples point to the importance of attending to the distribution of pedagogical know-how between novice and more experienced facilitators in informal learning spaces.

The open activity structure played an important role in providing the freedom for youth to participate in ways that led to engagement. However, facilitation was an important constraint for managing paralysis, non-participation, and disengagement. Given too much freedom, groups faced challenges with idea generation (not enough ideas and bad/incomplete ideas), mismanagement of time (too much/not enough time spent on choreography/technology development, not enough time thinking about the phenomenon); and incomplete or incorrect interpretations of phenomena. The feedback cycle helped to further constrain group work in ways that focused activities and engagement.

Flexibility and the Feedback Cycle (Useful Constraints)

The previous examples have shown that individuals and groups had the freedom to make changes in their learning arrangements, shift activities within group project work, and change the direction that their group projects took. The flexible design also allowed for decisions to be made about broader changes to the design of activities within and between iterations. Through a cycle of feedback that involved communication across *Make Time*, *Share Time* and module activities, groups shared their progress, questions, ideas and issues with facilitators, mentors, and their peers. Facilitators listened, observed and made note of emergent material, technical, and conceptual needs, interests, and shifts in participation and engagement during *Make Time* and *Share Time* and used them to inform modular design changes, to shift the focus and timing of scheduled activities.

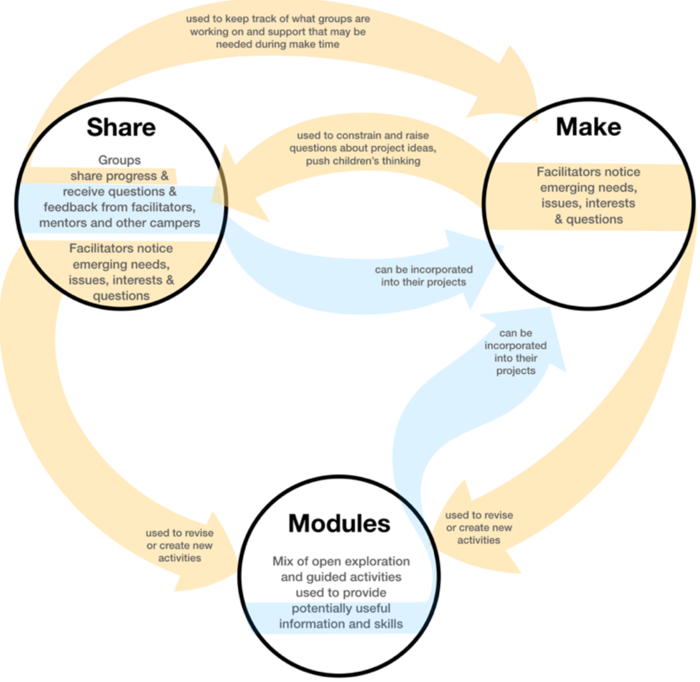


Figure 3.7. The Feedback Cycle

Facilitators made daily notes like the one below to keep track of what happening with each group.

> “All groups were working on choreography today and everyone seems to be making progress. Summer Rain is working on trying to show that the star is hot. Simone suggested using "hot steps" on a certain part of the music. Nia suggested that everyone make up a count of 8 on their own and then come back together. They are trying to fit the “hot” part onto a specific part of the music. They plan to make a dandelion star from a project they saw on the internet. They will need fiber optic wire for this. Find out where to order.
>
> Share Time was great today. It is taking much longer than it needs to, but it's awesome because the kids are really asking great questions of each other. Some questions really show their emerging interests in the topics as each group presents. They are starting to ask about things they hadn't ever previously thought about. (e.g., What is going to happen when the sun burns out?) and they are also asking really good critical questions of each other's projects (e.g. How does what you're doing fit with your electronic component?) They are offering good suggestions and ideas to each group. Almost too many suggestions. Three groups showed a little of their choreography today. This was really useful because it helped the other groups understand more about the presenting group's project idea and it helped the presenting groups because it allowed them to get some feedback from the audience's perspective - what makes sense, what is not clear, how they can make things clearer.”

Make Time. Because *Make Time* was the time set aside for groups to work independently on their projects, facilitators mostly left groups to develop and pursue their ideas during this time. Although there was some guidance from facilitators, youth developed new understandings of tools, technologies, and the content they explored on their own. Group interactions with facilitators and mentors comprised approximately 24% of the *Make Time* data analyzed. When groups ran into issues, they could ask for support from facilitators, mentors, or from peers in other groups or they could bring their issues to *Share Time*. Facilitators made note of emerging needs, issues, interests and questions which they used to revise or create new module activities and to constrain and raise questions about project ideas, and push children's thinking during *Share Time*.

Share Time. Share time was the time set aside for groups to share their progress and get feedback. Each day, after sharing what they did the previous day, what they learned, and what they still needed to know or better understand, groups received questions and feedback from facilitators, mentors, and other campers. *Share Time* was an opportunity for groups to get input in the form of questions that prompted deeper thinking, suggestions and advice on their projects which they could accept or reject. Often the questions asked pushed groups to do more research, raised new questions, or developed more interest in understanding a phenomenon, and gave groups ideas for how to focus their afternoon work. For example, during their presentation to the other groups about their progress on day 12, the girls reported that they had figured out spacing and counts for their dance and explained that they decided to use an over-sized inflatable balloon-like ball to represent their heart in their dance. They planned to place the ball, their heart, "in the center of [the] dance piece" and to dance the role of the veins. "In some part of the dance we're gonna attack the heart." "We are gonna kick it and hit it" because "we are supposed to be a representation of the heart being attacked." Their explanation raised questions from their audience about what really happens in a heart attack. Do the veins attack the heart during a heart attack? What actually happens to the veins, and what is the heart doing during the attack? The girls hypothesized that the heart would slow down, but when it was suggested that it might also speed up, they decided that they needed to do more research to better understand what was happening to the veins, inside the veins, and to the heart. This set the stage for their work during *Make Time* on that day. A benefit of nobody having content expertise was that everyone was learning, and questions were legitimate, not "teacher question-y," but driven by genuine interest in other projects. Facilitators also used *Share Time* to keep track of group progress and to note emerging needs, issues, interests and questions, which helped them enter into interactions with groups during *Make Time* and revise or create new activities. This period of the day allowed everyone to learn what groups were working on so people could more easily offer their assistance during *Make Time* or be on the lookout for things that might be helpful to another group.

Modules. Modules were daily workshops designed to introduce new and potentially useful tools and technologies which could be incorporated into group projects. A mix of open exploration and guided activities, modules offered guided facilitation with orienting questions that gave participants room to explore with a purpose. Examples of module activities are described in the facilitator memos below:

> "For the creativity module today, we started with the 3 random ideas exercise. The kids worked in small groups and pulled three random ideas out of the basket. They choreographed a movement phrase that incorporated all three ideas. After the first round, I talked to the entire group about using dance movements instead of acting out the words on paper. Each group tended to do more dramatic interpretations using props and talk instead of dance movements and phrases. They formed new groups and did a second round." (Iteration 2, Day 4)

> "During the Science/Tech morning workshop, the children played around at five different stations set up for exploration (littleBits, Makey Makey, ferrofluid, conductive clay with LED lights, Conductive paint, and energy sticks). The kids chose to spend a few minutes at a station of interest before switching to another station. The objective was to use this exploration to help them work on trying to explain how things work. They were asked to try to come up with questions that were interesting as they played with the objects at each station." (Iteration 2, Day 3)

Module activities were designed to introduce and build familiarity with new skills and technologies. Tools, skills, and ideas from modules could be incorporated into projects during *Make Time*. Modules were added or changed based on needs, interests, and engagement. Facilitators noted emerging needs and interests from *Make Time* and *Share Time* and used them to tweak modules. The following examples highlight facilitator actions taken at different points in the feedback cycle.

Changes based on material, technical, or conceptual needs. Facilitators worked with youth to decide what materials were needed, what information would be useful, what activities, and what tools would be beneficial. In the case of material needs, groups made lists of materials that were not available in the space as they developed their project ideas during *Make Time*. For example, once Kiwi had finally decided they would make a giant beating heart for their electrical component, they took an inventory of the materials they would need that were not available in the space. They made a list that included a large (36-inch balloon), red tissue paper to cover it, and additional LED lights. Kiwi reported on these material needs during *Share Time* and engaged in discussion with facilitators, mentors, and the members from other groups about the best ways to meet their material needs. Facilitators made efforts to get those materials or negotiated alternative options and materials were added to the space.

The feedback cycle also created opportunities for facilitators to enact within iteration changes based on conceptual and technical needs. For example, a discussion during *Share Time* revealed that the group working on a project about strokes was confused about aspects of the phenomenon. Not only were they confusing aspects of ischemic and hemorrhage strokes, they were also conflating aspects of the phenomenon as they tried to represent them (e.g., narrowing veins, blood clotting, weakening blood vessels and weak blood flow). Their confusion, which came through in the choreography they shared, led to many questions from their audience of facilitators and peers. The discussion that followed led facilitators to make the choice to add a module to the schedule that allowed groups to explore three different ways to represent an idea. While facilitators could have decided to work with that group individually during *Make Time*, the choice to change the module activity was made because the *Share Time* discussion revealed that thinking about multiple ways to represent their ideas through movement would a useful activity for everyone, not just members of one group.

Facilitators also added modules or shifted module activities to create opportunities for groups to troubleshoot issues they were having with the technologies they were working to implement and to engage physically around concepts. For example, when a number of groups chose projects that would require programmable Arduino boards, modules were shifted to accommodate a new module on programming Arduino. Questions raised during *Share Time* discussions about how energy moves through a circuit led to the addition of a physical activity on electron travel.

Facilitators also altered, shifted, and added activities to support interests explicitly expressed by youth and to help them explore in ways that supported their understanding. One example of an activity that was added based on an emergent interest was the resistor choreographic exploration discussed in the previous chapter. In this case, a deconstruction activity during *Make Time*, taking apart electronic equipment to see what was inside, led youth to inquire about the purpose and function of resistors in a circuit. Facilitators noticed that questions about resistors kept coming up in the *Share Time* discussion the following day and encouraged the children to research and bring back more information on resistors to share with the group, so we could learn together about what they do.

Space was created the following day morning during the science and technology module for the dancers to share any information they had found about what resistors are and what they do. They read from definitions they found on the internet. During the discussion, the facilitators attended to not only what was being said, but to the body language and tone of voice as they tried to explain the information they found, asking multiple times if explanations made sense or if youth understood the information they were sharing. They made the decision to shift the choreography module activity to a dance-making activity that had youth choreograph the function of a resistor in a circuit using the information they discovered from their research. The shift in activities was made to accommodate the developing interest in resistors and to allow the dancers to engage with the concept in a way that supported their engagement with ideas that were challenging to them, and it led to new understandings about resistors.

There were also shifts in the focus of activities and in the time allotted for certain activities based on participants' excitement around ideas or their explicit requests for more opportunities to work on certain things. One example of this was a camp-wide choreography project in the third iteration of the program (Summer 2015) that was intended to help scaffold thinking about how to represent science ideas using movement and dance. The goal of the project was to explore a science topic of interest together, allowing facilitators and mentors to model ways of utilizing choreographic and technological tools to represent concepts and processes, but the ideas that the youth were most excited about pursuing were about social concerns. Their ideas ranged from Black Lives Matter to pollution, non-renewable resources, domestic violence, and the terror group ISIS, world hunger, global warming, and natural disasters. Facilitators had to make choices about how to support the children's ideas and the goals of the activity. Led by the children's interest in addressing social concerns, and Black Lives Matter more specifically, facilitators suggested a choreography project theme focused on the news. The news project they created included multiple stories, including a story on Black Lives Matter, the enactment of a tsunami, and a story about Colorado wildfires. The 8-minute presentation had several different components, including choreography, stop motion light painting, and video. They built a giant TV screen that hung from the ceiling and a remote control to start the newscast using the Makey Makey and the projector.

Not only did the theme and focus of the project shift, but the timeline for completion also changed. The project was intended to be completed in the first week of camp, to serve as an example and provide strategies for problem solving and creating their smaller group projects. However, because of their energy and enthusiasm toward the project, facilitators allowed their work on it to continue and used the module time to accommodate their interest in continuing the activity.

In working to make adjustments, there were sometimes tensions. Facilitators were tasked with finding a balance between following the children's interests and making sure that they were learning strategies and STEM skills (i.e., circuit-building, programming using microcontrollers and drag and drop block-based programs like scratch, choosing reliable information sources, utilizing tools of measurement) that would help them with their group projects. In order to keep science centered and their ideas and interests central to their experiences, facilitators worked with youth as peers in making. Youth were not only co-creators of their group projects, but of their experience. The flexibility of the feedback cycle allowed facilitators to remain to true to youth interests and follow their lead while making sure that they had access to the strategies and skills that would help them with their group projects.

In order to systematically make decisions about what to change and track the changes made as we moved forward, facilitators shared their observations in daily debriefs at the end of the camp day. These debriefing sessions focused on the activities of the day, what we didn't do and why, what we noticed about issues that participants may have had, and how to best address them moving forward. Below is an example of a note from a facilitator debrief session:

> “We did the elephant toothpaste demonstration and talked about how hydrogen peroxide turns to oxygen with the help of a catalyst. I showed them pictures of a peroxide molecule and a water molecule. Latrice asked why the oxygen was so much bigger than the hydrogen. I told them about how peroxide left out overnight would turn to water. We talked about how the peroxide we were using today was for dying hair. I poured the peroxide into a clear bottle then added yeast to a half cup of water. I stirred the yeast and gave it to Lea to stir. Kids commented on the smell. We talked about how yeast is used to bake bread. Then I poured the yeast into the peroxide and it foamed over. The kids were excited to see the eruption. They put their hands in the foam and felt the heat. Then during the choreography workshop, we created a combination about the reaction. Dancers moved like liquid for hydrogen peroxide, another group of dancers played the role of the "catalyst" and then they formed a circle and erupted. I like the way the kids are starting to ideate. I think this set of activities worked well to get them primed to think about how to create movements/dances that explain science phenomena.
>
> We changed the design based on last year's kids to include heavy scaffolding to help them make the association between choreography and science explanations. But these kids don't seem to need it as much as last year's group. These kids seem to get it. We can let them work more independently in the choreography tomorrow and see what kinds of representations they come up with.” (Iteration 4, Day 1)

The debrief sessions were a way to help facilitators reflect on participant experiences and make decisions about whether and how to tweak program activities. For example, in this particular debrief, which took place on the first day of the 2016 camp (4th iteration), facilitators discussed the possibility that participants may need less scaffolding in thinking about choreographing science explanations than past participants may have needed.

Specific moments brought up during the debrief sessions were tagged for video review. Changes in the schedule were documented and then discussed with youth participants through quick check-ins at the start of the next day. The check-ins provided an opportunity for the youth participants to hear about the changes and the reasoning behind those changes as well as ask questions and make suggestions of their own. Meeting notes from the debrief sessions as well as the tagged videos were reviewed in order to understand shifts in participation and engagement and to make changes between iteration changes.

Significance

This analysis presents a shift in thinking about engagement by focusing on STEM engagement through moments of interaction. The examples in this chapter show that engagement should not be considered a stable characteristic, but a choice made by individuals in a given moment. The choice to engage in STEM exploration and activities was influenced by several factors: the freedom to choose their own ways to investigate; opportunities to be creative and iterate on their ideas; opportunities to use one another as just in time resources; opportunities to make meaningful contributions or support others in making meaningful contributions to the activity; and a shared goal that created a need and value for their exploration of STEM content. Analysis showed that having the freedom to choose their own ways to investigate allowed youth multiple entry points into thinking about the science phenomena they were investigating. The freedom to shift roles to help one another, find ways to meaningfully contribute and support others in making meaningful contributions, allowed them to continue working without getting frustrated when things got difficult. Having the freedom to think creatively about their representation of the phenomenon allowed youth to take ownership of their representational work, to ask authentic questions about the phenomenon, and to engage in discussion and negotiation about their representational choices. The freedom to iterate or to think of their project as a work in progress allowed them to remain open to the possibility that changes might be necessary and kept them from becoming frustrated when changes were necessary.

Facilitator interactions also had different consequences for engagement. The examples highlighted how *working for* and *working with* can be productive for or can constrain engagement depending on how facilitators frame the interaction. Facilitator/group interactions were most productive when facilitators positioned themselves as peers in the process and opened the door for youth to do the thinking. Finally, meaningful engagement was positively impacted by providing a flexible structure that allowed facilitators to attend to the interests, needs and ideas of participants, in the moment and over time.

Chapter 4. Understandings Enacted: Learning through Embodied Re-presentation, Embodied Exploration, and Kinesthetic Experience

In the previous chapters, I described the dance makerspace setting, the activities, and the aspects of facilitation and design that allowed participants to explore STEM content, tools, and practices in ways that were meaningfully engaging. This chapter will examine how science learning in the dance makerspace was supported through one of those forms of exploration, embodied interaction and expression. Through ethnographic descriptions, I will explore how participants constructed embodied understandings as they developed projects that integrated STEM, dance and making. I will begin to address what sense-making can mean and look like in this setting, as well as what and how the children came to understand and embody the ideas and phenomena they worked to represent. This analysis focuses on moments of cognition enacted. It builds on theoretical perspectives from experiential-interactionist literature and transactional understandings of epistemology to explore children's sense-making processes as they created dynamic science representations that combined choreography and electronic technology to explain science phenomena.

The focus on understanding enacted through the collaborative construction of multimodal embodied dynamic representations provides insights on research question 1: What does the "making" of embodied multimodal collaborative dynamic representations entail?

- How do choreographic representations get made and how is understanding built in the process?
- How are ideas translated across different modalities and reshaped to create new embodied meanings and physical representations?
- What understandings are built in the process?

I will show that the process of making their projects led children to understand phenomena-related science content in new ways, to engage in complex forms of perspective-taking, and to make their thinking explicit and accessible to each other to utilize for sense-making. The collaborative construction of embodied multimodal dynamic representations involved three types of embodied sense-making used to create complex models and represent multiple perspectives of scientific phenomena with increasing complexity: (1) learning through the construction of embodied representations; (2) learning through embodied exploration; and (3) learning through kinesthetic experience.

I build this argument through an analysis of embodied communication and sense-making through group interaction, using practical epistemology analysis (Wickman 2006), a method for studying learning in action, to highlight the ways that understandings were constructed and enacted. Practical epistemology analysis was used to analyze the project-making processes of the three focal groups. Their representational products were examined through a multimodal/semiotic lens. The findings from the in-depth analyses were compared first across each other, and then across moments of enacted understandings sampled from all cases using a constant comparative analysis (Glaser, 1995) to determine the full range of ways that embodiment supported sense-making practices in the dance makerspace. This chapter looks closely at the work of one group to examine their use of embodied communication and sense-making. It will show how a group of five youth dance-Makers created a dance project about the nervous system and worked to answer the question "How does the brain send messages to the body?" using their bodies to communicate and understand the phenomenon in new ways. I examined the group's conceptual learning through the process of collaboratively constructing multimodal embodied dynamic representations and the relationships between what they made, what and how they made sense of the tasks and the phenomenon they studied, and how their understandings were constructed and enacted. After an in-depth look at one group, I will share the range of embodied sense-making practices found across groups.

Understanding the Body's Role in Cognition

This work seeks to expand understanding of the body's role in sense-making. Current ways of thinking about movement and the body's role in cognition still reflect aspects of the Cartesian duality, the idea that mind and body are separate entities. As a result, we have come to think of "scientific thinking" as disembodied, related to the mind and not to the body. The field of cognitive science began with conceptual models of mind that were solely based on language and linguistics practices (Miller, 2013). This starting point created conceptual issues which have resulted in a limited understanding of understanding and has made it difficult to account for all of the resources brought to scientific sense-making. Second generation cognitive science created space for thinking about thinking as an embodied activity. Embodied cognition construes learning as emerging from the body and mind and highlights the body's generative activities of sensing and acting. While this expanded view of cognition supports the body's role as a sensory input system, it still says little about role that movement can play in sense-making. It still supports Western cultural views of the Cartesian split in which, according to Bowman (2004) "...the body [is reduced] to a vague sensorium, a collection of viscera whose only cognitively worthwhile jobs are to transmit sense data to [the] mind for processing and to do a mind's bidding." Movement can be more than just an accessory for speech, and cognition is often enacted; however, the field of learning sciences has yet to explore questions of what you can know by what you do.

Researchers that study embodied interactional approaches to cognition (Stevens, 2012) talk about cognition in action in ways that restore the body's role in understanding (Stevens & Hall, 1998; Stevens, 2012; Hall, 1996; Goodwin, 2000; Streeck, Goodwin, & LeBaron, 2011). This work repositions understanding as a representational process, suggesting that understanding is not necessarily found in the representation but in the iterative process of representing. An embodied-interactionist approach calls for attention to children's multimodal sense-making processes as they collaborate to create their projects. However, in this setting, multimodal, embodied sense-making experiences are also an essential component of the products being made. In order to make sense of the representations created, I used a multimodal analysis to interpret the final representational product and an embodied-interactional lens to examine the in-the-moment sense-making that led to new ideas, to understand how those ideas evolved, how they related to prior knowledge, and how new meanings were constructed through embodied sense-making. Practical epistemology analysis (Wickman, 2006) is an embodied interactionist approach to understanding sense-making, as its focus is on the meanings people make as embedded in their practices. It is also transactional. Transactional approaches to understanding regard knowledge as something practical, not something in the minds of human beings, but something that we do, often in a context in which we are interacting with others (Almqvist & Quennerstedt, 2015). The theory is a method for studying learning in action, by describing the actions people use to deal with events and to pursue their goals. It uses continuity, gaps/relations, and transformation to describe how decisions and relationships are constructed in interaction. Continuity, as defined by Wickman (2006), occurs when actions and language are not questioned but allowed to stand fast in interaction without question or hesitation. An interaction cannot continue when there is a gap in understanding. In order to fill a gap in an encounter, people must find relations whose use in the encounter stand fast. Transformation is defined as evidence of how experience and what we know is changed as situations are made continuous. PEA is a discursive analysis that focuses on how people proceed with activities and the consequences this has for what they learn.

Through the analysis of video data, artifacts created, memos and field notes, I will show three different ways that science learning and new understandings were supported through embodied interaction and expression. First, I will show how children used their bodies as knowledge-constructing resources for sense-making by collaboratively constructing physical analogies that helped them think about the phenomenon and understand it in new ways. Second, I will show how choreographing the process allowed them to use movement as a resource. The choreographic process allowed them to engage in complex forms of perspective-taking. Embodying different parts of the phenomenon led to new questions and deeper exploration. Finally, this analysis will show how children engaged in brainstorming through embodied multimodal communication, making their thinking explicit and accessible to each other to utilize for sense-making. Embodied exploration as a mode of sense-making was used to create complex models and represent multiple perspectives of scientific phenomena with increasing complexity.

A Case of Embodied Sense-Making: Dancing the Brain-Body Connection

In the remainder of this chapter, I explore the role of embodied interaction in sense-making through one case that shows various examples of the ways cognition was enacted. I focus on one group, *Fast on our Feet* (FOOF), as they made sense of the role of the nerves in the nervous system. I begin with this case as an exemplar for several reasons. *Fast on our Feet* was one of four groups in the second iteration of the program, the first iteration in which project groups were asked to dance a science explanation. The second iteration was an interesting transitional moment in the camp because the idea of using dance to explain science was new for everyone. This case demonstrates how youth participants attacked what was a novel problem for them, and how they chose to use their bodies in the process, providing a critical opportunity for understanding the potential affordances for using the body as a sense-making tool. This particular group was also diverse in age, gender and previous dance experience. This diversity led to a range of problem solving strategies and activities. Because there was no typical or general problem-solving trajectory, and each project group navigated their own path to project completion, I did not attempt to find a group that would be "representative" of all project groups working in the space. Instead, this case study presents a group that utilized a range of sense-making practices as they dealt with the different issues, questions, and problems that came up during their project development process. Later in the chapter, I will discuss the full range of ways that embodiment supported sense-making practices across groups in the dance makerspace.

The following ethnographic description offers a view of the brainstorming and choreographic activities of *Fast on our Feet* during the second week of the camp. It focuses closely on day 6, a critical point in their process, the first working day after they had decided and agreed on a topic to explore. In order to contextualize this point in their process, I begin with some general orienting descriptions of the group and their process, describing the overall arc of work (Strauss, 1985; Stevens, 1999) from the initial framing of the task and their first brainstorming meeting to their final presentation and performance. I then share a multimodal analysis of their final representation, show how it relates to their process, and explain the many ways that embodied exploration was used as a tool for sense-making.

Fast on our Feet

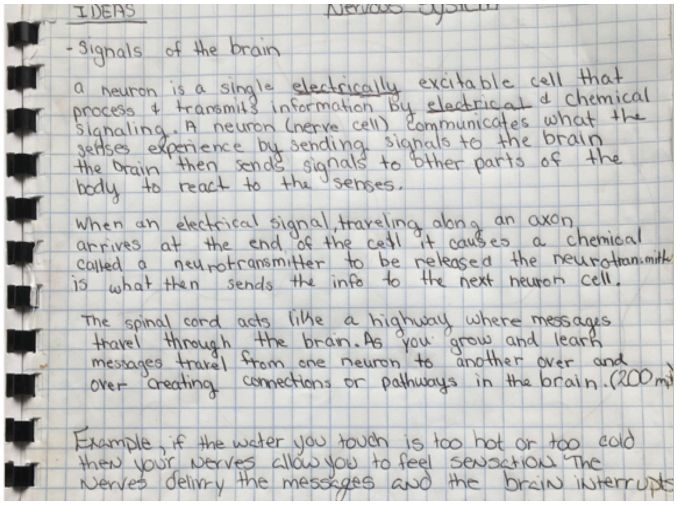
Shayna, Dejah, Kevin, Ti'Anna, and Laurielle brought a range of dance experiences, different levels of training, as well as various histories with each other, with the dance center, and with the practice of making to their work in the summer program. Shayna, at age 11, was the only person with previous maker camp experience, having attended the first STEAM Makerspace camp the previous summer because she "loved to dance and make things." A student of the dance center since the age of two, Shayna had taken classes in multiple dance styles, including ballet, tap, modern, African and hip hop. Her good friend Dejah was one year older. Dejah had also trained in multiple styles and the two girls had been dancing together in the same classes for five years. Kevin, the only boy in the group, was 13 years old and brand new to the center. He was in town visiting family for the summer and his older cousin, who knew he loved to dance, signed him up for the summer program. Kevin's father was a hip hop choreographer. Though Kevin had no formal dance training, he considered himself to be an improvisational hip hop dancer. He would often find times to practice breakdancing moves and freezes and was working on perfecting an aerial cartwheel to integrate into his freestyle repertoire. Ti'Anna was the youngest in the group. At age 9, she was considered a beginner dancer by the others. Ti'Anna had been taking ballet at the center for two years. While that was the extent of her formal dance training, she had also been spent two years training in gymnastics. Laurielle was the elder in the group at sixteen years old. She loved ballet and had been taking ballet classes at center since the age of twelve. But she also loved the power and raw energy of hip hop dance improvisation and choreography. The other dancers in the group respected both her age and her range as a dancer. These children were assigned to work together as a group toward the end of the first week of camp. They named themselves *Fast on ~~are~~ our Feet* (FOOF). While only two of these five dancers (Shayna and

Dejah) had previously worked together, their group interactions demonstrated that they all felt comfortable enough to contribute, to question and challenge each other, and to give and receive feedback as they engaged in a multiple step process to create an embodied multimodal dynamic representation of “How the brain sends messages to the body.”

Overall Arc of their Project Development

Phase 1: Becoming a group, brainstorming and idea development. The first phase of their process involved FOOF becoming a working group in the context of the dance makerspace. Phase 1 took place during the first week of the camp. It includes and is defined by both the activities that prepared the children to function as a group as well as their initial group interactions. This includes activities like Take Apart Tuesday, which was designed as a low barrier group activity to allow participants in their newly formed groups to get familiar with the tools and materials available in the makerspace while getting to know one another. During this activity, FOOF worked together to deconstruct an inkjet printer. They presented their findings and the questions raised by their experiences to the entire camp during the first *Share Time* of the summer. At the end of week one, all groups were given the project prompt. FOOF spent two afternoons brainstorming project ideas and engaging in iterative discussion and debate about how people become albino, whether super humans exist, and how the brain functions. They shared their developing ideas with facilitators and with the other campers and received feedback, deciding ultimately to focus on understanding the phenomenon of brain/body communication.

Phase 2: Research on the nervous system. FOOF's initial research phase began on day five, the last day of the first week of camp. During this phase, the children searched the internet via Google and YouTube for information about the functions of the nerves, the brain and muscles and how they work together in the nervous system. They watched videos and asked clarifying questions to facilitators who checked in with them periodically. They recorded their findings in the form of drawings and text in their design journal. The following explanation, shown in Figure 4.1, was written in their design journal:



IDEAS Nervous System

- Signals of the brain

a neuron is a single electrically excitable cell that process & transmits information by electrical & chemical signaling. A neuron (nerve cell) communicates what the senses experience by sending signals to the brain the brain then sends signals to other parts of the body to react to the senses.

When an electrical signal, traveling along an axon arrives at the end of the cell it causes a chemical called a neurotransmitter to be released the neurotran.mitt is what then sends the info to the next neuron cell.

The spinal cord acts like a highway where messages travel through the brain. As you grow and learn messages travel from one neuron to another over and over creating connections or pathways in the brain. (200 m

Example, if the water you touch is too hot or too cold then your nerves allow you to feel sensation. The Nerves delivry the messages and the brain interrupts

- Signals of the brain

A neuron is a single <u>electrically</u> excitable cell that process (sic) & transmits information by <u>electrical</u> & chemical signaling. A neuron (nerve cell) communicates what the senses experience by sending signals to the brain the brain then sends signals to the other parts of the body to react to the senses.

When an electrical signal, traveling along an axon arrives at the end of the cell it causes a chemical called a neurotransmitter to be released the neurotransmitter is what then sends the info to the next neuron cell.

The spinal cord acts like a highway where messages travel through the brain. As you grow and learn messages travel from one neuron to another over and over creating connections or pathways in the brain. (200 mph)

Example, if the water you touch is too hot or too cold then your nerves allow you to feel sensation. The nerves delivry (sic) the messages and the brain interrupts.

Figure 4.1. Description of the Nervous System (taken from a page in design journal)

Phase 3: Choreography, concept, and electronic component development. The dancers began working on choreography on Day 6. This marked the beginning of Phase 3, which lasted through the second week of camp. They worked both in the studio and in the makerspace. Going through the iterative choreographic process raised conceptual questions that led to more research, to new ideas for choreography, and to several re-designs of their electronic component. Their choreographic process involved playing with movements, timing, and spatial formations to construct an explanation based on the information they collected in their design journal, working through ideas for how to incorporate LED lights and energy sticks into their choreographic representation, experimenting with different songs, looking at videos and pictures in order to figure out how to construct circuits with conductive thread, asking questions, and receiving and incorporating feedback from facilitators and other campers. By the end of the week, the group had settled on an idea for their dance and figured out a plan for constructing the technological elements they would need to communicate their ideas. Their choreography evolved from freestyles solos and a circle to represent a message being received, to a story first about touching something hot, then about what happens in a car crash, then about each dancer having a different pain, and finally about one person who plays with fire.

Phase 4: Practice and refining choreography and concept. FOOF spent the last week of camp refining their choreography and constructing their electronic props, clothing that would light up at certain points in their choreography. They worked together and separately on their parts. As each dancer had a different role to play in the dance, they had to simultaneously attend to what one another did as they developed their individual parts of the choreography. They also discussed and designed costuming and painted t-shirts for the brain and fire characters.

Phase 5: The final presentation and performance. Phase 5 was the final presentation and performance of their work, which took place the evening of the last day of camp. The children presented their work to an audience of family members and friends, giving an initial overview of their piece, explaining the process of making it, then premiering their work.

A Multimodal Analysis

How the brain sends messages to the body. FOOF's final choreography was a dynamic representation that included five dancers playing different roles in the system, LED light circuits sewn onto their clothes, movements that represented the passing of messages from neurons to the brain and body, and the body reacting to touching something hot.

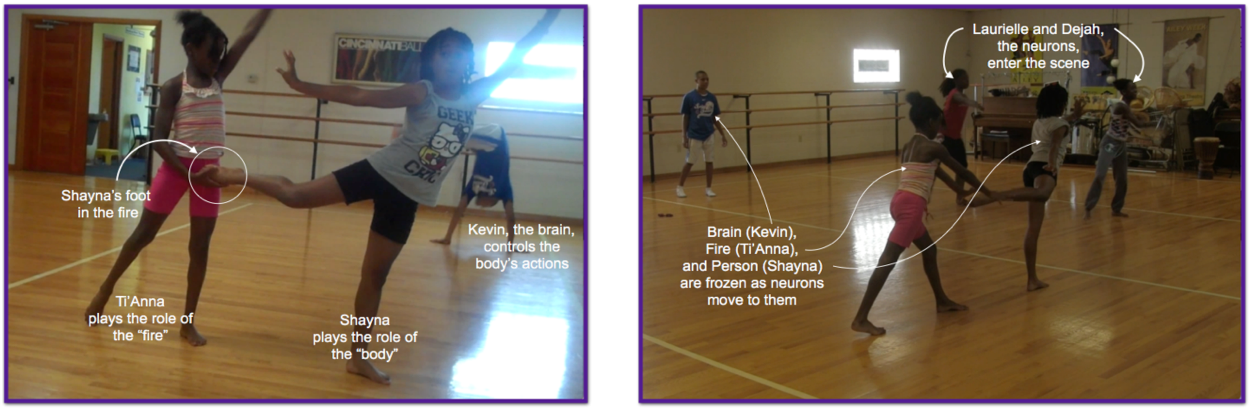


Figure 4.2. The group representing the components of the nervous system

The complexity of their representation was initially examined by attending to the multiple signs, symbols and modalities the children used to express these ideas. I began with a multimodal analysis of their final choreographic product (Kress, 2001; Kress & Van Leeuwen, 2001). The final dances were treated as multimodal texts because even though they were performed in the moment and required interaction between dancers, the interactions were decided and practiced beforehand. The multimodal analysis helped me to understand what content was represented and the forms it took.

Figure 4.3 is a graphical representation that shows the ideas and concepts that appeared in their final representation as well as the representational forms used to communicate those ideas. The dancers combined movement, choreographic conventions, physical materials and technological tools to represent: (1) the components of the nervous system; (2) relationships between those components; and (3) messages that travel through the nerves to the brain and to points in the body. These concepts were nested within a narrative about a person who comes in contact with fire. The five dancers played different roles in the system. Kevin played the brain, Shayna played the body controlled by the brain, Laurielle and Dejah played the nerves which passed messages between the brain and the body, and Ti'Anna played the role of fire, the element that caused the body to react in their story. The children designed and constructed LED light circuits that were sewn into their clothing using conductive thread. Dejah and Laurielle, who played the role of the nerves, wore dance pants with three lights in series connected to battery packs. Shayna, the dancer who played the role of the body, wore a sock with a circuit sewn in that included an on/off switch. The lights represented the instance when the motor neurons sent the first message to the brain that it had touched something hot. The lights were switched on when Shayna's foot came into contact with fire. The children also used movements to represent the passing of the message from neuron to neuron, from the body to the brain, and from the brain to the body. They used movement to show that the right side of the brain controlled the left side of the body and vice versa.

The table shows the relationship between the content the group represented and the forms they used to represent those ideas. In their final performance, they represented various components of the nervous system, including the brain, the body, and the nerves using different spheres of communication (narrative and iconic symbolization that took the form of modern and hip hop dance styles) as well as physical tools and electronics. They represented relationships between the components and additional story elements mostly by using dance composition tools. They also used music to represent the relationship between the brain and the body and a critical moment in their narrative explanation. Understanding the content that they chose to represent and the forms they used to represent it provides insight into how they were thinking about the phenomenon.

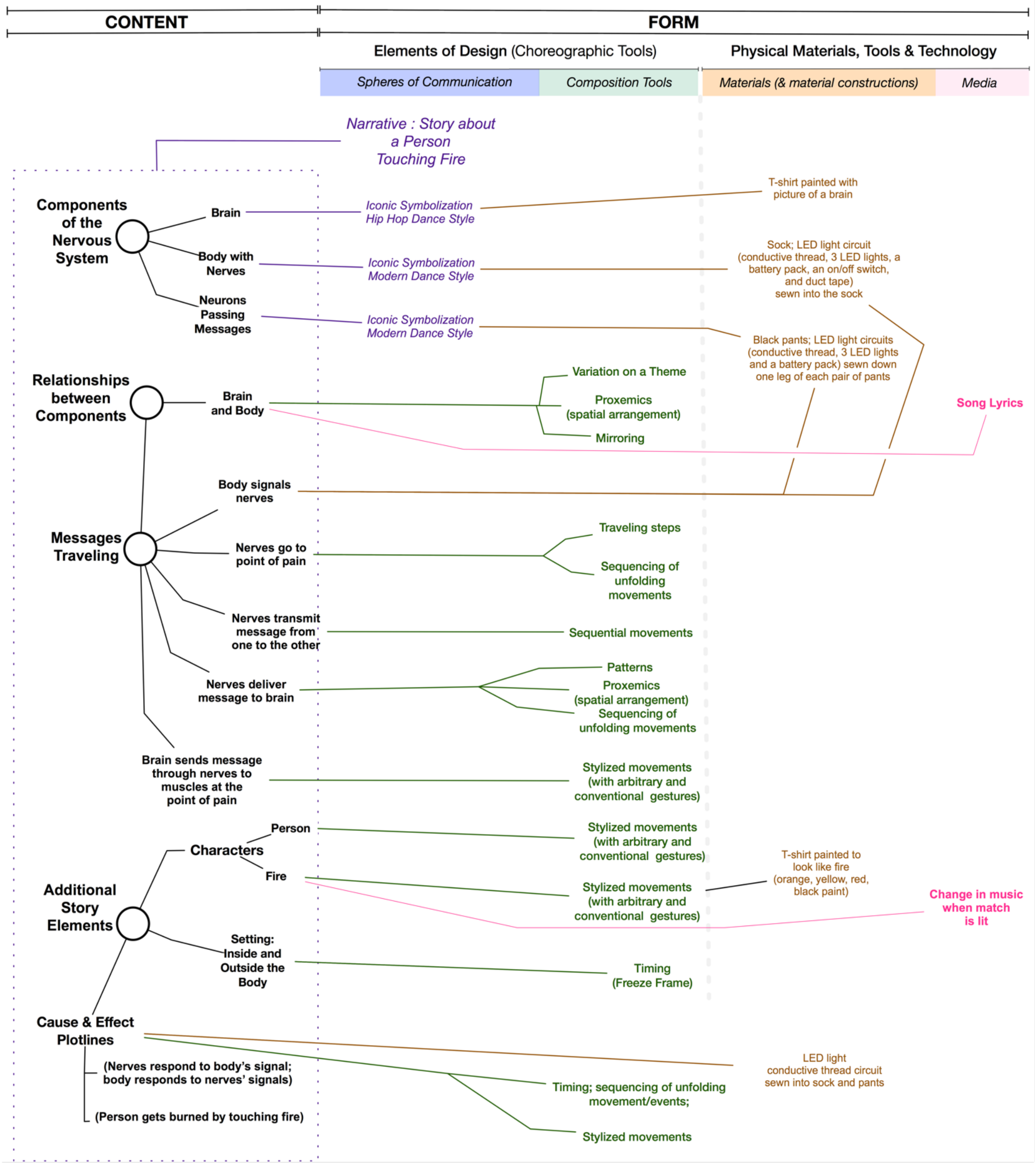


Figure 4.3. Multimodal Analysis of "How the Brain Sends Messages to the Body"

The multimodal semiotic lens is useful for illustrating what and how ideas showed up in their final representation. To understand the fuller learning story, however, it is equally important to understand the work they did to get to the final product. A transactional analysis digs deeper into the processes that led to the making of this representation, showing what the children learned through the representation-making process.

The Making of a Representation through Embodied Exploration

As they collaborated to construct a representation of the function of the nerves, the youth dance makers in this group engaged in an embodied exploration of the phenomenon. This embodied exploration included physical brainstorming and modeling, kinesthetic co-construction of individual ideas, and a practice of embodied communication. These physical modes of expression, processing, and synthesis supported the group's exploration and interrogation of the science content. My detailed analysis of their process begins with Day 6, the day after they reached a consensus on their topic and question of interest. On this day, the group began the work of figuring out what they were going to choreograph and construct to express their understanding of the phenomenon.

Fast on our Feet began Day 6 working in the upstairs studio. Each group had the opportunity to choose the focus of their work for the day and where in the building they wanted to work. FOOF, sharing the upstairs studio space with a group of three other girls, chose to start on their choreography while other groups chose to continue brainstorming and researching ideas, to look for music, or to begin collecting materials for their electronic components. The children had spent time in the previous week in science and technology modules learning about complete circuits and circles, constructing their own circuits, playing with littleBits and playing with energy sticks (7.5-inch plastic tubes with electrodes on each end that when touched simultaneously, flash LED lights). On the previous day, after looking at a couple of ideas on the Instructables website, Ti'Anna suggested that the group might make use of the energy sticks to show how neurons travel through the nerves to get to the brain, an idea that they wrote down in their design journal. The group started this work session by reviewing the information and ideas that they wrote in the design journal. After a quick conversation about music, they began moving right away. Shayna suggested they start in a circle.

Excerpt 4.1

Day 6 [00:03:34]

1	Shayna	Okay… everybody get in the circle… we could start like this
2	Ti'Anna	and everybody hold on to their energy stick
3	Shayna	You guys aren't connected so the **energy isn't flowing through**
4	(Ti'Anna, Kevin, and Laurielle connect by holding fingers)	

They began constructing a dance that served as an analogy between messages traveling and energy flow, using energy sticks to represent the messages that pass through the neurons. The initial idea was to create a dance in which each person would perform a freestyle solo holding the energy stick and hand it off to the next person to represent the message being passed. The energy stick was to represent the message, an electrical signal that passed through the neurons. The dancers represented neurons, dancing with the sticks so *"they can see the energy flowing through our bodies."* They would end the dance by connecting in a circle, holding energy sticks between hands so that the audience could see by the illumination of light that the message had been received. The room was noisy as they talked and moved, collectively building on their idea. They recognized that it was important to their process that they be able to hear each other and decided it would be better to work in the studio space downstairs. This move gave them more space to work without having to compete with the voices of other groups that were sharing the space upstairs. As will be shown in the descriptions of their work that follow, communication was key part of their project development process.

In my analysis of the subsequent work that followed their transition to the downstairs space, I used PEA to look at moments of continuity in their communication practices as well as moments where gaps were recognized, and relations created to show evidence of their learning. The examples below illustrate that embodied communication was an accepted and understood practice by showing how multimodal embodied language was used to communicate ideas, how the children understood this way of communicating and responded to it both verbally and non-verbally, and how they worked together to kinesthetically construct each person's ideas.

Embodied Communication as a Group Practice

The following example shows how children used their bodies and other multimodal resources to work through their ideas. The group had been constructing an analogy for message travel as energy flow using a circle formation and holding energy sticks to show a message being received. In the excerpt below, Dejah initiated a change by suggesting they move the formation from a circle to a line, *"Everybody should line up... come line up."* As the children spread out across the floor in a side by side line, she explained her idea.

Figure 4.4. Fast on our Feet moving through Dejah's idea

Excerpt 4.2

Day 6 [00:25:00]

1 Dejah: So now, so now that could be the fire, right? (pointing to the energy stick in Laurielle's hand)
2 Laurielle: **mm-hmm**
3 Shayna: **yeah**
4 Dejah: or whatever, or the cardboard could be like… and you know you could… either the fabric, or… yeah you could have the fabric right there, poke holes in it, and attach the LED lights… so that could be the fire
5 Dejah: So, we're like holding each other da ta taaaaa (reaches her hands out to the side)
6 **(Everyone grabs hands)**
7 Dejah: So, like then yeah you can touch the fire and then it could like dim up right
8 Laurielle: **mm-hmm**
9 Dejah: And then everyone… right then everybody things can go dim up
10 Shayna: Yeah and then it be like doo doo doo (waves her arms to the beat of the music they have chosen) …then her, Ti'Anna be like CHHHHHP (raises left arm)
11 Laurielle: **Oh, I see what [Shayna's] saying I see what you [Dejah] were saying**
12 Dejah: And it- no- th- th- we are the nerve thingies so that yeah ours can just turn up like zhoop and they go zhoop zhoop zhoop zhoop zhoop and she just be like whoop (jumps)
13 Ti'Anna: **(jumps)**
14 Shayna: **yeah**

As Dejah expressed her new idea, there were several moments of continuity when the group interactions proceeded without question or hesitation (Wickman, 2006). Those moments are highlighted in bold in the text above. For example, in lines 1 and 4, Dejah introduced a new idea and identified an additional element, a fire prop that they would need to construct. She quickly suggested that the fire could be made using cardboard, fabric with holes poked in it, and LED lights. This suggestion stood fast in the interaction. It was not questioned or challenged by any of the group members, which is evidence that the children felt they could indeed construct the prop using those materials and it would be a reasonable task for them to accomplish. In lines 2, 3, 8 and 14, Laurielle and Shayna responded verbally to Dejah's explanation in ways that allowed them to communicate their understanding without disrupting the flow of the interaction. When Dejah reached her hands out as she sang "da ta taaaaaa" in line 5, the children offered a nonverbal enacted response, communicating their understanding by grabbing each other's hands. Both verbal and non-verbal enacted responses were treated by the children as acceptable ways of communicating in this context.

The children used a multimodal resources of sound effects, words, and actions to describe and explain their ideas to one another. Dejah's explanation in line 12, *"we are the nerve thingies so that yeah ours can just turn up like zhoop and they go zhoo zhoo zhoo zhoo zhoo and she just be like whoop",* provides an example of the inextricable relationship between words, gestures and other sounds in Dejah's language. Her meaning is difficult to understand without taking into account the embodied messages in her actions. For these children, who have developed a disciplined perception for communicating choreographic intention, her actions serve as indexes, referential signs that signify her meaning (Stevens, 1998).

Figure 4.5. Dejah expressing her idea through multimodal embodied communication that is understood by her group members

Dejah’s idea was that Laurielle would touch the fire, a message would be sent to Ti’Anna through the nerves (Dejah, Shayna and Kevin), and Ti'Anna would react. As illustrated in Figure 4.4 above, Dejah pointed with her left hand to an imagined LED light circuit controlled by a dimmer switch sewn onto her right sleeve and performed a twisting action as she said, "zhoop." Using both hands to point, first to Laurielle on her right, then sequentially to Shayna, Kevin and Ti'Anna, she uttered "zhoo zhoo zhoo zhoo" to indicate the order in which they would turn their lights up. Finally, she demonstrated the action that Ti'Anna (who was at the end of the line) would take as she reacted to the message. Ti'Anna emulated that action, communicating her understanding of her role in Dejah's explanation.

Both Ti’Anna and Shayna reacted as Dejah explained her idea. Shayna’s response in line 13 was a verbal affirmation, while Ti’Anna in line 14 offered an embodied, situational, and sequential response (Mondada, 2011) as evidence of her understanding. By jumping at the right time to show that she received the message, Ti’Anna took the situatedly appropriate action (Mondada, 2011), proving that she understood what to do. When Dejah repeated her idea seconds later with accompanying turns and arm gestures, *“She should go like… doo doo doo doo… TURN UP… pshhw… and then be like dyoop dyoop dyoop dyoop”* the other children's eyes followed her hand as she pointed, and Ti'Anna anticipated her turn to jump without Dejah demonstrating it. Communicating with gestures and sound effects was an effective way of working for this group. It was a way of communicating that made sense to them, and it was useful to them for accomplishing the task. It was useful because many of the movements they were utilizing did not have codified names. Gestures and sound effects were also useful because they allowed the dancers to connect their conceptual ideas to movement without needing to take the time to translate them into words. Having the space and the freedom to communicate in these multimodal and embodied ways allowed them to engage in the process of investigating the phenomenon of message travel through the nerves in ways that were meaningful and natural to them. It became an essential part of their brainstorming process. Embodied communication supported their exploration of the phenomenon by providing an opportunity to make Dejah's interpretation of the phenomenon visible without her having to worry about using technical terms or science vocabulary. Once it was visible, it was available to interpret, re-interpret and re-structure. It provided a visual anchor and foundation on which other ideas could be built (Kirsh, 2010).

Because movement was the medium used to create their shared representation, part of the collaborative work that went into their brainstorming process involved moving together to kinesthetically construct visual representations for ideas as they were being shared. As in the example above, when Dejah begins to express her idea, the others immediately got involved in moving to bring it to life. Not only did they watch and attend to her movements, reacting with their bodies as she explained, they moved in and out of formation, grabbing hands and making shapes with own bodies, not waiting for her to finish explaining her idea before they began constructing it. Attending to one another's nonverbal actions was a tool that these dancers used often, as they worked to string together their separate parts in the choreography, collaborating kinesthetically to figure out how the part they played fit in to the larger explanation. As they worked through the process of developing the line idea, Dejah, Shayna and Ti'Anna all had ideas about how to accomplish the passing of the message. In each case, their group members enacted the ideas as they explained them.

New Ways of Thinking about Representation

Embodied brainstorming led the children to think differently about ways to represent the phenomenon they studied and to think differently about their bodies as representational tools. Dejah's idea changed the way they had been thinking about accomplishing the passing of the message. Her suggestion to create a line and illuminate their LED lights sequentially not only stood fast with Shayna, but it invited her to add her own new idea, that their bodies could be used to transfer the message from one neuron to the next. This is evident from Shayna's response to Dejah in line 10: *"Yeah and then it be like doo doo doo (waves her arms to the beat of the music they have chosen) ...then her, Ti'Anna be like CHHHHHP (raises left arm)."* Another example of multimodal embodied communication, Shayna's words, *"then it be like doo doo doo… then her, Ti'Anna be like CHHHHHP,"* do the work of calling attention to her body movements, which map on to her idea of the message traveling through. Shayna used an arm wave with a shoulder isolation to show the energy/message moving through her body. The wave began in her right shoulder and moved through her upper body and through her left arm as she sang the beat of the music *"doo doo doo…"*. Her left arm raised up with a reflexive flinching movement as she demonstrated her movement suggestion for Ti'Anna, a reaction to the fact that Laurielle had touched the fire and Ti'Anna had received the message that passed through the rest of the dancers. She used words as well as sound effects and actions to fully communicate her intention. But substituting the use of LED lights with movement, a ticking motion arm ripple in canon, to represent passing the message from Laurielle to Ti'Anna also showed a shift in thinking about how to use movement to express ideas.

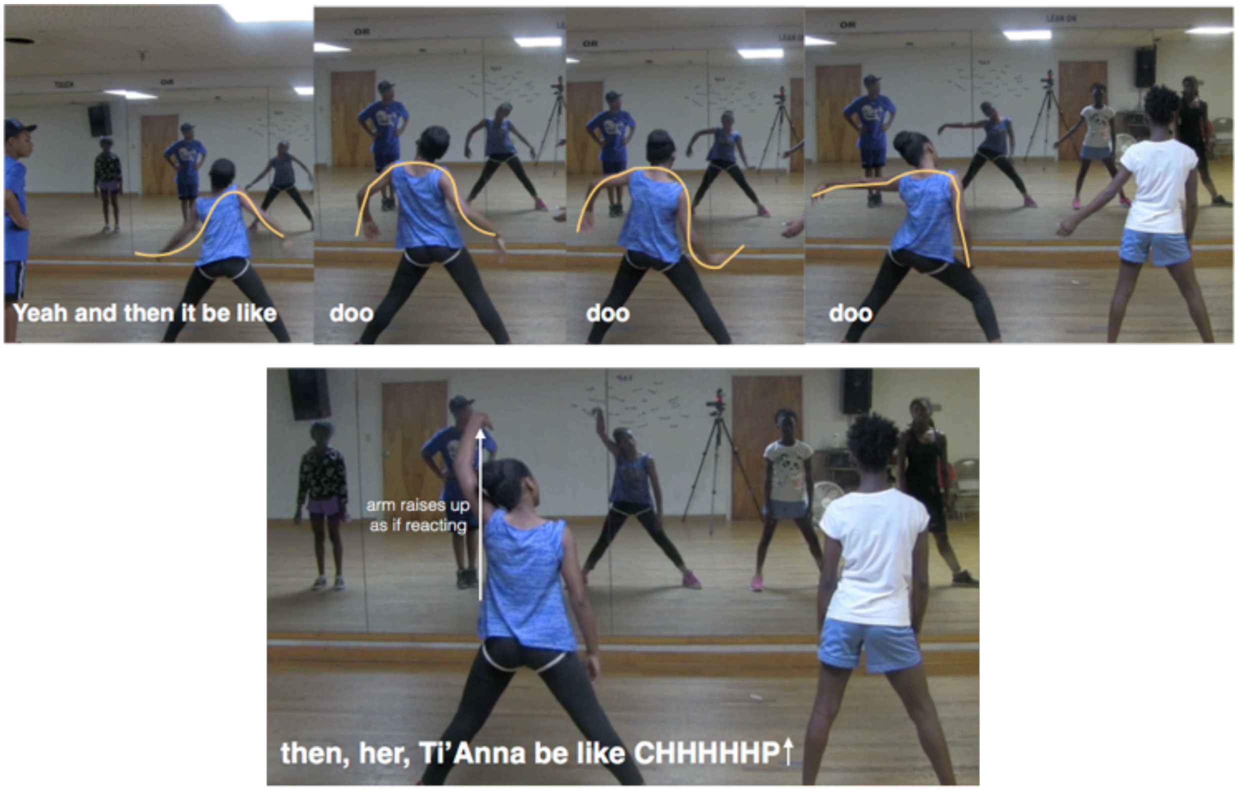


Figure 4.6. Shayna embodying message travel with her arms

Shayna's idea was that they use a specific type of movement along with their close proximity to one another and linear spatial relationship to communicate the passing of the message. The group was initially using freestyle solos to represent each neuron "holding the energy." Because the solo itself was meant to illustrate the neuron holding the energy, the children did not consider their specific movements or their spatial arrangement as consequential to the representation. Their idea was to use movements from hip hop dance in their freestyle dance solos, and their measure for whether or not a move was appropriate was based on aesthetic values. Initially they were thinking about dance in terms of movements they could do well, what fit the music, and what they liked. Shayna's movements in that early phase of brainstorming included shoulder and arm isolations, but prior to Dejah's suggestion, Shayna had not assigned specific meanings to her movements.

Dejah's idea pushed Shayna to think differently about how to use movements to communicate the idea they wanted to represent, the idea of messages traveling. In response to Dejah's original idea, Shayna reorganized her shoulder and arm isolation movements to create a specific meaning, to express a certain idea, the idea of message travel through the nerves. Shayna's movement choice required a change in the medium used to represent the traveling message. Her arm wave and shoulder isolations became a symbol for the idea they were working to communicate. Her suggestion changed the way they symbolically accomplished the passing of the message and changed the ways the group proceeded to think about using movement in their representation.

It is important to recognize the role Shayna’s movement plays in this example. Her thinking cannot be easily separated from her doing. Her actions in response to Dejah were not only integral to her ability to express an idea, but also communicated a new way of thinking about representing ideas. They also show how she was making sense of the phenomenon.

Multimodal Translation

So far, I have discussed three different points in the evolution of FOOF's choreographic explanation during their brainstorming and idea development phase. These three points included three different ideas for the symbolic representation of a message being passed through the neurons in the nervous system. In the first iteration of their work, they represented the passing of the message by passing an energy stick that each dancer would hold as they performed an individual solo. The second representation of message travel, Dejah's idea detailed in Excerpt 5.2, used constructed LED light circuits attached to their clothing that would light up sequentially and on demand using a dimmer switch. The third idea, Shayna's idea presented in Excerpt 5.3, required the movement of their bodies to represent the passing of the message. The selection of a form of representation has profound consequences for which aspects of a phenomenon become most salient (Jewitt, 2008). In other words, the representational choices influenced what they were likely to think about. Translating the idea of message travel from a textual representation written in their design journal, to an electronic prop, to movement, allowed the children to engage in different ways of thinking about the concept of “passing the message."

In the first iteration of their idea (a translation of text to movement), the decision to represent the message using energy sticks allowed them to focus on the analogy of messages as electrical signals. The passing and receiving of the message in this iteration was represented quite literally, as the energy stick was passed from one dancer to the next. The neurons were treated as individual actors who held the energy before giving it to another neuron. Dancing with the stick could be interpreted as dancers moving during the solo because they “have” (are in possession of) the energy. Once they pass it to the next dancer, they no longer “have” the energy, so they stop moving and the next dancer begins. This interpretation is supported by Dejah’s suggestion that they dance holding the illuminated energy sticks “so they can see the energy moving through our bodies.”

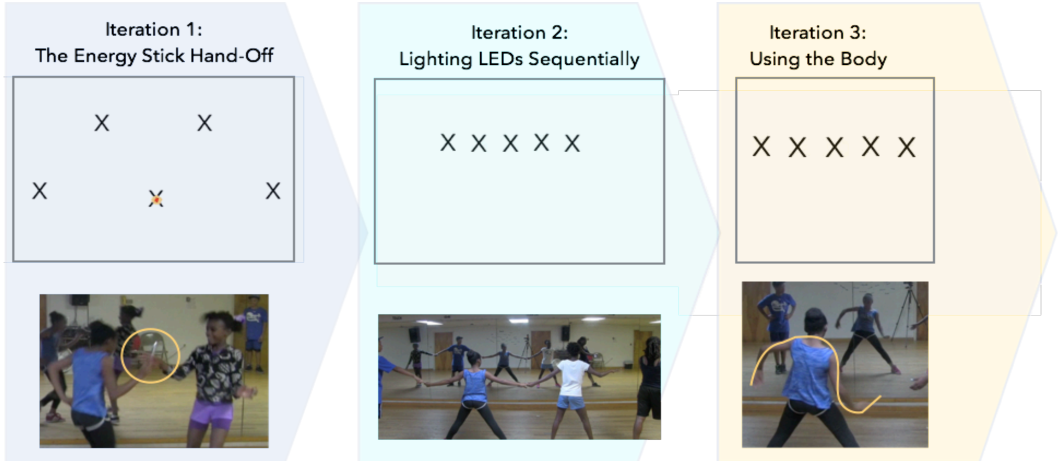


Figure 4.7. FOOF’s Multimodal translation of the idea of nerves passing a message

The choice to change from a circle to a line (Figure 4.5) allowed them to make a conceptual shift from representing energy as being held and carried by individual neurons to energy passing through the neurons, creating a more 'accurate' representation of how a message would be passed through neurons in the nervous system. The new version considered the neurons not as independent actors, but as part of a system that must work together to accomplish the passing of the message.

Shayna’s initial perspective shift led the group to think differently about how to use their bodies in the choreography. Instead of the dancers representing the neurons and the energy sticks still functioning as the primary representation of the message being passed, body movement was used as the representation of message being passed. In this version (Figure 5.6), dancers were the neurons and the message passed through their bodies. They went from holding the energy and just being a carrier of it (kind of outside the system) to embodying the energy. To do this, they had to make some choices about how to move. Because their movement now represented the passing of energy from neuron to neuron, they could not just perform movements that they liked or felt went well with the music. They had to also choose movements that for them represented the passing of energy.

This process of working together to translate and transform an idea using multiple modalities created an opportunity for the children to think about the phenomenon from both an individual and system perspective, and to think about and explore multiple aspects of the phenomenon simultaneously. The practice of perspective-taking is an important one in engineering and design (Rheingold, 1990). As they explained their ideas, they had to think about what their individual bodies must do and what the whole picture would look like in order to communicate the idea effectively. They also began to take on the perspective of being inside the phenomenon, exploring what they would do, how they would move if they were nerves. This type of perspective taking is a valuable tool for science exploration, and one sometimes used by scientists as they attempt to understand systems and phenomena (Ochs et al., 1996; Fox-Keller, 1983). Perspective taking in this case involved simultaneously thinking of whole and part in a dynamic system in which the parts are moving and not visible. As their representation changed from one iteration to the next, they continued to engage with the complexities of understanding their roles in the system from multiple perspectives. We see from this example that the process of working through their choreographic ideas led to a conceptual shift from thinking about energy as being carried by individual neurons to energy passing through the neurons. It also had implications for how they began to think about the role of the nerves in the nervous system.

Embodying What Nerves Do: The Jittery Nerves Gap

The previous examples have illustrated the different ways that their bodies played a role in the children's sense-making. As they moved through the process of brainstorming ideas for their dance, the children were intentionally moving their bodies in ways that generated new understandings and perspectives. They engaged in embodied collaborative brainstorming, arranging their bodies to help each person express their idea. In this process, each group member was required to participate and to understand their role in the phenomenon and its relationship to the whole picture they were trying to create. They also expressed their understanding of the phenomenon through embodied communication, a combination of words, gestures and sound effects. The next example shows how using their moving bodies to embody the phenomenon of messages traveling through the nerves allowed them to clarify their ideas about how nerves function in the system.

Embodied sense-making problematized the children's initial thinking and exposed gaps in their understanding that had to be resolved in order for their work to continue. When gaps surface and relations are construed, understanding is transformed. In this particular case, a gap was identified through the children's language and actions when they tried to translate their understanding of the role of the nerves from one expressive medium to another. Multimodal translation from a written description of nerves in their design journal to nerves as LED lights to nerves as moving bodies changed their focus from neurons as electrical signals and components in the system to neurons as actors, creating an opportunity for them to ponder how messages get passed. It also led them to some new questions. Their choreographic ideas about how the nerves should enter, what they should do, how they should react and move in the dance highlighted a problem that would need to be solved, a gap in conceptual understanding that kept them from moving forward. When they couldn't resolve it themselves, they brought the problem to me as facilitator:

Excerpt 4.3

Day 8 [00:01:14]

10 Dejah: So, we had questions and concerns and stuff because like… we are coming up with ideas so like one idea was that we get th- like a car crash… so like the LED lights would be the nerves and also us

11 Me: Mm-hmm

12 Dejah: So, we just show them jittering around then Laurielle said that's not you know how the nervous system works

Laurielle's insistence that the choreographic ideas being proposed by her group members did not represent the way the nervous system works led to group to an impasse. They could not continue creating choreography because they could not agree on how to choreograph the function of the nerves. Their attempts to choreograph the function of the nerves, to represent the neurons through movement, exposed a lack of clarity and uncovered their misconceptions about how nerves function in the system. While they had been able to clearly articulate the explanation that they wrote down and had been working with in their design journal, the children's conflicting ideas about how to represent the nerves led them to question what nerves actually do. They had been using energy sticks up until this point to represent the flow of the messages through the body. Using energy sticks and LED lights as the neurons allowed them to exploit their understanding of energy flow through a circuit and to represent the nerves as electrical signals. The idea of how nerves function, how messages move, or what nerves actually do was unproblematic when they were representing the nerves with LED lights. It only arose as they tried to translate the idea into the movement. When it was time to make choreographic choices about how they would move to represent the nerve in the system, they were puzzled by trying to dance what nerves actually do. Some of their ideas about the role that the nerves should play in their choreography are represented in the figure below.

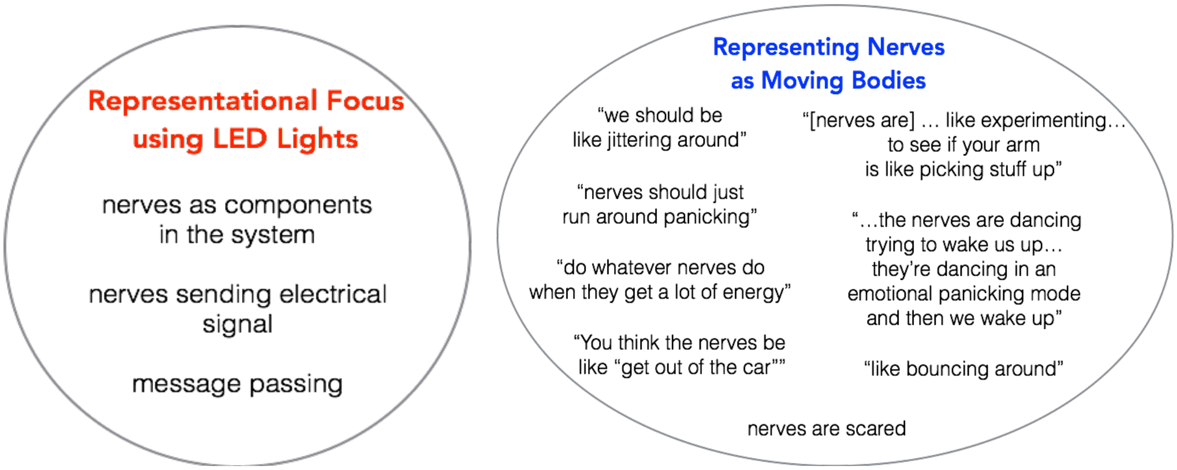


Figure 4.8. FOOF's ideas about how to represent nerves using as moving bodies

Attempts to resolve the gap and create new relations: Nerves on a mission to fix the problem. As questions were raised about the best way to proceed in their choreography, I engaged with them first to get a sense of what they understood and were trying to explain, and then to help them to clarify their understanding. As facilitator, I made several attempts were made to tend to the gaps in the children's conceptual understanding. They are bolded in the excerpt of the transcript below. Moves were made to call attention to the conceptual gap by both me as the facilitator and by group members. As I asked clarifying questions, the children attempted to construe relations about nerve response. Choreography development could not proceed because the children were still uncertain or unclear about how they should represent the nerve response. They engaged in an iterative cycle of question-response-idea until a relation was construed that stood fast for the group.

Excerpt 4.4

Day 8 [00:02:50]

31	Dejah:	So, would like- would it work if we like were the like the LED lights and us would be like the nerves… and like	
32	Me:	Yes	
33	Dejah:	be like jittering around but dancing, but you know jittering around	
37	Shayna:	Yeah and you know like one person could be like the person	
38	Me:	**but, what are you jittering?** **Like what does the jittering around represent?**	(clarifying question) (clarifying question)
36	Dejah:	It represents	
37	Kevin:	the nerves	(nerve response)
38	Dejah:	like getting in a car crash	
39	Kevin:	being scared	(nerve response)
40	Dejah:	So, it's like um… we're like what it- what is it called?	
41	Me:	**yeah, but are your nerves scared?**	(clarifying question)
42	Kevin, Dejah, & Shayna:	Yes	(contradicting group responses)
43	Laurielle:	No	
44	Me:	**Your nerves are scared?**	(clarifying question)
45	Kevin:	No, we're the nerves are not scared, they're	
46	Dejah:	It's a panic attack like she says	(nerve response)
47	Shayna:	yeah	
48	Ti'Anna:	It's like we're	
49	Shayna:	because like… your body starts shaking like you're scared… 'cause like when you like it something bad happen to you like you can't even stand up on your own…like you feel like you 'bout to fall	(nerve response)
50	Kevin:	Emotional dance	
51	Laurielle:	**But but but but technically the nerves would be reacting to try to fix the problem**	(nerve response)
52	Me:	Right	

53 Laurielle: **They wouldn’t be like, “Oh my Gosh!” They would be perfectly fine like, “uh… oh okay”** (nerve response)

In this excerpt, Dejah introduced the idea of nerves "jittering around." The children's responses to clarifying questions about what the jittering would represent, (i.e., the nerves being scared, getting in a car crash, panic attack, body starts shaking like you're scared) showed a confusion between the role of nerves and nervousness. They had a hard time parsing out the differences between nerves and being nervous, what happens inside the body and what would be experienced on the outside of the body, and the role of emotions versus the role of nerves. They seemed to rely on everyday experiences to make sense of the concept, but their experiences were not enough to help them get inside the black box. So, they ran into problems of how to move forward in the dance.

However, this was a generative choreographic discussion that included ideas about choreography, ideas about the concept, and ideas about their electronic component, the wiring of LED lights and circuit-making (not included in the excerpts of transcript shown here); all of these were part of this sense-making event. As the interaction progressed, certain ideas, like nerves "trying to fix the problem," became stable and began to stand fast, and their understanding of the role of the nerves evolved.

Excerpt 4.5

Day 8 [00:03:38]

51 Laurielle: But but but but technically the nerves would be reacting to **try to fix the problem**
52 Me: Right
53 Laurielle: They wouldn’t be like “Oh my gosh!
54 Me: Your nerves wouldn’t be scared
55 Ti’Anna: You could be like
56 Laurielle: They’d be perfectly fine, like “uh oh okay”
57 Me: Your nerves would be **on a mission** to **try to figure out what’s wrong** with your body and **fix the problem**
58 Ti’Anna: (raises her hand)
59 Shayna: That could be the theme of the dance!
60 Dejah: Yeah

61 Ti'Anna: So-

62 Shayna: We could be **on a mission**…

63 Dejah: So, after we get in the car crash… we get in the car crash and then the **nerves would be you know trying to fix it**

64 Ti'Anna: (raises her hand again) So like in the beginning we could do the car crash and then the **nerves are searching out** to where the problem is

65 Dejah: We already have a beginning

66 Shayna: Yeah we'll be like… **secret agents but we're nerves**

67 Me: Okay let her finish her thought

68 Ti'Anna: So, we would be like **on a mission** to um to figure out where the prob is…

69 Dejah: Problem?

70 Me: Mmhmm

71 Ti'Anna: problem is so we would probably go (laughs) so we could u- use dancing into **figuring out where it is when we search**

72 Me: Uh hun

73 Ti'Anna: **We could like go to the brain, get the information, go back to the problem, fix the problem**

Using movement as representational form allowed the group to clarify their ideas about how nerves function in the system. It encouraged deeper thinking about the phenomenon as it required them to puzzle through the difference between being nervous and the function of the nerves. The children came to recognize and fill gaps in their collective understanding by locating them in embodied representations. Although the children's ideas shifted as they continued to develop the choreography, the idea of nerves "on a mission to fix the problem" was carried forward to the final version.

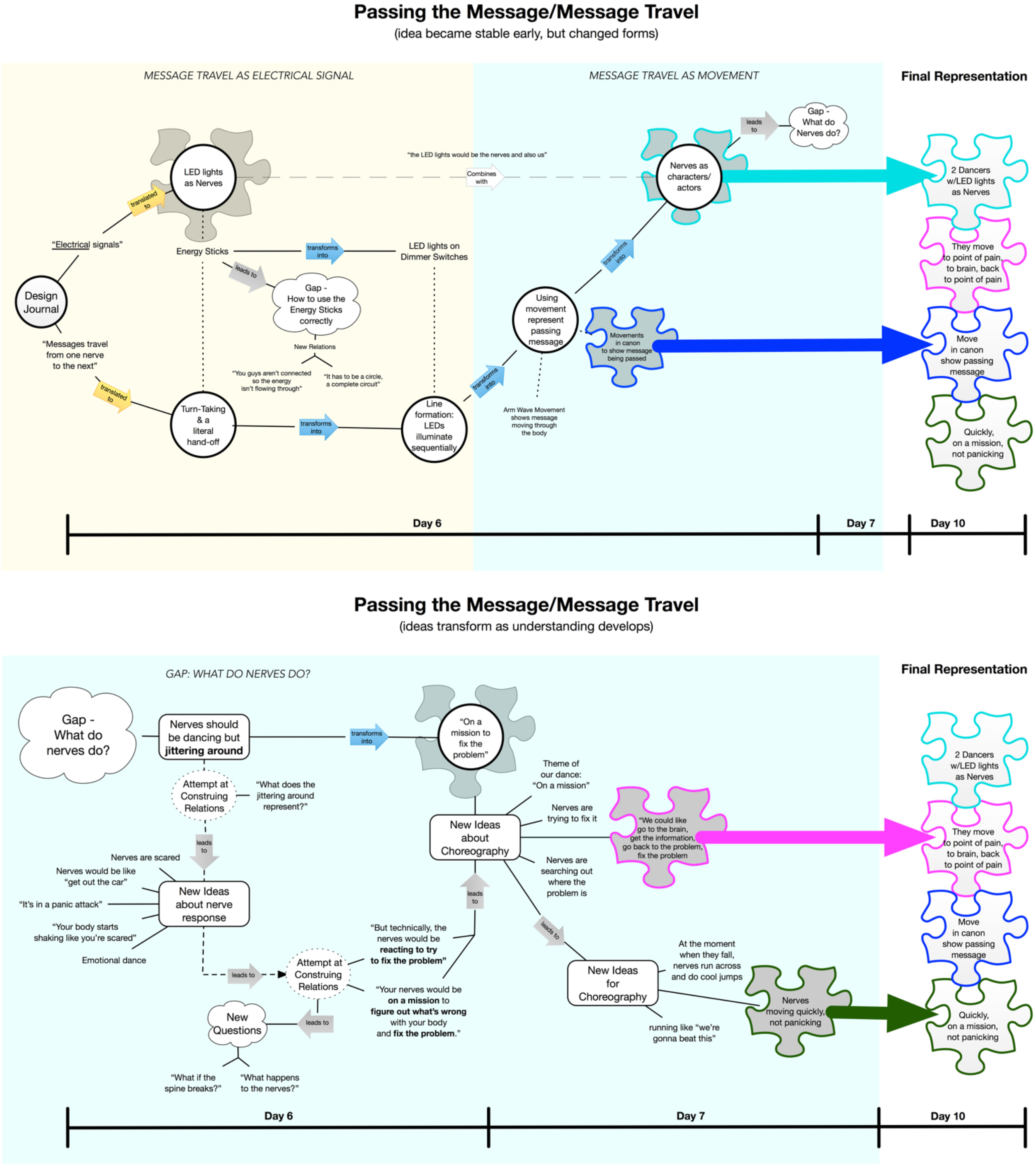


Figure 4.9. FOOF's Road to Representing Message Travel (a) shows how ideas became stable early, but changed form; (b) shows how ideas transformed as understanding developed

Figure 4.9 illustrates how and when the idea of message travel took shape in their choreography. It is a representation of their process, looking at moments over time. Read from left to right, it shows the various ways that this group chose to represent the *passing of a message* through the neurons in the body, and how the idea evolved from day 6 to its final form in day 10. What began as a written explanation in their design journal was translated and transformed. Two ideas written in design journal were translated, “message travel as electrical signals,” and “messages travel from one nerve to the next.” The representation follows the trajectory that each of those ideas took. Different ideas stuck at different points. The puzzle pieces represent the point at which ideas stuck. For example, LED lights as nerves stuck fairly early on and remained an important part of their representation. The idea of nerves moving quickly but not panicking was an idea that stuck much later in the process, after gaps were exposed and new relations were construed. Gaps in the group’s understanding were exposed in the choreographic process and led to the development of new relations and new ideas. Their final representation of message travel included all of these elements, and the idea was represented through multiple modalities. Figure 4.9 represents a generative choreographic discussion that included ideas about choreography, ideas about the concept, and ideas about their electronic component, the wiring of LED lights and circuit-making (which are not included in the figure), all of which were part of this sense-making moment.

Pathways for new questions. Taking on the task of embodying the nervous system led to new and diverse ways of thinking about the phenomenon. I have shown how the group engaged in perspective-taking as they worked through their ideas for representation, thinking in terms of both part and whole and taking on the perspective of each component in the system. Creating movements that would represent how nerves would behave in the system also led to authentic puzzling moments, opportunities to think through real questions that were consequential to their progress. Their initial questions, brought about by confusion about what and how to choreograph what the nerves do, pushed their thinking about the function of the nerves and this raised other authentic questions.

Excerpt 4.6

Day 8 [00:04:45]

76 Shayna: So you know how we said that like the nerves travel up the spine like a highway, so like, it should be like, like a car theme… like we're going up
77 Ti'Anna: a highway
78 Shayna: Ooh I just thought of it. So, like what if something like… how, like **when your like spine breaks… I just thought like how would the nerves go up?**
79 Me: You'd die
80 Ti'Anna: You'd die
81 Me: Or you'd be paralyzed
82 Dejah: Yeah
83 Shayna: Yeah
84 Me: from wherever the spi- spine breaks down
85 Dejah: **Wait, what happens to the nerves?**
86 Dejah: **I'm gonna go look that up.**

This excerpt shows how authentic moments of puzzlement led the children to greater interest in understanding and to seek to clarify their understanding of the concept. In line 76, Shayna makes reference to an analogy that compared the spine to a highway, which led her to question what happens when the spine breaks. Moments like these, which occurred at many points throughout their process, are seeds of scientific inquiry learning, which according to Dewey begins with "the presentation or discovery of a puzzling experience" (Stevens, 1997). Shayna's question led Dejah to ask a question of her own and then take the additional step to say that she would go look it up, showing a developing interest in answering new related questions.

Multiple Understandings

As they collaborated to construct an embodied representation of the function of the nerves, the youth dance makers in this group engaged with new questions and deepened their understanding of the phenomenon of message travel through the nerves. However, this process of negotiating their group representation required more than just sense-making about that concept. It pushed their representational thinking, required engineering and creative design skills, and challenged them to apply prior and developing knowledge about other phenomena in the world. In one instance, the children were working to understand both message travel and energy flow as they negotiated a spatial arrangement for their representation that made conceptual sense. The following excerpt offers a picture of how their bodies, along with the energy stick, became resources for making sense of energy flow through a circuit as they worked through their representational idea of messages traveling through the brain and body. The work of integrating different tools for representation into their choreography created an interesting balance between enacting understanding and developing understanding, allowing tools for representation to also become tools for sense-making. Part of the work involved understanding how to use the tool and part of it required making sense of the concept. Moving to think about how to make sense of the concept, they developed in tandem understandings of both the question they were seeking to answer (about how the brain sends messages to the body, how nerves work) and the technology they were using to choreograph their explanation (the energy sticks).

In this case study so far, I have identified both moments of continuity and moments of transformation, when the children identified gaps and filled them. The previous examples have focused primarily on verbal communication, however non-verbal, physical communication was an important way of communicating understandings and making sense of concepts as well. The next example shows how dancers attended to non-verbal gaps in understanding and responded to fill them through actions. As Ti'Anna presented a new idea for representing message travel, Shayna saw that Ti'Anna's idea would not work the way that she was explaining it. Shayna recognized the need for a complete circuit in order for the energy stick to illuminate. She attended to Ti'Anna's gestures in her explanation, recognizing the gap and used embodied communication to fill it.

Excerpt 4.7

Day 6 [00:31:15]

1	Ti'Anna:	I have an idea. The LE- the um... the energy sticks could be tou- like we could hold them like this so that it would be like... you could see how they... run through and connect.
2	Laurielle:	Mm hmm
3	Shayna:	Yeah
4a	Ti'Anna:	So, we could have 'em in our hands. 'Cause like (walks over to Laurielle and grabs the other end of the energy stick) we're holding each other…

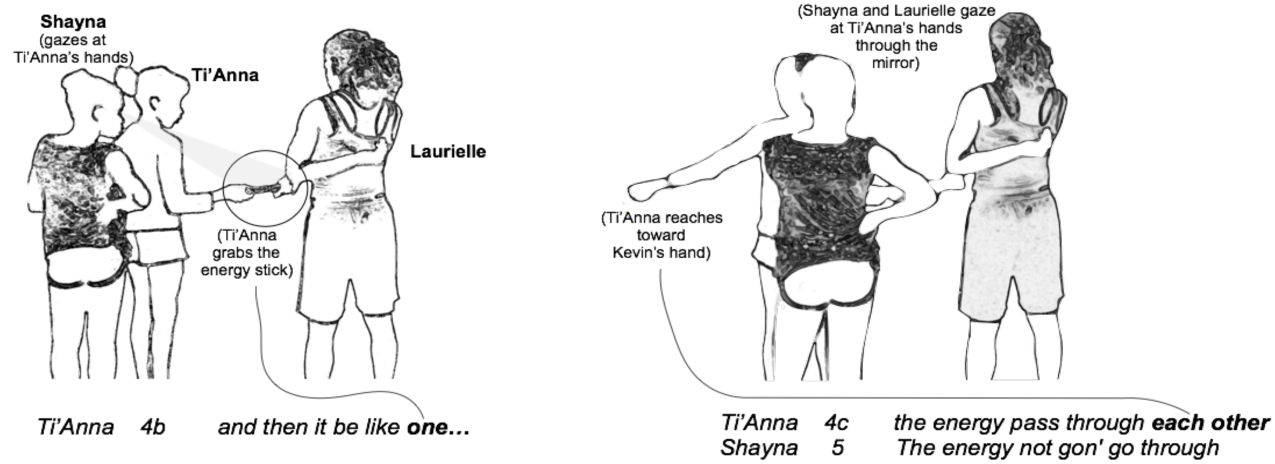


Figure 4.10. As Ti'Anna attempts to explain her idea, Shayna recognizes that the idea will not work the way it has been proposed because the energy stick will not work in the way that Ti'Anna is trying to use it.

Ti'Anna used her hands simultaneously with talk to express her idea. Shayna, listening and watching Ti'Anna's hands, recognized that Ti'Anna's had gap in understanding about how the energy stick worked and exposed it. In line 5, she tells Ti'Anna that because of the way she has positioned her arms, the energy is not going to go through. Then, Shayna attempted to create a new relation. Shayna understood that there needed to be a complete circuit in the shape to make the energy stick illuminate. She moved in to show Ti’Anna.

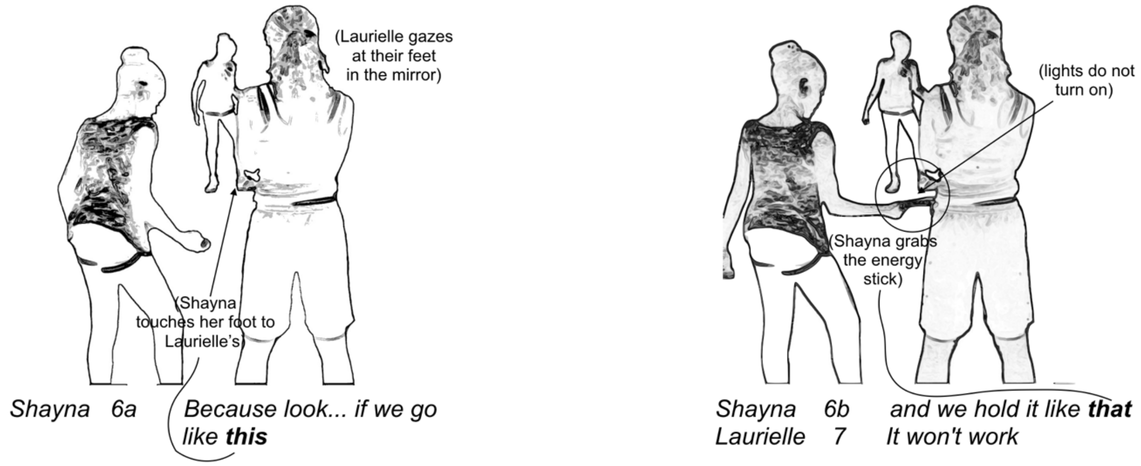
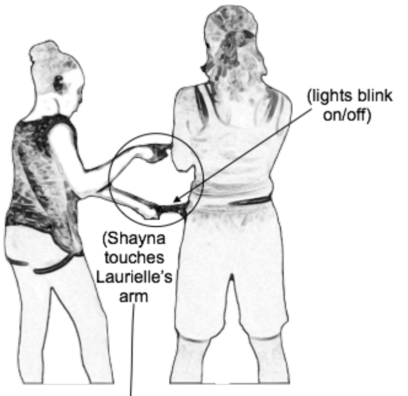


Figure 4.11. Shayna Recognizing and Filling Gap in Ti'Anna’s Embodied Explanation

Shayna placed her foot next to Laurielle’s and grabbed the stick with her hand to create a complete circuit (or circle), but the stick did not light up as she anticipated. She did not account for the fact that both she and Laurielle were wearing rubber soled shoes, which acted as insulators to keep the energy from flowing through. Shayna may or may not have realized her mistake, however, she did not hesitate to take another shot at demonstrating her understanding, making the connection for the both Ti’Anna and Laurielle, who initially thought they had to be standing in a circle for the lights to work. When Shayna re-grabbed the stick with her other hand and touched Laurielle's arm with her finger, the stick illuminated.



Laurielle 8 yeah It has to be a circle
Shayna 9 ***we have to...***
Laurielle 10 So if we're in a line... It still would be a circle… I get it I get it I get it

Figure 4.12. Shayna and Laurielle engaging in embodied sense-making

Shayna's actions led both Ti'Anna and Laurielle to a new understanding and they continued to work.

This example illustrates the symbiotic, interdependent relationship between conceptual understanding, representation, and the body. It is reflective of their work throughout the making process. The children made sense of multiple ideas and concepts through their interactions, engaging in work that was simultaneously cognitive, technical, creative, and embodied. Previous work on making has defined it as a broad category of often interdisciplinary activities that can include a range of practices, including tinkering, making or designing, engineering, and even scientific and technical investigation. (Vossoughi & Bevan, 2014; Blikstein, 2013; Martin, 2015; Martinez & Stager, 2013; Honey & Kanter, 2013; Resnick & Rosenbaum, 2013; Halverson & Sheridan, 2014). The children's work shows evidence of these practices, tinkering with energy sticks and playing with different representational ideas, making and designing through choreography, engineering when designing and constructing LED light circuits to fit into their choreography and also when coming up with the process to do so, and scientific investigation, engaging in conceptual thinking about the phenomenon. They utilized these practices in conjunction with dance as an art form and dance as a representational practice as they engaged in creative dance-making, and representational thinking more generally as they chose the most appropriate modalities to communicate meaning. The body played an integral role in their creative problem-solving practices. Research has shown that making practices can be mutually and reciprocally generative, that creative production exists "at the crossroads and fringes of disciplines" (Brahms, 2014), and that the "forms of meaning-making embedded in the process of creative problem solving and design can productively blur the lines between science, engineering and the arts" (Vossoughi & Bevan, 2014). But this work shows how it can also blur the lines between the body and the mind. By documenting conceptual learning while describing the ways in which it coalesced with other forms of sense-making through embodied and multimodal representational practices, this example illustrates one of the many ways children came to understand through making.

There are, of course many mediating factors that influenced how the children made choices about what would end up in their final representation. Practice-based theorists of representational activity have shown how representational acts are mediated by multiple factors that may at any given moment conflict. Danish and Enyedy (2006) have identified several of these factors, including the environment in which representation is being created, local norms for representation, the activity in which the student is engaged, individual understanding and preferences, the available tools and materials, and the other people present. So, it is important to consider the representations created in context. While, one could argue that it is problematic that the group did not necessarily create an accurate scientific representation, as dancers in this out-of-school creative space, they were very aware that their representations were not scientifically accurate. Their representational choices reflected not only their understanding of the concept, but also their dance values, what they felt they could accomplish in the time and space available to create, their range of ability levels, and creative choice. It was not a science class, and there were no specific curricular content goals. It was a creative space to try new things, play with tools and materials, and make something cool. That is how they positioned the task. That is how it was framed. That being said, that fact they remained committed to understanding the science in the task speaks to the power of allowing children to utilize their own repertoires of practice and follow their own interests as they engage in inquiry.

The group made choices about what to include in their representation through a process that included conversation and negotiation, making conscious decisions about what to include and what to leave out. This is the same type of process scientists engage in when inventing representations (Stevens & Hall, 1997). No representation is perfectly accurate. By definition, it cannot be. A representation is an abstraction of the real thing, one that makes certain features of a phenomenon salient by leaving out others. The children's final interviews showed that they could explain why they made the choices to include certain things and leave others out.

> Shayna: "So say, [your] hand touched the stove and then the nerve [would] travel through your arm like a highway... and then it will go to your brain and be like "Ding!" and then it will travel back down and then you will hurry up and move, but it will happen in like, like (snap) that. **We didn't really show how fast it happens in the dance, but we did it with a freeze frame. We wanted to show the nerves like a highway, but it got complicated because we didn't have enough people.** We changed our dance four times and the fourth time it looked like the audience could really understand our concept."
>
> Dejah: "Um... we did this move to show the nerves sending the message from one nerve to another nerve, so we could send it to Shayna… because the way they flow together and the way that we pictured it in our mind, that's how the nerves would like send [signals] to the body. **The next move wasn't part of the nerves, it was just us coming together again.** "
>
> Kevin: The electronic component is the nerves rushing through the human leg as she gets burned by the fire. **We used LED lights to show it happens instantly.**

This case has highlighted many of the ways science learning in the dance makerspace was supported through embodied exploration. Embodied exploration in this case included: the use of bodies as knowledge-constructing resources used to create and explore physical models and analogies, the use of movement as a resource for collective sense-making, and the use of movement and other modalities as tools for communication. A practical epistemology analysis showed that the children's strategies of embodied exploration supported deep engagement with the content, creating opportunities to make their thinking explicit and to consider the phenomenon from multiple perspectives. Embodied exploration supported the development of new understandings and opportunities to consider new questions related to the phenomenon.

Toward a Theory for Sense-Making through the Collaborative Construction of Embodied Multimodal Dynamic Representation

This was an exploratory study to understand how youth would choose to engage their bodies as they explored science ideas, concepts, and content in the process of making collaborative embodied multimodal dynamic representations of science phenomena. Groups made their own choices about how they would go about creating their projects, and not every group chose to work the same way. Looking at the range of project-making strategies and embodied sense-making practices across the data set allowed me to generate some broad theoretical categories for sense-making through the construction of embodied science representations. Through a comparative cross case analysis of embodied interactions, I have identified three ways that the construction of multimodal dynamic representations led to sense-making: (1) learning through the construction of embodied representations; (2) learning through embodied exploration; and (3) learning through kinesthetic experience.

Learning about a Concept through Embodied Representation

All groups engaged in embodied re-presentation of the ideas, concepts, and phenomena they studied. By *embodied re-presentation,* I mean interpreting, combining, reformulating, and translating ideas that were researched and collected about a phenomenon to create a new representation, to re-present in a new embodied form. Hall makes the distinction between representation as an object, or a noun, and re-presenting as an activity, or a verb, in his work on representation as a shared activity (Hall, 1996). Embodied re-presentations were explanations of science understandings constructed with moving bodies, which were often combined with other materials and media (e.g., electronic technologies, music, other material props).

Across groups, embodied re-presentation of science phenomena drove sense-making about phenomena in different ways. First, the process of developing choreographic ideas led to groups to raise new questions about their phenomena of interest and to think about them from different perspectives. For example, developing and discussing ideas for their choreography led FOOF to think about how nerves move, and it also led them to think about the phenomenon from multiple perspectives. Not only did they consider the phenomenon from the perspectives of part versus whole, as discussed in an earlier example in this chapter, they also thought about the phenomenon from the perspective of dancer versus audience. Embodied re-presentation not only required thinking about what movements would reflect certain ideas but also thinking about how an audience would perceive what they saw. This type of perspective taking was an important part of the choreographic process for many groups. Groups also engaged in debate and discussion to negotiate and justify their creative choices. Lack of clarity in choreographic representations raised questions that led groups to revisit their developing understandings of the phenomenon of interest. Also, groups used their developing conceptual understandings to make decisions about choreography when creative tensions arose – the need to resolve creative tensions led to new thinking about the phenomenon.

Learning through Embodied Exploration

A second way that youth made sense of science phenomena was through embodied exploration. *Embodied exploration* means using the body through movement, gesture and/or spatial formations to work out one's thinking about an idea, concept or relationship related to a phenomenon. For example, in learning about the concept of energy flow, and specifically how electricity can move so quickly through wires in a circuit, youth during one of the science modules compared different ways of representing traveling electrons in a circuit. They created and compared two different physical analogies, one in which dancers stood side by side in a line and passed a touch from one end of the line to the other, and another in which one dancer representing an electron would run in a straight line from one point to another. Comparing the two analogies allowed them to see and feel the differences in speed and make connections between what they felt and what they were learning about electricity. Physically exploring concepts made bodies central in reasoning about phenomena. Project groups used their bodies to create these kinds of physical analogies and to explore rules and complex relationships in their phenomena, like the moon's orbit around the Earth as the Earth travels around the sun. Embodied exploration allowed youth in this case to use their bodies to understand the complexity of the pathways of planets in orbit and to experience the perspectives of earth, moon, and sun (i.e., what does the moon "see," what does the sun "see"). Embodied exploration provided opportunities for groups to work through their developing representational ideas and to construct shared understandings as they physically engaged with phenomena by giving them a physical representation to play with that could be easily manipulated and evaluated as understanding evolved and allowing them to experience the phenomena from an inside perspective. Embodied exploration was used more in groups that had more experienced dancers. Groups that engaged in embodied explorations to help them make sense of the science were able to explain the science more clearly as they shared their progress during *Share Time*. Groups that did less embodied exploration received more questions from facilitators, mentors, and peers during *Share Time* that were phenomenon-related.

Learning through Kinesthetic Experience

Finally, youth engaged with science phenomena through kinesthetic experience. Embodied exploration and representation-making provided participants many opportunities to engage with scientific phenomena through bodily experience, to get a feel for concepts, relationships, and tensions related to phenomena in their bodies. For example, in developing their projects with energy sticks, and the Makey Makey, youth experienced what it means to be a conductor of energy, to complete a circuit that allows energy to flow through. While trying to represent sickle shaped blood cells, group Fiji physically experienced the difficulty of moving past another in close quarters when the shape of the movements changes from circular, smooth, and flexible to C-shaped, rigid and pointy. Dancers in group Stardust felt the impact of gravity, centripetal and centrifugal forces on their bodies as they created and performed work that explored the gravitational forces exerted on planets. These kinesthetic experiences provide a way to ground the abstract science concepts that can be complex and challenging to understand.

Significance

Although the primary focus of the design was not necessarily on teaching science content, analysis shows evidence of more than a superficial level of thinking about ideas related to a scientific phenomenon. Through a process of multimodal embodied engagement, children developed an interest in better understanding the phenomena they chose to represent. They recognized and filled gaps in their understandings by locating them in embodied representations and those ideas remained a part of their final choreography. In addition to conceptual understandings, the children also developed their understanding of circuitry and energy flow through a circuit, as well as representational and creative thinking skills. The types of learning outcomes in this context were conceptual, technical, and creative. Sometimes inextricable, they built on one another and involved the body in ways that are undeniably important, and critical to how learning happened and to what was learned. These understandings might have been hard to recognize with standard representational media that focus narrowly on symbolic (usually written or verbal) expressions of understanding.

This chapter has shown the varied and complex processes of children's representation making and what can be gained from allowing them to translate thinking between modes and particularly into physical modes of expression. Working in this way in this space provided unique learning opportunities. Multimodal embodied exploration allowed children the freedom to integrate all kinds of materials, tools, and technologies into their representational thinking and to communicate in ways that made sense to them, ways that often included multiple sign systems, talk, sound effects, images, and movement. The process of embodied brainstorming often required the dancers to physically co-construct one another's ideas in real time, which meant that all dancers shared the responsibility for bringing each person's idea to life. They became invested in one another's ideas, helping each other to make sense of each one, because they needed one another to execute each one. The ability to rapidly reorganize, to quickly shift from one idea to a very different one, was also an affordance of using bodies as representational tools. It allowed the group to explore multiple very different iterations, to play around with what to include and take out of their model. This medium gave them the space and freedom to easily change and revise their ideas. This analysis pushes us as educators and education researchers to consider the body as a tool for sense-making, potentially widening the lens for what counts as cognition.

Chapter 5: dance/Making as an Integrated Representational Sense-Making Activity

Like the previous one, this chapter is an analysis of learning in the setting. Chapter 4 zoomed in to examine cognition in moments of micro interaction. Through detailed descriptions of the complex processes of children's embodied sense-making practices, it showed how physical modes of expression supported exploration and interrogation of STEM concepts and phenomena. However, the dance Makerspace was not just a STEM space, and STEM content-based learning goals were not imposed on the youth dance/Makers. Developing projects that incorporated dance, music, and other artistic styles in this collaborative free-choice environment included opportunities for youth to set and work toward a variety of different learning goals and to exercise creative freedom, which played an important role in how they came to make sense of their chosen phenomena and of the task. In this chapter, I scope out to look at the many factors that influenced understandings enacted in this context that blurred the boundaries between art and science through making.

As making becomes more popular as a way to engage children in STEM in both formal and informal settings (Stevens et al., 2016), there is increased interest in understanding learning in these interest-driven spaces. Making has often been characterized as a STEAM activity. Described by Sheridan et al. (2014) as a learner-driven practice focused on creative production rather than on specific skill or content mastery, it has been shown to support interdisciplinary learning and practices through activities that leverage the relationship between STEM and the arts (Brahms, 2014; Sheridan et al., 2014; Vossoughi & Bevan, 2014). However, arts integration into STEM making and learning is still an area of active research. There is little clarity in the field around what the "A" in STEAM making represents or about how to fully integrate it into maker-centered learning experiences (Radziwill, Benton, Moellers, 2015; Clapp & Jimenez, 2016). In this chapter, I explore *making to learn* in the context of an informal STEAM environment where STEM and dance influenced what participants created and learned. The goal is to understand how ideas, skills, and practices mediated and were mediated by the process of constructing choreographic representations (embodied multimodal dynamic representations of science phenomena). These questions relate to both research questions 1 and 2:

RQ1. What does the process of "making" embodied multimodal collaborative constructions of dynamic representations involve?
  - How do choreographic representations get made?
  - How is understanding built in the process?

RQ2. How do participants experience the dance makerspace as a learning setting?
  - How do they understand the experience, its purpose, its value?
  - How do they engage with and experience the relationship between STEM and dance?

In the sections that follow, I draw on prior literature on representational mediators and practices in science learning and on the data collected to propose a framework for understanding how knowledge, practices, and values influenced representational decision-making in the STEAM making environment. I utilize the lens of representational mediators and practices to show that in constructing creative representations of science phenomena, youth negotiated meanings and enacted understandings by thinking across conceptual, representational, and technical dimensions; and they utilized interdisciplinary practices that supported problem solving, sense-making, and sustained inquiry. This work reveals the symbiotic relationship between science and art practices in creative problem solving. Through it, I seek to bring creative thinking and artistic production into conversation with the learning sciences – to identify the ways that the arts can be resources for science learning and STEM can be a resource for the creative thinking (21st century skill that is important for youth to develop), and to clarify the role that the arts and creative thinking can play in informal urban STEM learning environments for broadening participation in STEM among underrepresented populations. To begin, I ground the analysis in a discussion about participants' interpretations of their work in the learning space.

Participant perceptions of the dance makerspace

In order to understand how youth made sense of their work in the dance makerspace, it is important to first understand how they experienced and framed the making activities in this hybrid setting. What it means to make in a STEAM context remains an open question, in need of further investigation. This investigation begins by examining what it meant to youth participants, how they experienced and described the relationships between dance, science, and technology in their work in this setting.

To understand participant perceptions of the dance makerspace, I analyzed 24 participant post-interviews across all four iterations. I used a modified grounded theory approach (Glaser & Strauss, 1967; Charmaz, 1983; Strauss & Corbin, 1990) to develop the codes. Participant statements about their experiences working in the makerspace were inductively coded to see what themes emerged and were most prominent. There were three key ways that participants framed their project work and experiences in the dance makerspace: (1) problem solving through dance; (2) dance-making that integrates science and technology; and (3) storytelling through dance. I expand on each framing below using examples from the data to provide context for the ways in which the dance/Making process unfolded and for the kind of work that was done as groups developed projects in the dance makerspace. I argue that youth framed this experience as *dance plus (+)*, a dance experience that allowed them to utilize, learn, and integrate many different skills and practices. I also share participant thoughts on what they learned as a result of participating in the dance makerspace program.

The following diagram, Figure 5.1, is a network map that shows how participants described their experiences working in the dance makerspace. Responses from three interview questions about their perceptions of the program and their project work were coded and their ideas were organized into 8 main categories, shown in the diagram with numbers representing the number of times that code came up.

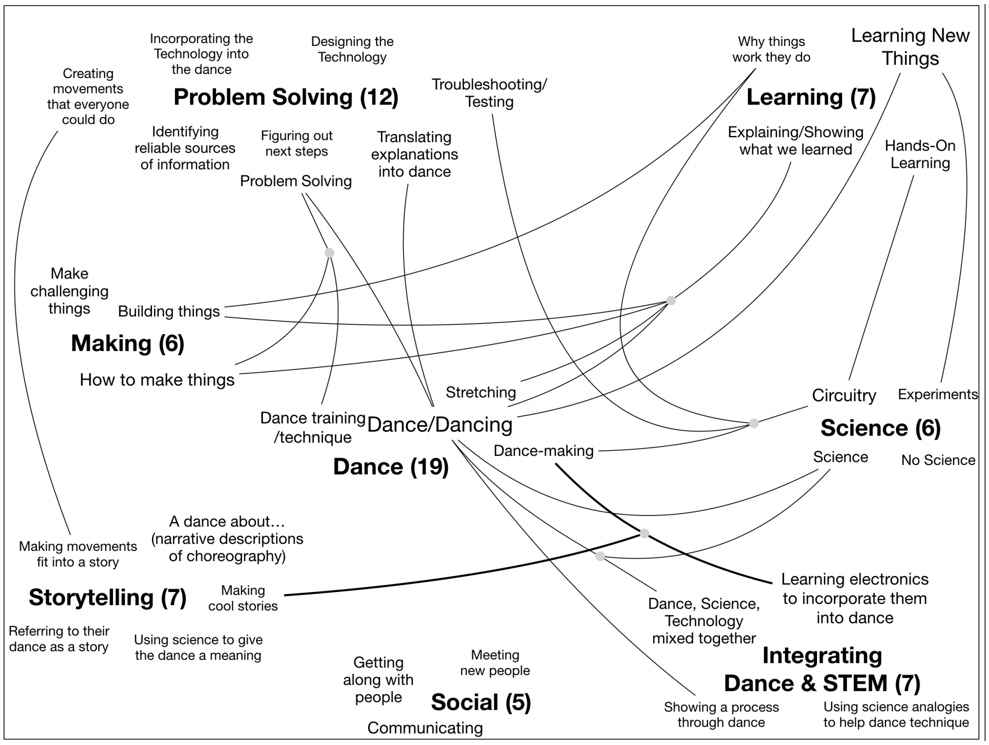
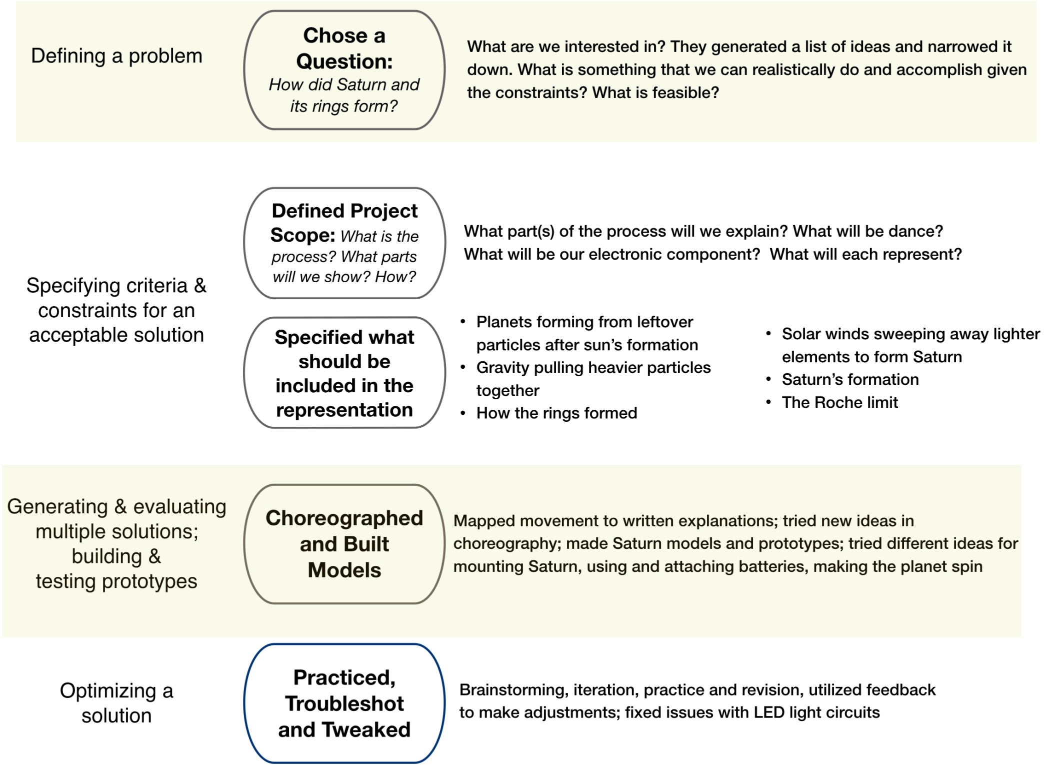


Figure 5.1. Network map of emergent and coupled themes from participant interviews

The connecting lines show the ideas that youth coupled in their responses. For example, dance or dancing was mentioned 19 times in the 24 participant interviews. This is not surprising, as the program was framed as a dance camp and a large majority of participants identified as dancers; their interest in dance brought them to the program. They also talked about opportunities to learn. Learning was mentioned seven times, and their talk about learning was connected to dance, to making, and to science. Interestingly, the connections they made between learning, making and science were not about learning to make or learning science. They talked about how making things led to learning about why things worked; how the hands-on application of science learning about circuitry led to learning about why things work the way they do. Also, explaining their learning was noted as an important part of their process of making, which they connected to building things, stretching, and dancing. Other themes were problems solving, integrating dance, science and technology, and dance as a form of storytelling. I expand on these three themes below.

Problem solving through dance. Across participant interviews, youth expressed that problem solving was an essential part of the work they did during the program. For example, according to one youth participant, the camp was "an amazing experience because you not only get to have dance training, but you get to like figure out problems." Problem solving was not in the explicit framing of the program or activities, however, aspects of problem solving were mentioned as a key part of the experience by several participants. Youth framed the making experience as problem solving, but also connected problem solving to the work that dancers do. The problems they solved were framed around the task of dance making which they readily engaged in. Youth talked about the necessity to solve problems that emerged through the process of making choreography and through the process of making the electronic components that were part of their choreography. Their talk about problem solving centered around choreography, troubleshooting technology, integrating technology into the choreography, planning project work, and multimodal translation (processing information through one modality and re-presenting it through another).

Each group tackled multiple problems in the process of making their projects. Not only did youth identify problem solving as an important practice, but through project-making, they engaged in activities that align with NGSS standards for problem solving, including "defining problems, specifying criteria and constraints for acceptable solutions, generating and evaluating multiple solutions; building and testing prototypes; and optimizing solutions" (NGSS, 2013). They, however, engaged in problem solving through a choreographic process. For example, the steps in on group's problem-solving process are highlighted in Figure 5.5 below:



Defining a problem	**Chose a Question:** *How did Saturn and its rings form?*	What are we interested in? They generated a list of ideas and narrowed it down. What is something that we can realistically do and accomplish given the constraints? What is feasible?
Specifying criteria & constraints for an acceptable solution	**Defined Project Scope:** *What is the process? What parts will we show? How?*	What part(s) of the process will we explain? What will be dance? What will be our electronic component? What will each represent?
	Specified what should be included in the representation	• Planets forming from leftover particles after sun's formation • Gravity pulling heavier particles together • How the rings formed • Solar winds sweeping away lighter elements to form Saturn • Saturn's formation • The Roche limit
Generating & evaluating multiple solutions; building & testing prototypes	**Choreographed and Built Models**	Mapped movement to written explanations; tried new ideas in choreography; made Saturn models and prototypes; tried different ideas for mounting Saturn, using and attaching batteries, making the planet spin
Optimizing a solution	**Practiced, Troubleshot and Tweaked**	Brainstorming, iteration, practice and revision, utilized feedback to make adjustments; fixed issues with LED light circuits

Figure 5.2. Stardust's Problem-Solving Process

Once this group decided on a topic, the first problem they had to solve was figuring out what aspects of the phenomenon to represent. One student expressed this choreographic conundrum in her interview, *"It's like so many things that go into how a planet was formed you can't really explain like the whole process of it all."* Grappling with these types of issues is essential to the work of representation-making and has been shown to be a fundamental work practice of scientists (Stevens and Hall, 1997; Goodwin, 1993, 1994, 1995; Woolgar, 1990; Star, 1983) and science learners (diSessa, Hammer, & Sherin, 1991; Hall, 1996). When the group ultimately decided to use a foam ball to represent Saturn, it led to new problems to solve, including how to make the rings spin and not the planet; how to construct a sphere out of a cardboard box; how to activate the switch to start the rotation of the rings during the choreography without stopping the dance; how to show particles breaking up in the Roche limit; how to fit the large battery inside the planet; how to hang or mount the planet so that the motor can still spin; and how to get their LED light circuits to work using multi-colored LED lights. Creating projects that combined choreography and electronics to explain a science phenomenon was a problem-solving activity.

Dance-making that integrates science and technology. Another major theme was integration. As will be shown later in the analysis of group practices, the process of dance/making provided opportunities for integrated thinking across various dimensions that are typically paired in oppositional dichotomy. From the participant perspective, youth discussed their projects as providing opportunities to integrate dance and other things, most often electronics and technology. They talked about integration in terms of integrating concepts (i.e., ideas for how to integrate the electrical component into the choreography concept) and in terms of figuring out how to physically integrate their electrical components into their choreography. For example, in iteration three, group Fiji utilized a Makey Makey microcontroller and aluminum foil tape to make a floor circuit board which they used to activate the projector at a point in their choreography. In her post-interview, Denise expressed the challenge of figuring out how to choreograph the moment when they needed to start the projector. “When we did our dance, for the electrical part, we had to figure out how to do one of the steps [while putting] our hands and feet on the tape, so the video could come up on the screen.” Activating the projector at the desired time in the choreography required creating functional circuit with the conductive aluminum tape and their bodies. Dance/making meant thinking about the science, technology, and dance as a unit. Brittani expressed that her "favorite part of working on the dance [was] getting to play with the circuitry and figure out why it does or doesn't work." For her, the technology was integrated into the dance-making process. She thought about it as part of the dance. While Brittani admitted her favorite part was the technology, she still framed the project as a dance-making project, not a project to learn how to make and troubleshoot circuits. She came for the dancing but her favorite part, like many others, was "mixing [everything] up". While participants acknowledged that they did science in some of the camp activities, in general, they did not see their group project work as doing or learning about science. They instead positioned their project work as a way to use science or to mix science and dance to express something cool. When learning about science was mentioned, it was not in the context of their projects, but in the context of module activities and experiments.

Storytelling through dance. Another interesting emergent theme was storytelling. The project was not explicitly framed as storytelling. However, many participants expressed a connection between science and storytelling in their interviews. The science created a context for storytelling through dance, and the technology provided a medium (an additional modality) for creating.

Narrative was an important feature of a lot of group projects. For example, FOOF explained the process of the brain sending messages to parts of the body by constructing a narrative about a person who comes in contact with fire. In their choreography, Dreamers combined a story about a man whose heart needed fixing with the functions of the heart and blood flow. Dreamers chose to represent the heart from multiple perspectives, both the inside and outside of the body. In the first part of their dance, they used movements to represent the functions. In the second half of their dance, they played the role of surgeons in a story about a man whose heart needed fixing.

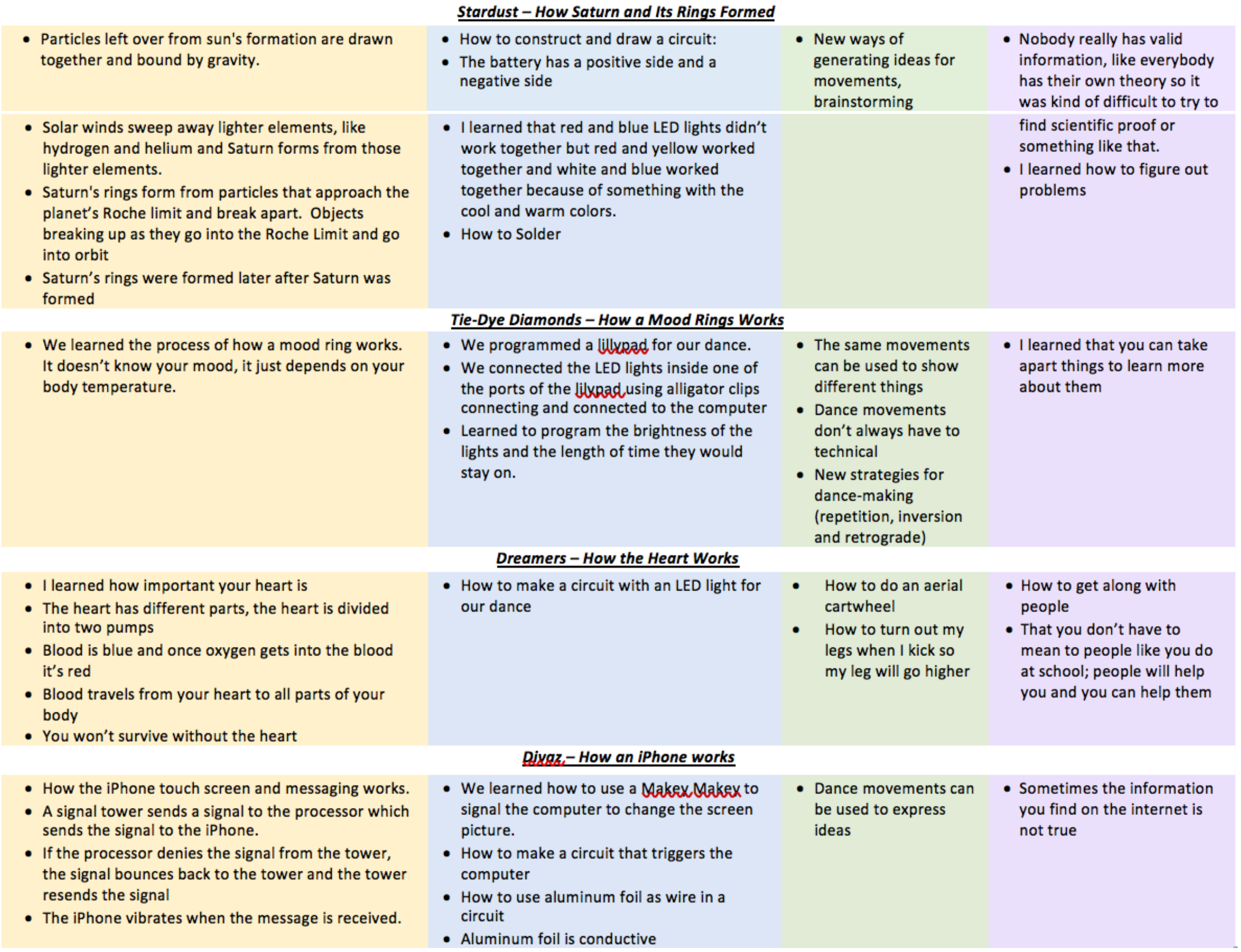
They constructed the man out of cardboard, painted on his internal organs (lungs, kidneys, intestines), and built a shelf out of popsicle sticks to hold their clay model heart. The clay model of the heart also included an LED light that they programmed to blink to the rhythm of their song. The blinking light was an analogy for the beating heart. At the end of their piece, two dancers did surgery on him, which amounted to connecting the Arduino Board to the LED light in the clay heart with an alligator clip, to make his heart work again, or beat with the LED light. Storytelling was a tool for organizing their knowledge about the phenomenon for presentation.

A dance camp where you can do more than just dance. My analysis of participant interviews revealed that participants interpreted their experiences in the dance makerspace as dance plus (+). Most defined it as dance, but not just dance. They talked about dance with opportunities for problem solving, and opportunities to make new things, to learn new things, and do work that was hard, exciting, challenging, and frustrating. There was an element of the unknown that was also exciting for them. They were ready to engage, particularly those who were repeat participants, and were comfortable with not knowing exactly what they would do but knowing that they would be solving problems and working with others to do it.

In the participant post- interviews, youth also talked about what they learned as a result of participating in the makerspace activities and collaborating to create their projects. There are gaps in the literature regarding how to understand and assess what youth are learning as they engage in STEAM making. Participant interviews revealed that youth did not think of their learning in the informal STEAM environment as one dimensional. The following table highlights the things that youth reported they learned during their final interviews.

What Participants Learned

Phenomenon-Related Knowledge	***Technical Knowledge***	***Dance Knowledge***	***Other***
FOOF – How the brain sends messages to the body			
• If your hand touched the stove and then the nerve will like travel through your arm like a highway, and then it will go to your brain and be like, "Ding!" and then it will travel back down and then you will hurry up and move, but it happen in like, (snap) that. • Nerve signals travel through the spinal cord and to different parts of the body like a highway • There are two different types of nerves (sensory and motor)	• Learned how to design and sew LED light circuits to wear on their socks and pants • A circuit is a full circle • Learned how to connect multiple LED lights in series	• Choreography does not always have to mean using dance steps you learned in class	
CAUTION! – How a Volcano Erupts			
• Lava is magma in the earth's core • Magma rises through cracks in the earth's crust and explodes through openings in the tops of mountains • Lava travels to the center channel of the volcano • Volcano eruption is an explosion that shakes the earth • Lava bubbles and becomes hard as it cools	• How to make a circuit using conductive clay as a switch		• Well the most important things that I learned is that you have to work hard if you want to be a dancer. • I can do hard things, things are not as hard as I thought they would be once I start to do them
Summer Rain – The Life Cycle of a Star			
• We didn't know that stars come out like they're babies. It's not really that they come up like women, but so they have a cloud, and I guess you call that like the mommy, and it's spinning around in her own little cloud of dust making it hotter and it's just a cloud of gas and dust and all that, and apparently once it gets hot enough it compresses itself, it makes a baby star. • It takes a million years for stars to explode	• To make LED series and parallel circuits • Soldering • How to create, edit and cut music (digitally)		
Chalad – What Causes a Stroke?			
• An ischemic stroke is one of the most common kinds of strokes. It occurs form a blood clot that forms in the brain. An ischemic stroke is caused by high	• How to make a circuit by connecting alligator clips to both sides of the circuit • In order for the LEDs to light up everything should be connected	• Dance movements represent blood flowing, not just wavy arms	
cholesterol levels which causing narrowing of the arteries. • The difference between an ischemic stroke and a hemorrhage stroke		• Strong movements can be used to show strong blood flow	
Kiwi – Why do People Have Heart Attacks?			
• A heart attack is actually a cardiac arrest which means the heart beats fast then slow. It is a cardiovascular disease. A heart attack happens when there is a subtle blockage of blood flow to the heart. Some of the symptoms of a heart attack are chest pains, sweating, nausea, shortness of breath. • A heart attack happens when a piece of your artery becomes fatty inside and plaque that's inside comes from fatty foods and being stressed out so that's why you have to not eat fatty foods and not be stressed	• That resistors keep too much energy from going through a circuit • How to hook up and program the Arduino • How to program lights to blink using an Arduino • How to edit video		• How to communicate with people in my group
Fiji – What Happens When You Have Sickle Cell?			
• Normal red blood cells are shaped kind of like donuts • Sickle cell is a red blood cell disorder that is inherited from your parents. • Sickle cells are not flexible and can stick to vessel walls. • Sickle cells is when your cells are like a sickle shape like the moon when it's like a crescent moon, well some are like the sickle cells, not all. • When your cells are flowing through and since they're in a sickle shape it's harder for them to flow through. And once a sickle cell gets caught on something and then it can't move and then another sickle cell gets caught on that one and then another gets caught on that one, so they get caught and then they can't go past, and the blood can't go through, so it's causing like a very sharp pain.	• How to make a stop motion video. It took a really long time because you couldn't just make it, we had to do it as in little little steps • How to hook the projector to the computer and the Makey Makey • How to make an aluminum foil circuit board. Don't cross the wires or it will short circuit		



Stardust – How Saturn and Its Rings Formed

• Particles left over from sun's formation are drawn together and bound by gravity.	• How to construct and draw a circuit: • The battery has a positive side and a negative side	• New ways of generating ideas for movements, brainstorming	• Nobody really has valid information, like everybody has their own theory so it was kind of difficult to try to find scientific proof or something like that. • I learned how to figure out problems
• Solar winds sweep away lighter elements, like hydrogen and helium and Saturn forms from those lighter elements. • Saturn's rings form from particles that approach the planet's Roche limit and break apart. Objects breaking up as they go into the Roche Limit and go into orbit • Saturn's rings were formed later after Saturn was formed	• I learned that red and blue LED lights didn't work together but red and yellow worked together and white and blue worked together because of something with the cool and warm colors. • How to Solder		

Tie-Dye Diamonds – How a Mood Rings Works

• We learned the process of how a mood ring works. It doesn't know your mood, it just depends on your body temperature.	• We programmed a lillypad for our dance. • We connected the LED lights inside one of the ports of the lilypad using alligator clips connecting and connected to the computer • Learned to program the brightness of the lights and the length of time they would stay on.	• The same movements can be used to show different things • Dance movements don't always have to technical • New strategies for dance-making (repetition, inversion and retrograde)	• I learned that you can take apart things to learn more about them

Dreamers – How the Heart Works

• I learned how important your heart is • The heart has different parts, the heart is divided into two pumps • Blood is blue and once oxygen gets into the blood it's red • Blood travels from your heart to all parts of your body • You won't survive without the heart	• How to make a circuit with an LED light for our dance	• How to do an aerial cartwheel • How to turn out my legs when I kick so my leg will go higher	• How to get along with people • That you don't have to mean to people like you do at school; people will help you and you can help them

Divaz – How an iPhone works

• How the iPhone touch screen and messaging works. • A signal tower sends a signal to the processor which sends the signal to the iPhone. • If the processor denies the signal from the tower, the signal bounces back to the tower and the tower resends the signal • The iPhone vibrates when the message is received.	• We learned how to use a Makey Makey to signal the computer to change the screen picture. • How to make a circuit that triggers the computer • How to use aluminum foil as wire in a circuit • Aluminum foil is conductive	• Dance movements can be used to express ideas	• Sometimes the information you find on the internet is not true

Figure 5.3. Participants Reflections on what they learned.

In their reflections, the children expressed learning on multiple dimensions: phenomenon-related, technical and artistic skill-related, and socio-emotional. In collaboratively constructing representations with their bodies, they had to grapple with how to combine their ideas and integrate a set of physical materials (including their own bodies) with semiotic tools to bring their ideas to life. They had to make decisions about what features to represent, what movements to use to represent them, what to leave out, and what media and modalities they would use to represent the essential ideas. These types of decisions are considered to be important representational practices in the context science learning (Stevens & Hall, 1997) and correspond with the authentic representation-making practices of scientists (Lynch 2006; Woolgar, 1990). However, representation-making in this context was as much an art as it was a science practice, and representational decisions were influenced by many factors. In the analysis that follows, I utilize the lens of representational mediators and practices to show that in constructing creative representations of science phenomena, youth negotiated meanings and enacted understandings across conceptual, representational, technical, social, and material dimensions.

Representation and the Act of Dance/Making

In studies that have looked at learning in the complex, informal environments where learners are participating in making activities, understanding has been described in many ways. Brahms (2014) described understanding as evolving and increased participation in maker communities of practice (Lave & Wenger, 1998). This work was mostly about understanding maker practices. Researchers who have focused on the understanding that comes from participation in making activities have positioned understanding as action, defining developing understanding as "expressing realizations through affect or utterance; offering explanations for strategies, tools, or outcomes; and applying knowledge" (Bevan, 2015), or "know-how that is mobilized in practice" (Lemke et al., 2015). Researchers have also pulled on constructionist ideas to talk about understanding in makerspaces (Sheridan et al., 2014). From a constructionist standpoint, understanding is in the making. In other words, they see the design, development, and construction of digital or physical artifacts as contributing directly to conceptual understanding because understanding involves *meta-representational competence*, knowing which tools, ideas, and resources are best suited for what purpose in order to express an idea (diSessa, 2004; Hammer, Sherin, & Kolpakowski, 1991). The artifacts created are said to serve as evolving external representations of the learner's thinking (Papert, 1993). Embodied-interactionist literature (Stevens, 2012; Hall, 1996; Goodwin, 2000; Streeck, Goodwin, & LeBaron, 2011) positions understanding as a representational process, suggesting that understanding is not necessarily found in the representation but in the iterative process of *representing*. This calls attention to the multimodal activities that lead to representational decisions. Danish et al. in their research on representation-making in science learning have shown that when children are encouraged to create, evaluate, and modify science representations collaboratively, representation making becomes a process of negotiation, mediated by multiple perspectives and available resources (Danish & Phelps, 2011; Danish & Enyedy, 2006). They have argued that understanding children's invented representations requires understanding the mediators that influence their creation, the practices that shape their representational choices, and their actions as they occur in context (Enyedy, 2005; Hall & Rubin, 1998).

Representational Mediators and Practices in the STEAM Dance Makerspace

The dance makerspace as an informal STEAM context posed a unique challenge for assessment of sense-making. The dance makerspace was an interest-driven, free choice environment that blended STEM, making and art. The projects created were not science representations, but creative representations of science phenomena. Project groups were not working on the same activities or within a defined set of classroom and disciplinary practices, with specific norms for representing. In project development in the dance makerspace, the children were free to develop their own project ideas, invent their own problem-solving approaches, and pull from different disciplinary skills and practices. To understand the learning that was taking place through representational work in this STEAM interest-driven context, I could not assume that a standard set of disciplinary practices or norms for representing were guiding children as they worked. I had to understand what experiences and practices they were drawing from, how they incorporated various different practices, what problems they were solving, and what they saw as relevant to their process. In order to understand the relationship between mediators and practices, I analyzed the final presentations and did a backwards trace of each group's final piece, analyzing video process data to identify the decision-making points in their processes and determine the mediators, practices, and values that drove decisions.

Previous studies provide some insights about the factors that influence representation-making. In their work, Danish and Enyedy (2007) identified mediators that young children use as they invent representations to make sense of content. They identified examples of possible mediators as "an individual's goals, the larger motives shared by a group that give rise to an individual's goals; an individual's understanding of the referent; an individual's personal preferences, the physical environment in which an individual or a group is creating their representation; the tools available; the other people present (or imagined); the social structures that facilitate coordination between people; and the local norms (in this case, science class) for the specific classroom context that dictate the 'appropriate' way in which students should engage with other people and with artifacts." They developed a Negotiated Representational Mediators (NeMR) framework to describe representation-making in context of the science class and better understand how students learned to appropriate science practices as they constructed representations. Danish and Enyedy's work is useful for identifying mediators and practices that are relevant to children as they create science representations. However, to better capture the representational mediators that influence decision-making in the STEAM learning environment, I have expanded on their work, developing a nested mediator framework.

To develop the framework, I analyzed video recordings of interactions in the space during project time from a random sample of project groups. In the video data, I looked closely at moments of representational decision-making, negotiation and conflict for representational actions, the observable acts that directly impacted what and how representations got made (e.g., adding a feature to a drawing or model, programming LED lights to blink faster, asking for help, singing together), and coded them for relevant mediators. These data were coded inductively, keeping in mind the broad categories identified by Danish & Enyedy's NeRM framework, but also recognizing that in a STEAM context with different constraints I would likely see different mediators. Like Danish and Enyedy, I defined mediators as those elements that enabled or constrained what and how representational choices were made (Danish and Enyedy, 2007; 2011). I analyzed the data looking for themes and patterns across groups using an iterative constant comparative method (Glaser & Strauss, 1967) to determine relationships between the codes that were generated and classified them into types. The coding process led to three mediator categories: (1) *knowledge*; (2) *group dynamics and practices*; and (3) *the resources and values of the setting*.

The nested mediator framework helped to identify the various types of knowledge, practices, and aspects of the activity setting that influenced the representational choices made by each group, and the relationship between them. In the pages that follow, I elaborate on the themes that emerged within and across these categories and share examples that show how the nested mediators interacted to influence the making experience and the final representation. I conclude this chapter with a discussion of how dance/Making was a medium for problem solving and integration of arts and STEM practices, integration of dance and technology, and integration of narrative and analytical ways of thinking (Bruner, 1986).

Scientific, Artistic, and Technical Knowledge Mediators

The first category of codes deals with representational decisions mediated by shared knowledge in the group. Knowledge as a mediator impacted *what* and *how* representations were constructed. Knowledge mediators included content related to the phenomena being explored, STEM technical knowledge, dance knowledge and skills, and representational knowledge and skills. I have organized them into three dimensions, shown in Figure 5.1 below. They represent scientific, artistic, and technical aspects of knowledge that groups utilized to make representational decisions in the STEAM dance makerspace.

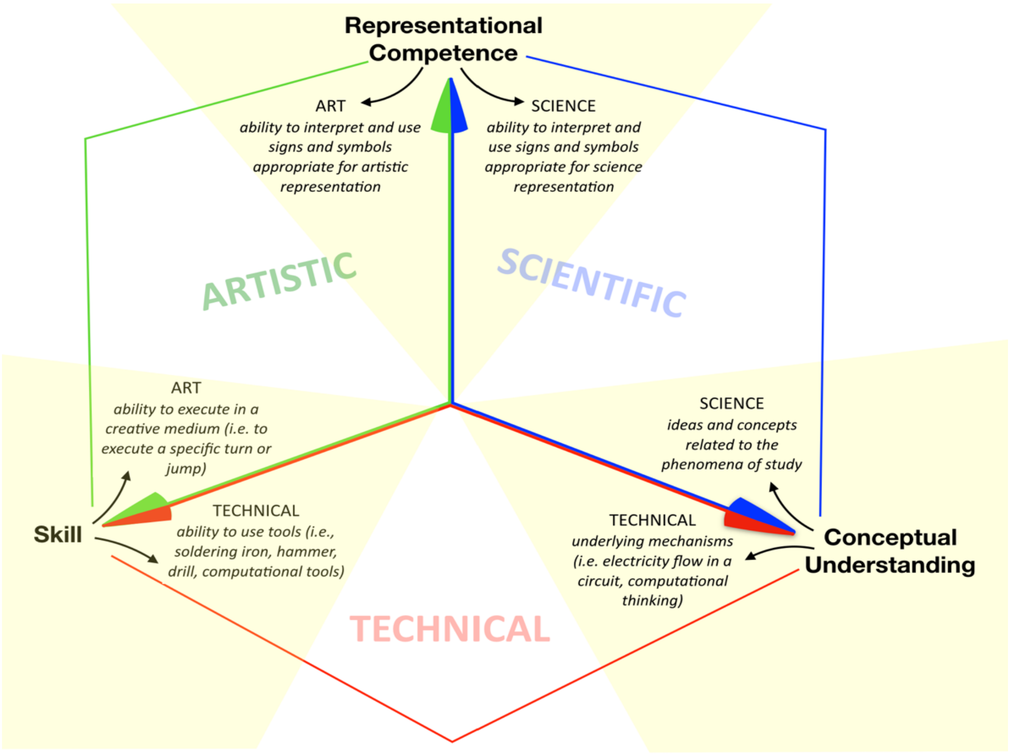


Figure 5.4. Three Dimensions of Knowledge Mediators

The blue represents the scientific dimension. The two axes reflect representational choices mediated by understanding ideas and concepts related to a scientific phenomenon and the ability to interpret and use appropriate signs and symbols for science representation, or representational competence (diSessa, 2004). This dimension is where most research on learning through representation is focused. It includes studies that have explored learners' abilities to evaluate, compare and construct mathematical, graphical, and scientific representations to support math and science learning (e.g., diSessa et al., 1991; diSessa, 2002; Roth & McGinn, 1998; Enyedy, 2005; Prain & Tytler, 2013). The blue and red dimensions, the scientific and the technical, have typically been the focus of maker-centered learning. It includes studies that have explored relationships between activities and the development of STEM skills and practices (e.g., Jacobs & Buechley, 2013; Kafai, Peppler, and Chapman, 2009; Resnick et al., 2009; Sheridan, Clark, & Williams, 2013). The green dimension, the artistic dimension, has kind of occupied a space of its own with an of honorable mention status in STEM. Whereas the arts have been acknowledged as a useful tool for helping engage and motivate youth in STEM learning, they have most often been relegated to a more peripheral place in design and research on making, even when contexts claim to have a STEAM focus (Radziwill et al., 2015; Clapp, & Jimenez, 2016). In STEAM making environments where STEM and arts are meaningfully integrated, work is happening on all three dimensions. The following example illustrates the integrated relationship between artistic, scientific, and technical understandings, skills, knowledge and representational competencies in group project work in the STEAM dance makerspace.

Episode 1: Stardust – Making Saturn. This episode took place during the fourth iteration of the camp and features four girls from the group Stardust. Lea and Krystle, both 13 years old, were camp veterans having attended all four years of the STEAM Makerspace dance camp. Portia, age 11 was participating for the second time. Lea, Krystle and Portia were familiar with the context and had each worked with at least one of the other group members in a previous group context. Grace, 15, was new to the camp but had a few years of previous dance experience at her performing arts high school. In this excerpt, which focuses on activities of the second week of camp, the girls split their make time between working on choreography in the dance studio and working on ideas for their electronic component in the Makerspace. This was characteristic of how groups worked in the space. At this point in the week, they had already been assigned to their group and tasked with creating a dance that explained their answer to a question of interest by combining choreography and an electronic component. After brainstorming multiple ideas, they settled on a dance about how planets, specifically the planet Saturn and its rings formed. They had been working together on their project for three days.

During make time the previous day, Stardust identified and decided on five ideas that were essential to their explanation: 1) how “leftover material from the sun’s formation begins to come together;” 2) how “small particles are drawn together and bound up by forces of gravity forming larger particles;” 3) how “solar winds sweep away larger elements (rocks and hard particles);” 4) “Saturn’s formation from the leftover lighter gases;” and 5) “Saturn’s rings forming from particles that approach the planet’s Roche limit and break apart.” This episode features the work they did to construct a representation of Saturn, its rings, and Roche limit, which is the circular radius (invisible barrier) around the planet that is the minimum distance at which an object can approach or orbit the planet without being destroyed or disintegrated ("the Roche limit is around the planet and like if a comet or something go in like the boundary of the Roche limit or whatever, they start to break apart..."). To represent the planet Saturn, they played around with two different ideas focused on two different modalities, the idea of using their bodies to make the planet and constructing a foam model of the planet. As the analysis will show, their final representation was a combination of both, heavily influenced by their understanding of content, their skills, and their representational competencies. While their representational choices reflected an understanding of the content related to the phenomenon, those choices were mediated by both their representational competence and their technical skills. They negotiated these tensions, integrating knowledge from all three dimensions to create a representation that communicated the core ideas and essential characteristics of the process of planet formation.

Integrating Knowledge, Skill and Representational Mediators. In the following excerpt Stardust is sharing and building on choreography ideas with a teen mentor, Nia, who they have ask to provide them with feedback regarding what they have created so far. After showing Nia the choreography ideas as they have developed thus far, Lea asks Nia if she kind of understands what they are trying to show. They engage in a process of explanation and feedback, which leads to new ideas and pushes their thinking about how to represent the phenomenon.

Excerpt 5.1

Day 7 [00:11:41.26]

1	Lea	I wanted to know as an audience member, if you kind of understand... some of it, like if you understand what's happening?
2	Nia	I could tell that it was space, I could tell it had to do with the solar system, and something about rotating maybe
3	Lea	Yeah we gotta kind of explain it better
4	Krystle	Yeah
5	Nia	What are you trying to convey?
6	Lea	Okay, so we're trying to explain the process of how Saturn was formed and its rings... (goes back to the design journal) and so... da da daaaaa... it's all over the place... Here it is, so we got it
7	Lea	So, it says (reading) “after the sun was done forming, leftover material began to come together,” so there's like leftover particles and we're the leftover particles
8	Nia	and what's forming?
9	Lea	After the sun's formation...and so then like, this part (goes out on the dance floor and holds her hands out) Wait, hold our hands together... (They join hands in the backward facing circle) When we go into the hinge, that's us like clumping together 'cause that's what they did,

10 Lea and then the second step was that (reading) “smaller particles drew together bound by forces of gravity into larger particles”
11 Portia So, when we like did... (arm reaching up) duhn duhn, all that stuff (lifts leg and turns) and then we came together in the middle and did like that (reaches arms forward) this is Saturn
12 Nia *That's* Saturn?
13 Lea Yeah, I think we should explain that better, because that don't look like Saturn
14 Nia Ooh maybe you could have a voiceover… Okay so you know how you're like explaining to me now... And you don't have music… maybe your music can be a voiceover...
15 Krystle No, 'cause the dance has to explain it

Looking closely at moments in their process reveals the various ways that Stardust’s representation of Saturn's formation was mediated by their knowledge of the phenomenon, their representational competence, technical and dance skills. The girls’ goal was to use choreography to explain their understanding of the process that led to the formation of Saturn and its rings. Their knowledge of the process of Saturn’s formation was an important mediator in the representation they were developing. When asked what they were trying to convey, Lea responses (in lines 7 and 10) demonstrated her developing knowledge of content related to the phenomenon, and in lines 7-11, Lea and Portia explain how their choreographic decisions have been informed by their understanding of the phenomenon. However, there was a tension between their understanding of the phenomenon and the movements they initially chose to represent it. They attempted to create movements that would reflect their interpretation of the phenomenon and make their understandings about the ideas they were representing explicit. However, they had an issue getting their message across, in representing their understanding in a way that was clear and understandable. Nia’s critique in line 12 and Lea’s subsequent response, “Yeah, I think we should explain that better because that don’t look like Saturn,” reveal the tension between the ideas they were trying to show and their ability to make representational movement choices that would reflect them. In this case, their artistic representational competence was a mediating factor that constrained the representation of their understanding of the content. Explaining their choreography to Nia helped them to recognize the limitations of their shape's representational power. Her question, "That's Saturn?" in line 12 pushed them to modify their representation of the planet. The group was determined to use movement to represent the phenomenon, but they also recognized the need to "explain it better." They did the full dance again, stopping when they got to part where they "make Saturn." Instead of continuing with that part of the choreography, they attempted to work through an alternative choreographic representation:

Excerpt 5.2

Day 7 [00:16:33]

20 Lea and then, somehow, we come together... and make the planet... (they are trying to make a shape with their collective arms to make the planet Saturn)
21 Lea I guess we could try to make a circle shape here…
22 Portia (can't figure out the right way to reach and twist to make the shape. They work a few seconds to help her figure it out…)
23 Grace Other way
24 Krystle Other way
25 Lea Wait, facing me… wait (demonstrates) this way
26 Portia Wait (tries to figure it out)
27 Lea This way (demonstrates again)
28 Portia Wait (Still can't figure out how to copy Lea)
29 Krystle (touches her shoulder and turns her around)
30 Portia Oh (laughs)
31 Lea Wait (Portia is still not facing the right direction)
32 Portia Oh, like this
33 Krystle (says something about being on the outside…) Or turn that way
34 Lea I'm this way
35 Portia Maybe we could put some kind of shell on our backs
36 Lea Your imagination is so wild...
37 Portia You know like how penguins huddle up? I could be in the middle like that
38 (They try it with Portia in the middle)
39 Nia Oh… If you have the… it you have your uh… Saturn on its um platform, you can stand around it
40 Krystle See! That's what I was talking about… platform guys
41 Nia Instead of trying to have [Portia] like a little scared child, she could be around the sculpture

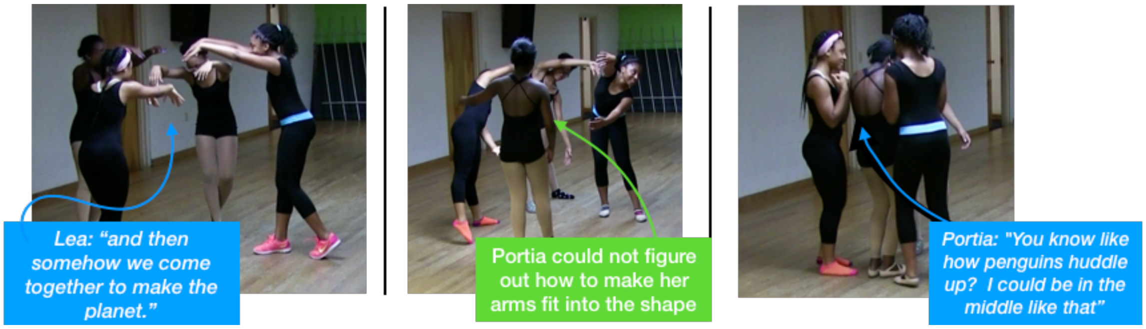


Figure 5.5. Attempting Different Representations of Saturn

In this excerpt, the girls worked together to construct a new representation of Saturn. This time, Portia struggled executing the suggested arm movement. Even after the others worked with her for several minutes, she still could not figure out how to place her arms correctly in the shape they were trying to make. In this case, her inability to execute the dance movement mediated their representational decision-making. After many failed attempts, Portia suggested an alternative to using their bodies to represent the shape of the planet, "maybe we could put some kind of shell on our backs" (line 35). This move suggests that Portia was not satisfied with their representation of the shape of the planet. Her next suggestion was that they huddle like penguins with her in the middle, perhaps to accommodate for the fact that she was struggling to make the shape with her arms. Nia, still observing from the side, suggested that a different type of representation, a model of Saturn on a platform, would be a more appropriate representation than the penguin huddle, which was not having the desired representational affect.

In this example, group Stardust utilized knowledge on all three dimensions to make their decisions as they constructed a representation of Saturn's formation. Their representational choices were mediated by their understanding of how Saturn and its rings formed, by their dance skill level, and by their ideas about what an appropriate representation of Saturn should look like. The graphic below illustrates many of the factors that influenced Stardust's decision-making around what should be included in their Saturn representation.

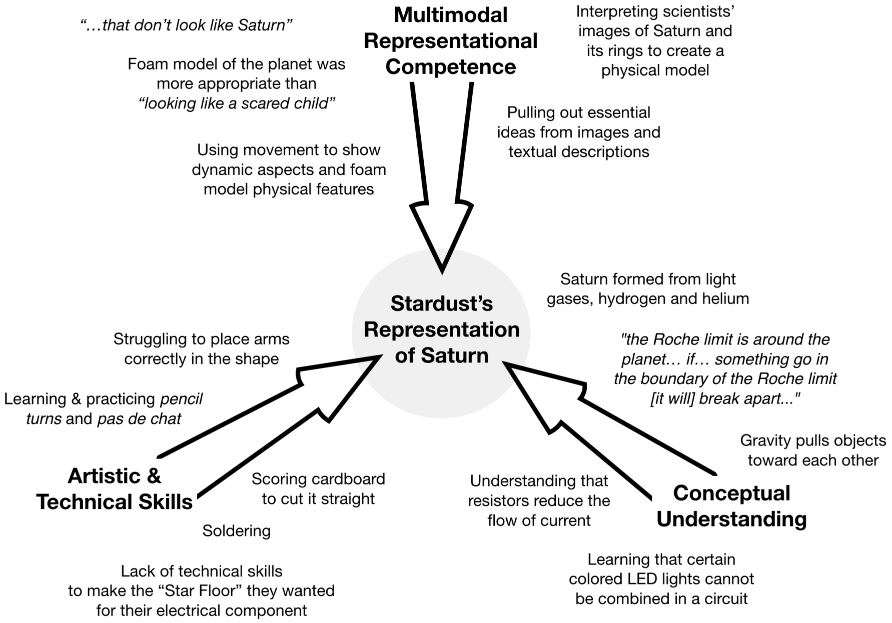


Figure 5.6. Stardust's Representational Decisions Mediated by Knowledge, Skills and MRC

Groups integrated knowledge from all three dimensions in order to create their final representation. As will be shown throughout the subsequent examples in this chapter, the thinking involved in integrating the scientific, the artistic, and the technical to create representations was both expansive and flexible. One example of this is in the multiple ways that Stardust represented Saturn and its formation. They combined their artistic skills and representational competence with technical skills in circuitry, design, and construction to express their conceptual understandings. They integrated scientific and artistic representational competencies, showing the process of gases forming into a planet using moving bodies that coalesced around a physical model that represented the shape and color of the planet. They integrated their technical and artistic skills with knowledge about Saturn's rings to construct a model with orbiting rings made with LED light particles, glitter and glue sticks. They integrated new technical knowledge about circuitry (learning to solder) with their understanding of choreography to create a pull switch feature on their Saturn model so that they could start the orbiting rings at the right time in their explanation. Negotiation and refinement of their ideas involved practice and repetition with their bodies, and they embodied their developing understandings as they constructed the representational ideas to physically expressed them.

This example shows that there are many understandings expressed by creative representations, and representations can differ depending on which dimensions are given priority as they are created. Those decisions are influenced by group dynamics and practices.

Identifying and Understanding Group Practices

Representational decisions are made up of actions and practices that are often influenced by the social (Varelas, 2010; Danish and Enyedy, 2007; Penney, 2016). The social dimensions of learning in science classroom settings includes interactions with teachers and classmates that shift thinking or understanding about conceptual content, and classroom structures that facilitate interactions between students and instructors. In informal *making to learn* settings, where youth are not bound to science or school practices, the social dimension includes the ways in which youth choose to organize their learning arrangements (Penney, 2016) and their work practices. Informal STEAM settings give more freedom for youth to establish their own goals, their own work flows, and utilize a variety of practices that govern the ways in which they negotiate creative decisions. These practices, which are influenced by relationships within the group and their interpretation of the setting and the task, create the context for how knowledge is applied.

Utilizing the continuity construct from Wickman's (2007) practical epistemology analysis, I determined group practices by looking at the utterances and actions that *stood fast* in group interactions, defined as the words or actions that were used in repeatable patterns and relations made to previous experiences. I looked closely at talk, actions and interactions in moments of negotiation, tension and decision-making within groups across the data set. I looked at ways of communicating within groups, ways of asking for help, planning next steps and keeping track of progress, and the impact that these practices had on the representational decisions that were made. What emerged was a set of practices that took place at the intersection of art and science.

Arts and science practices in this setting were challenging to tease apart for two reasons. First, the arts and sciences often share overlapping practices, especially when it comes to creation and discovery. For example, in developing new representations, both scientists, engineers and artists engage in abstracting, analogizing, improvisation, and iterative cycles of revision and editing (Root-Bernstein & Root-Bernstein, 2003; Eisner, 2002; Sawyer, 2011). Second, group exploration of phenomena in this setting was approached in ways that were interdisciplinary, that combined art and science practices in more than a simply additive way. The process of making choreography became a way of engaging with STEM content and practices through dance. Groups explored science content and experienced STEM practices in the context of dance-making, and as a result, were pulled into science phenomena in ways that became personally and physically engaging.

STEM Practices in the Context of Dance/Making: Modeling, Abstracting, Dimensional Thinking

Modeling and abstracting are typically thought of as STEM practices, used by both scientists and engineers. However, these practices are also used by artists. There are disciplinary distinctions between how and why these practices are used in each of the three domains. Scientists use these practices to engage in inquiry as they investigate and develop theories about the natural world. Engineers use them to better understand problems that can be solved through design and develop plans for those solutions (NGSS, 2013). Artists engage in these practices to explore ideas through the creation of artifacts that highlight, bring attention to, or raise questions about certain features. To make their projects, groups engaged in practices of modeling and abstracting; however, these practices could not be defined as simply science, engineering, or art because they integrated science, engineering and art. They were STEAM making practices. STEAM practices in this context involved exploring science ideas using both STEM and arts as tools for making and investigation. These practices became interdisciplinary tools for thinking and engaging with information and ideas and led groups to new ways of thinking about how to represent their chosen phenomena.

Modeling was a consistent creative practice used across groups for a variety of purposes. In some sense, the final representation that each group created can be thought of as a model; however, much of the modeling work done in the process of making did not show up explicitly in final representations. Modeling was used not only as a representational tool, but as a tool for exploration, thinking, and practice. The point of making models was not just to construct discipline-specific representation of concept or process, the models constructed by groups often served a purpose within larger problems they were trying to solve. The process of STEAM modeling helped groups to determine the most appropriate signs and symbols to use in their final representations. It also helped them to develop skills that were important and necessary to complete their projects. Science education and education research focuses on modeling as a scientific disciplinary practice, on how students use, construct, and interpret models as disciplinary-specific ways of representing STEM knowledge (e.g., Prain & Waldrip, 2006; NGSS, 2013). In this setting, modeling as a STEAM practice was not just a matter *of* modeling of but of modeling *for*. Examples in the following vignette will illustrate the three ways that modeling was used as a STEAM practice: (1) to provide inspiration and help generate project ideas; (2) to test out ideas, solve problems, and help groups figure out technical design features; and (3) to represent aspects of phenomena in the final representations.

Episode 2: Stardust – Making Saturn. Along with their developing choreography, Stardust constructed three physical models of Saturn (Figure 5.6) as they developed their project, only one of which was intended for their final performance. In the initial stages of project development, Stardust used modeling to help them generate ideas for their project and think about how they wanted to represent their phenomenon.

1st Model – for inspiration 2nd Model – to figure out the circuitry 3rd Model – to use in choreography

Figure 5.7. Stardust's three different models made of Saturn.

Modeling for Inspiration. Stardust began *Make Time* on day 6, the first day after they agreed on a topic to explore, brainstorming ideas about what to do for the electrical component of their project. The brainstorming session, which led to multiple ideas for their representation, was accompanied by clay-model making.

Excerpt 5.3

Day 6 [01:39.20]

1 Lea: Alright we gotta figure out our electro- tronical component
2 Portia: So, we- we can make some models of some clay for right now
3 Krystle: Yeah
4 Lea: Alright... Get some clay guys...
5 Krystle & Portia: (go over to the materials bins and return to the table with a bags clay)
6 Portia: They mixed all the colors... Aw man...
7 Lea: So, what are we doing with this clay?
8 Portia: Just making a model of Saturn
9 Lea: Why? What is it supposed to do for us?

10 Krystle: Give us inspiration

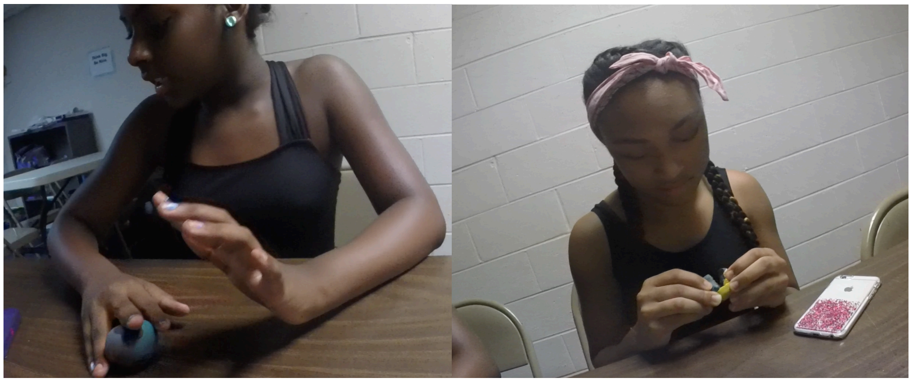


Figure 5.8. Portia and Grace beginning to make models of Saturn with clay.

As they sat down to brainstorm what to do for their electrical component, Portia introduced the idea of making models out of clay. They had not agreed on a particular plan. When asked by Lea what the clay was for, Portia suggested that it could be used for inspiration. This suggestion was not questioned but embraced by the group. Each person grabbed their own chunk of clay and began to make individual clay models of Saturn. They worked with the clay as they brainstormed ideas for the project. Their attempts at modeling led to new ideas and questions:

11 Lea: Look, my circle’s perfect. How can we make its rings?
12 Portia: I want to make a ring
12 Grace: This one weird circle. It’s hard to make the rings with this clay
13 Krystle: We should make Saturn and like take it apart, so we could like have something in the middle, to see... like I don't know
14 Portia: Oh, I think I know what you’re about to do. You’re about to put some- You’re about to put some string around it
15 Krystle: Maybe
16 Portia: I'mma make a big Saturn, since it's a... giant clay... the rings can be [made of] something else. Why don’t you use these popsicle sticks?

Modeling with materials in the initial stages of idea development helped Stardust think about possibilities for a representation of the planet. Brainstorming ideas with materials in hand also allowed Stardust to think about the affordances and constraints of materials as they thought about the representation they wanted to make. For example, in line 12 above, Grace commented on how difficult it was to make Saturn's rings out of clay. In the next line, Portia noticed Krystle experimenting with string to make rings and began to consider different materials for her rings.

After working for several minutes, Krystle shifted her focus to making a stand for the planet. As they worked, ideas for a possible electronic component became more concrete.

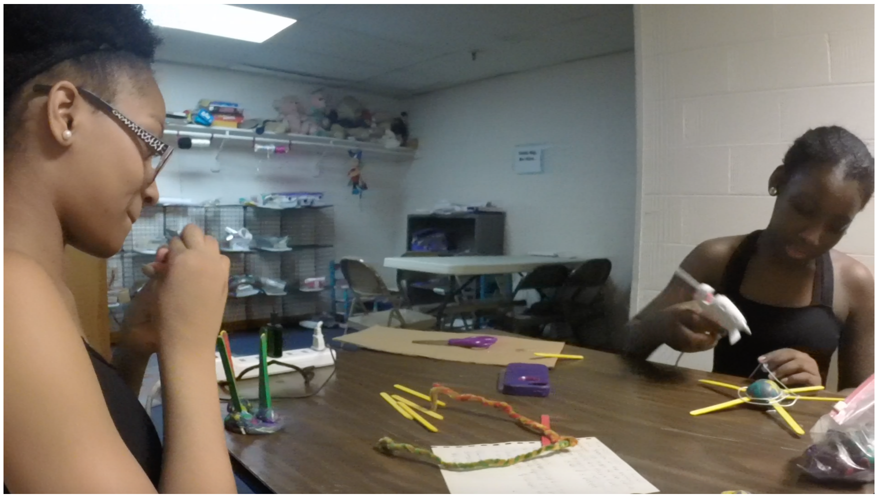


Figure 5.9. Krystle working on a stand for Saturn and Portia using string and popsicle sticks to make Saturn's rings

17 Krystle: Okay, so like we could have some thingy right there and then have like a platform, and then like these little things turn, and we make the planet and then but like it turns the rings around
18 Lea: Oh... I get what you're saying
19 Portia: What'd you say?
21 Krystle: Like okay so Portia has the planet... this is just like a stand... and then like it would be holes... going out and like they connect to the rings... and then it's like a little opening right here on the planet and then like the rings spin
22 Lea: Oh, that's cool
23 Krystle: We could have like a little platform and then like a foam that stick up, and then make the rings turn. That is one idea
24 Lea: We should like put lights on like it- whatever material we're gonna use for the rings so it can be like the particles like the ice particles or like the dust particles and stuff and then...
25 Lea: So we would have to figure out how it would rotate... if we do that

This initial phase of modeling was a way for Stardust to generate ideas using the materials and tools in the space to inspire their creativity. They took advantage of the opportunity to get their hands dirty, to develop ideas while also getting familiar with the tools and materials in the space and using them to explore the possibilities of what they could do. This could be seen as more of an artist's practice, but in this case, the children were being inspired to think through how to best explain and represent the process of a science phenomenon. Modeling for inspiration was a starting point for many groups. The practice of modeling as a practice of hands-on brainstorming helped them figure out what to do for their final representation, what ideas needed to be included, and how they should represent them.

Modeling for Clarification/Developing a Prototype. Stardust's second phase of modeling served a different purpose, to clarify the technical aspects of their representation. Brainstorming with materials in the makerspace as well as with movement in the dance space led Stardust to develop a representation of Saturn's formation that included choreography to represent hydrogen and helium gases coming together to form the planet and a foam model to represent Saturn once it had been formed. They wanted to use movement to show how asteroids, comets, and other objects broke apart as they approached Saturn's Roche limit to form its rings and to add LED lights to their foam model to represent the small particles orbiting in rings around the planet. At this point on day 8, they were not yet sure how they would integrate the foam model into their dance or how they would get the rings to spin. Before they tried to figure that out, they focused on getting the circuitry right.

Excerpt 5.4

Day 8 [GOPROVISOR: 00:01:46]

1 Lea: So now we're on our electrical component and we're trying to make it, like... so we're trying to use you know those little nail shop fans
2 Lea: We were gonna take apart the fan and use the part that makes the blades spin and somehow put that on the ball 'cause we're gonna have like a little ball and then have like rings around it... whatever, so we were gonna put the little part that make the blades spin in the fan like somehow on the ball and it's gonna make the whole thing spin around... you kinda get it?
3 Shayna: Yeah
4 Lea: Yeah...and for like... we were gonna use like light to make... to be like individual dust and ice particles... 'cause it's made of like ice
5 Shayna: Like in the rings?
6 Krystle & Lea: yeah
7 Portia: (looks up from gluing something on her Saturn model): and glitter
8 Krystle: and glitter
9 Lea: yeah

10 Lea: So we're trying to figure out... a way... can we like start- trying to make like a little model of how-
11 Krystle: How we're gonna use it?
12 Lea: No like, with the lights and stuff actually on it
13 Krystle: Oh yeah
14 Shayna: Okay so like how the lights will work?
15 Lea: But yeah but not the fan little part... yeah

The purpose for building their second model was to figure the wiring for the LED light "ice particles" that would be attached to the orbiting rings, to model the circuitry. Their second model, constructed of cardboard, was more of a functional prototype than the first. It was intended to capture an important part of the function (how the lights would work) and the appearance of the final design although the final Saturn model would be created with different materials and at a different scale. At this stage in their process, modeling was not just about understanding the phenomenon. They engaged in modeling not as scientists, working to develop a representation with explanatory power, but as learners, using the practice as a thinking tool to help them explore and investigate many aspects of their project. Through the process of modeling, they raised new questions, thought through design features for their final model, practiced making functional circuits, and engaged in dimensional thinking, problem solving and troubleshooting. These activities influenced their representational decisions.

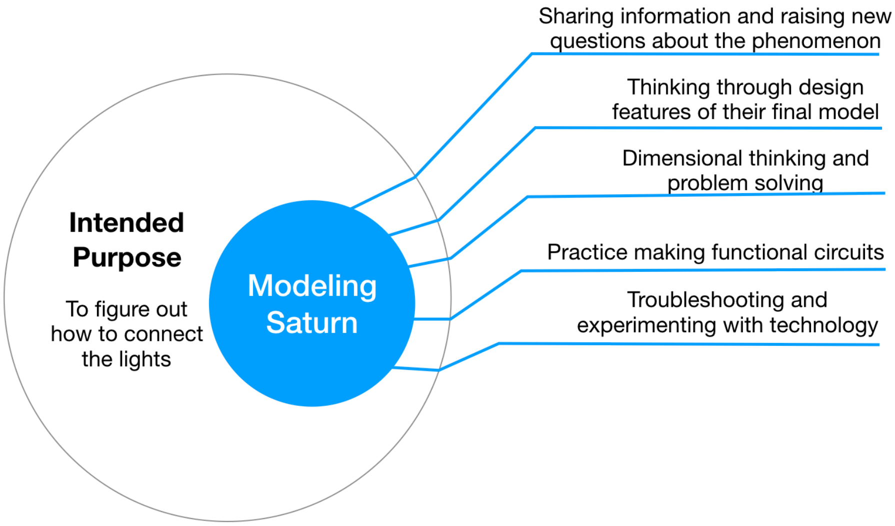


Figure 5.10. Modeling as a thinking tool.

Their work building the prototype began with constructing the planet from materials that were available in the space. Constructing the planet provided opportunities for them to engage in dimensional thinking and to think through various design features for their final model. They collected a variety of materials, including cardboard, paint, glue, scissors, felt paper, wires and batteries, and brought them back to their work station. As they surveyed the available materials, they began to think about two things at once: how to use those materials to make a ball that would represent the planet in their prototype and what materials they would need to make their "real" Saturn, the model for their final representation.

16 Lea: So how we gonna use a ball because we don't like have any balls.
17 Shayna: Should we get some string?
18 Portia: Uh I don't know.
19 Grace: Can we use tissue paper?
20 Krystle: Uh… you can carve it into a ball or something… like tape it around each other into a ball.
21 Lea: Tape what?
22 Krystle: Like tape the things into a ball, the felt paper or cardboard.
23 Portia: We're trying to figure out how we're gonna make Saturn?
24 Lea: We gotta put it into a ball… and we gotta figure out something for our real Saturn

The girls used the process of building a prototype of Saturn to engage in a discussion about materials for their final model. They considered several different options, discussing the material constraints and the desired features of their final representation.   Because there were no materials available that would fit their immediate needs, they also had to figure out how to construct a ball for their prototype out of flat cardboard. After collectively brainstorming a few ideas, they settled on cutting the cardboard into half circles that they would glue onto a cylindrical core. The process of making the cardboard prototype highlighted in the graphic below shows of how modeling with cardboard provided opportunities for dimensional thinking and influenced their design decisions.

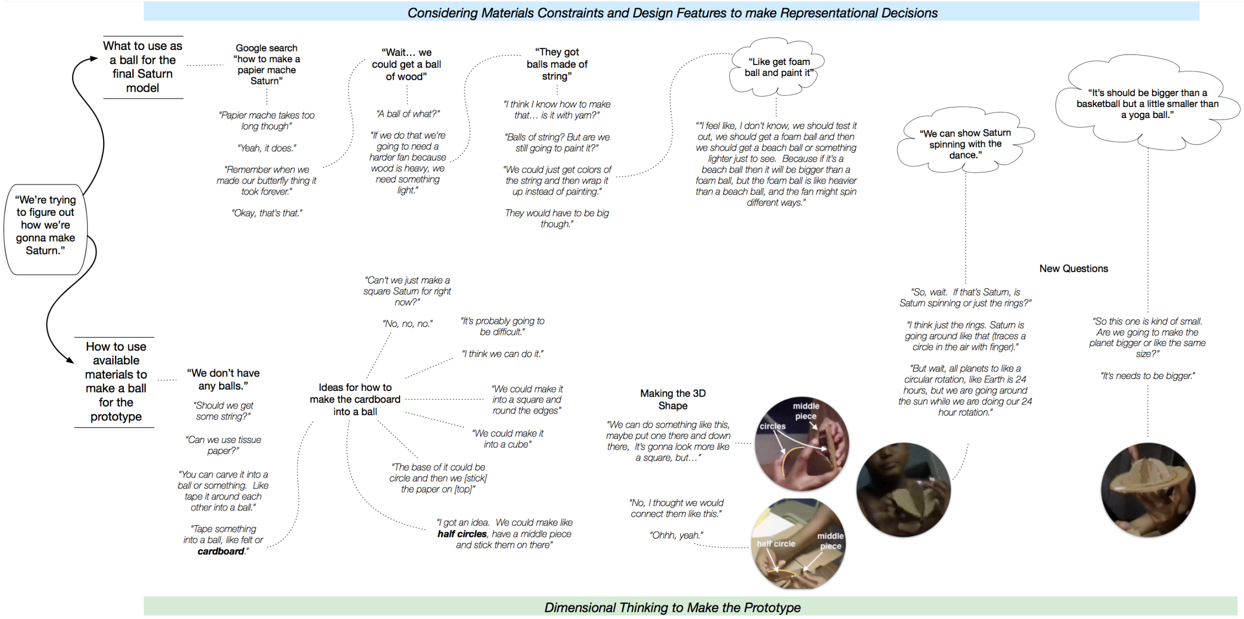


Figure 5.11. Prototype Process Diagram: How constructing model led to dimensional thinking and influenced design decisions

Through the process of building the cardboard model of Saturn, the girls engaged in dimensional thinking and problem solving. After brainstorming multiple ideas, they worked together to figure out how to construct a spherical shape from the two-dimensional cardboard to represent the planet. Thinking about how to attach cardboard rings to the cardboard sphere raised a new set of design questions for their final Saturn model; whether the planet and rings should rotate, how to show the rotating rings, and what size the planet in their final model should be.

Once the cardboard planet and rings were constructed, Stardust turned their focus to modeling the circuitry. Modeling the circuitry involved making practice circuits with LED lights, wires, and resistors, testing different conductive materials to determine which would make the best wire for their circuits, and deciding how to design circuits that would fit and work on the rings in their final model. As shown in the process diagram in Figure 5.12 below, modeling the technical aspects of the design required troubleshooting and experimentation. It also required Stardust to engage with artistic and representational ideas.

Constructing a prototype led to conversations about the phenomenon and joint attempts to construct circuits that would work in their final model. They used modeling as a way to practice circuit-building, ask questions, affirm their understandings, and apply new knowledge and technical skills. They also engaged in troubleshooting, experimenting and hypothesizing when the technology did not work in the ways they expected. Embedded in their attempt to bring their technical ideas to life were design conversations that required attention to choreographic choices. For example, decisions about where and how many batteries to use for the LED lights and fan motor had implications for how they would display the planet. Their design discussion quickly expanded to include a discussion of where the planet should be and how it should be used in their choreography. Should it hang or be mounted? Should it be carried by dancers? Should the foam model or the choreography be used to represent particles that make up the rings and materials breaking into particles?

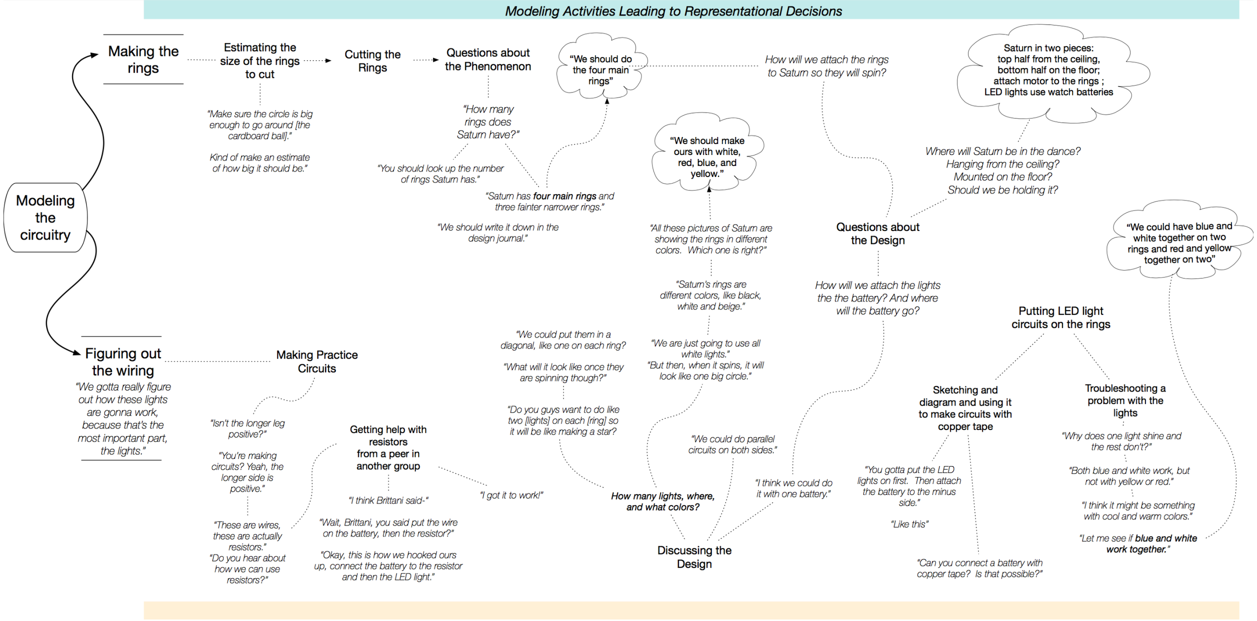


Figure 5.12. Modeling Circuitry Process Diagram

The questions raised through their modeling process illustrate one way that technology and dance became integrated through project work in the dance makerspace. This topic will be addressed further later in the chapter.

Modeling for Representation. Finally, groups developed and used models as part of their final representations. Some of these models took the form of physical props, (i.e., Stardust's foam Saturn with LED lights on the rings), while others were constructed using choreography. Making these representations required them to abstract the essential ideas about the phenomenon or process and translate them into multiple modalities in an integrated way. For example, the girls from group Stardust extracted these essential ideas from their research on how planets form:

1) After the sun's formation, leftover particles began to clump together;
2) Particles were pulled together by gravity;
3) Solar winds swept away the lighter elements like hydrogen and helium;
4) Saturn formed from the lighter gas elements;
5) Saturn's rings formed around the planet as objects approaching the planet were broken apart by the Roche Limit;
6) The rings are made up of particles that broke apart in Saturn's Roche Limit, dust and ice.

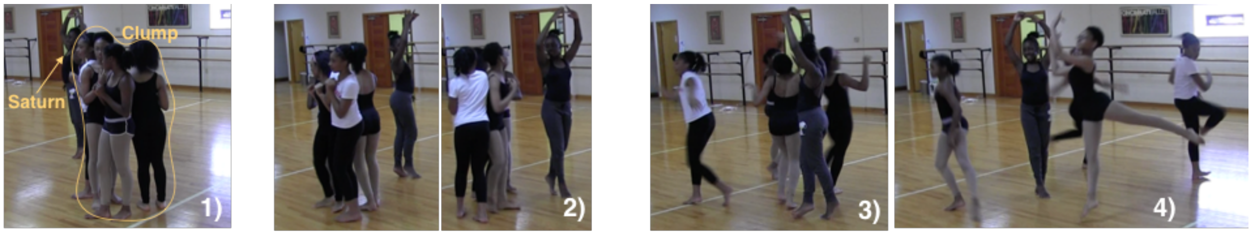
Constructing their representation was a process of testing out and iterating on multiple ideas to determine which features were most appropriate to represent with which media and materials. They tried many different choreographic ideas as they thought through the best way to model the formation of Saturn's rings.

Iteration 1: "Two people can be the Roche limit and hold hands, somebody can come in and they let go hands, then that person can disintegrate or break apart."

Iteration 2: Krystle starts spinning by herself, then Lea joins in, then Portia, then Faith, then they all break apart

Figure 5.13. First and Second Iterations Representing Saturn's Rings and Roche Limit

In their first iteration, they focused on the idea of particles approaching the Roche limit, which was represented by two girls holding hands. The particle, played by the third dancer, would break through their arms and then fall to the floor to "disintegrate or break apart." Unsatisfied with this representation, they iterated on the idea and created a way to show objects approaching the planet, the spinning rings, and the particles being pulled into orbit. In the next iteration, they decided to hang a foam model of Saturn from the ceiling and make their circle around it to represent the orbiting rings. Their circle was to represent "the Roche limit and… the rings at the same time." Another idea was to use multiple bodies in a clump to represent an object moving toward Saturn. The dancers in the clump would break apart when they got close enough to the planet to be within its Roche limit.



Iteration 4: Clump that moves toward Saturn and breaks apart when it gets close and then individual particles orbit

Figure 5.14. Fourth Iteration Representing Saturn’s Rings and Roche Limit

Ultimately, they created a representation that used multiple modalities to highlight many essential ideas. Saturn was represented by a foam ball and one dancer whose role was created to facilitate turning on the switch to start the rotating rings on the foam model. The other four dancers represented the orbital pathways of objects that approached the Roche limit and broke apart to form Saturn’s four main rings. LED lights were used on the orbiting rings of the foam model to show the particulate nature of the rings; the shape and color of Saturn was also represented by the foam model. Stardust used choreography to highlight the dynamic aspects of the process (i.e. gases being swept away, particles pulled together by gravity, objects approaching the Roche limit) and used their foam model to highlight the physical features of the phenomenon (i.e., particles of dust and ice, the shape and color of the planet). Modeling the phenomenon and iterating on their ideas impacted how they developed ideas and thought about the representational possibilities by prompting discussions about the important features of phenomenon, which were essential, and which could be left out of their final representation. This process of abstracting has been described by Norman (1993) as an engine of cognition. Root-Bernstein & Root-Bernstein (2003) describe it as an essential thinking tool for scientists and artists:

> "Because sense experience and sense imagery are so rich and complex, creative people in all disciplines use abstracting to concentrate their attention. Abstracting means focusing on a single property of a thing or process in order to simplify it and grasp its essence" (p. 380).

From a STEM perspective, abstracting typically involves "stripping a physical situation of all extraneous characteristics, such as shape, color, texture, etc., and zeroing in on point and mass, spring and distance" (Root-Bernstein & Root-Bernstein, p. 380). Artists tend to focus on those extraneous characteristics as well as on emotions to communicate ideas, create a sense of beauty, or to explore the nature of perception (Eisner, 2002). Abstracting as a STEAM dance-making practice involves translating ideas discovered during research from words and images into movement in space and time. It also means thinking about what an audience would need to see to understand the explanation of the phenomenon. Scientists who have engaged in the process of translating their research to dance have expressed that making these types of representations "forces you to distill everything you've been working on into a few key concepts… [and focus] on the overall patterns, the most important players, and how they interact" (Bergman, 2014). In their reflections on the dances they created, participants spoke about how their models were made of choices about what to represent. For example, Lea explained that in making their Saturn dance, "the hardest part was trying to explain the whole process because, it's like so many things that go into how a planet was formed you can't really explain like the whole process of it all. So... we like [took] the main steps, main processes of like how it was formed and put in the dance."

Modeling as a dance-making practice served a variety of purposes. Groups made models as a way of brainstorming, to prototype their ideas and to clarify their understandings of concepts and phenomena. They worked through their developing ideas using physical materials, bodies and movement, and utilized the process of modeling to inform their design decisions. Modeling helped groups to refine and constrain their ideas because they got to see what it would take to translate their ideas to reality. It provided hands-on or embodied ways of exploring options.

Exploring Science Content through Dance-Making Practices

Dance-making inspired research. The process of dance-making required groups to research their topics of interest in order to develop choreographic explanations. They explored science content related to their phenomena of interest as a way to inform their choreography. The science content provided a theme and direction for their work, creating a context for storytelling and inspired research about their phenomena of interest. For example, as Stardust began to develop ideas for their choreography, they drew upon their knowledge of the process of planet formation to decide on movements and formations to use in their dance.

Excerpt 5.6

Day 3 [02:29:15]
1 Krystle: Isn't a planet made like out of gas or something?
2 Lea: I don't know
3 Krystle: We could be like gases
4 Lea: Like gas and dust
5 Lea: 'Cause I was thinking like, you know how Saturn got a lot of rings, right? So, like (does a turn with arms in a circle shape in front of her)
6 Lea: Ooh I think I just came up with a first move (turns around with arms in front)
7 Portia: So, we're gonna start off as dust first?
8 Lea: We could be like dust that's in space and then we like find each other
9 Portia: So, should we be like scattered at first?
10 Lea: Yeah, we could like space out
11 (They move to different places in the room and that becomes their starting formation)
12 Lea: So, we gotta look up more information because we don't have like a whole thing about the planets. I'm not sure what's first. I will get some more information tonight.

The girls used the process of planet formation as a way of structuring their choreography, the movements they would use, how they would connect movements, and their spacing. They quickly realized they would need to do research in order to build a dance based on the phenomenon of planet formation. Their work in the studio in the following days was all about getting a better understanding of the phenomenon.

Excerpt 5.7

Day 5 [01:16:30]
1 Lea: Alright we gotta do some research for the planets, we gotta do step by step how it's [formed]
2 Lea: So, what I have is... um... says like the rest of the planets, Saturn formed from the solar nebula about 4.6 billion years ago. This solar nebula started out as a vast cloud of cold gas and dust

which was dis- disturbed somehow, perhaps by colliding with another cloud or the shockwave from a supernova. You can also check out these cool telescopes... wait- no… Wow, that's a lot.

3 Lea: Krystle what are you writing down?

4 Krystle: (holds up her paper so Lea can see it)

5 Lea: What is a protostar?

6 Lea: It says cloud compressed down forming protostar in the middle. What does that mean? What is a protostar? We should write it down. Aw man, this is a lot.

7 Lea: It says a protostar is a contracting mass of gas that represents an early stage in the formation of a star before nucleosynthesis has begun. Wow

8 Krystle: So we have to show how the cold gas compressed.

9 Portia: We need to know why it got its rings

10 Portia: (does an internet search on "how Saturn's rings are formed")

11 Portia: (Reading) When objects like comets, asteroids and even moons broke up into orbit around Saturn's very strong gravity, pieces of these objects kept colliding into each other and broke up into even smaller pieces. These pieces gradually spread around Saturn to form its rings. The rings are thought to be short-lived compared to the age of the solar system. If we lived in a very different time, we may not have seen rings around Saturn."

12 Lea: The exact location of the Roche limit depends on the density, strength and shape of the bodies but generally it's about 2-3 planetary radii from the center of a planet..." So radii does that mean radius? ohh...

13 Lea: It says if the moon gets into the Roche limit then earth would have rings...

14 Lea: I wonder if a spaceship or something goes in the Roche limit, I wonder if it will break apart. That would be crazy if a person got inside... I don't know if it would work on people...That would be sad

15 Lea: Ohh. I just found the answer... It says space ships and small satellites less than a km or so in size are more likely to survive inside the Roche limit. If they consist of metal, unfractured rock or ice they will have enough strength to resist being pulled apart. Larger bodies may stretch plastically until the stresses are so great that they break apart.

16 Lea: Hmm... That's interesting too... It says if a massive swarm of particles were in orbit around a planet outside the Roche limit, they might aggregate into a moon.

The Roche limit became part of their choreographic representation of Saturn's formation. They played around with multiple ways to represent the Roche limit and formation of Saturn's rings in their choreography. Their research on the science content often raised new questions and new directions for exploration and provided opportunities for them to become familiar with the signs and symbols scientists used to describe phenomena, which led to new knowledge that they could use to make representational decisions.

Using narrative to choreograph explanations of science phenomena. Science not only supported storytelling through dance, but the act of developing narratives was a tool for understanding the science. In dance, narrative is a tool that can be used to structure the development of choreographic compositions (Wright, 2003). For some groups, utilizing a narrative structure in their choreographic explanations became a way of sense-making and organizing their ideas about the science phenomena they explored. For example, FOOF's representation of the process of message travel through neurons in the nervous system took the form of a story about a person who came in contact with fire. In order to construct their story, they had to create characters, a setting, elements of cause and effect, a moment of conflict or tension and a resolution. Seeing the nerves as characters in their story raised the question for them of how nerves move in the system, which became an important question that they wanted to answer. The storytelling framing also supported their representational choices in other ways. For FOOF, thinking of their representation as a story that would be shared with an audience caused them to make the choice to add a freeze frame to their choreography, so their audience could see their story unfold one element at a time. Exploring science content through dance as storytelling, groups were not just limited to "scientific explanations." This was important as interest in the science phenomena they studied often stemmed from their personal experiences. Group Fiji's interest in understanding sickle cell anemia, for example, came from a group member's interest in understanding why her close friend who had been diagnosed with the disease was often in so much pain. The group felt it important to show not only the process of sickled cells clumping but also the pain that it caused. Approaching explanations as narratives provided a structure for including emotion, feelings, and affect along with scientific concepts they were learning as they constructed their choreography. Using dance composition tools and practices like narrative to engage in representational thinking about science phenomena was an interdisciplinary practice that influenced representational choices.

Values of the Activity Setting

They are many understandings expressed by creative representations, and representations can differ depending on whether and how scientific, technical, or artistic dimensions are given priority as they are being created. Group practices influenced how conceptual understanding, representational competence, and skills were prioritized; and just as representational choices were influenced by the practices groups engage in, those practices were also shaped by the values and structures of the activity setting. The values of the activity setting set the stage for what participants and project groups thought they were supposed to do and the representational choices they made.

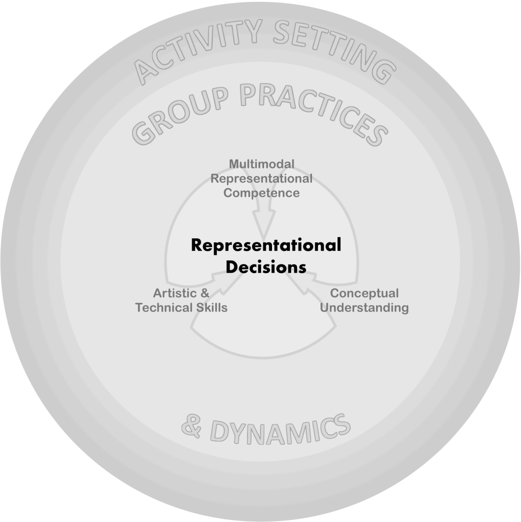


Figure 5.15. Nested Mediator Framework

The values of the space can be understood by looking closely at underlying assumptions at play in group practices (Danish & Enyedy, 2007; 2011). Looking across their modeling, research, and design practices shows that groups approached STEM exploration using values that are implicit in dance participation and dance-making, and that they approached the project as a dance-making activity. The overlap between dance and STEM provided opportunities for integrated thinking on three dimensions: art and science; dance, body and technology; and narrative and analytical modes of thinking.

Integration on Three Dimensions

Multi-literacy researchers have criticized current theories of meaning-making and communication as being too heavily focused on language and number. The new concept of multi-literacy acknowledges multimodal ways of thinking and working (Kress, 2000a, 2000b), and challenges the false division of mind and body in the processes of learning (Bruner, 1996; Kress, 1997; Wright, 2001). There is increasing evidence that learning involves the integration rather than the separation of parts (Wright, 2003). Dance/Making was a medium for integrated making practices that helped youth explore phenomena in ways that reached beyond the typical dualisms – science and art, mind and body, thinking and feeling, creative and analytical – that have shaped science education and been problematized in feminist and sociocultural literature (Brickhouse, 2001; Bowman, 2004). The examples above speak to the powerful interplay between art and STEM, dance and technology, and narrative and analytical modes of thinking in the practices of groups as they developed their projects.

Integrating Art and Science

Dance/Making in the context of STEM provided many opportunities for overlap between the arts and the sciences. As groups developed project designs and choreography, they did research and made models to understand the phenomena they studied. While research was required to understand and develop explanations, it was also utilized to help dancers make sense of the roles they would play in performance. Dancers used the information they were learning through their research to “get into character,” and the desire to authentically embody the roles that they played in their representations motivated them toward understanding the subject matter. The process of embodying science ideas, processes, and concepts required and developed an understanding of subject matter. Youth explored science content, developed interest, and remained engaged because the creatives outcome mattered to them, even the outcomes of intermediate steps. In practice, they worked together to prepare for their final performance, to develop precision and cohesion as ensembles, but through repetition and practice they also developed embodied understandings of the concepts they worked to represent, and they refined their representational ideas. Varelas et al. (2010) suggest that this type of embodied meaning-making through performing arts is a powerful way for youth to engage with science.

Participants did not necessarily distinguish between STEM and arts but combined them into a set of practices and utilized them as useful tools for problem solving. For example, as Stardust prepared to make hang their final Saturn model, they engaged in a process of estimation to determine an appropriate length of the stick on which the planet would be mounted. From an outsider’s perspective, one might say that they were integrating math practices, art and technical skills, conceptual understanding. From their perspective, they were trying to figure out how to solve a problem that was critical to the success of their dance. In another moment, they used a song found on the internet to brainstorm ideas for how to structure their explanation of Saturn’s formation. In this informal STEAM context, where STEM and arts were not separated or placed in opposition to one another and youth were immersed in purposeful activity driven by processes creation, youth felt comfortable employing STEM and dance as resources as needed. As a result, they developed of multiple skills, competencies and understandings.

Integrating Dance and Technology

Recent work on making to learn has looked at the relationship between making and technology by focusing on how making activities result in learning related to engineering, circuitry, design, and coding (e.g., Jacobs & Buechley, 2013; Kafai, Peppler, and Chapman, 2009; Resnick et al., 2009; Sheridan, Clark, & Williams, 2013). While youth in dance makerspace did certainly engage in engineering and design practices, circuit-making, and computer programming, it was with a focus on learning to utilize them to articulate their ideas in conjunction with expressive movement. Dance and technology were integrated in the design and construction as well as in performance of the embodied, multimodal dynamic representations of science phenomena. The prototyping example in the previous section (illustrated in Figure 5.11) shows the integrated relationship between making, dance, and technology in group project work. In that example, the process of modeling the LED circuit involved applying technical understandings as well as making choreographic choices. Thinking about the relationship between the technology and moving bodies in space was an essential part of the design process because in each dance project, an electrical component was integrated into the choreography as a key component of the representation. Groups integrated technology into their choreographic compositions in a variety of ways, including: designing electrical components that would amplify or enhance what bodies alone were able to represent; incorporating technology into choreography through props that were designed to act as characters or help create a context and were interacted with in order to explain the phenomenon; and incorporating props designed to represent a state and to change state to signify a critical point in a process. They also created choreography that integrated the technology into movement phrases. Examples of dance and technology integration are provided in the Table 5.1 below.

The design and construction process required thinking about multiple dimensions at once, as did performance. Dancers had to juggle the physical affordances of the technology in real world setting they were in with ways of moving that were aesthetically acceptable and true to the scientific system and phenomena they were representing. For example, group Fiji designed a stop-motion video using clay to represent blood cells getting stuck together in their representation of sickle cell. In their dance, they performed a series of movements that represented the sickle shaped cells and moved to a formation that would start their projection by touching two conductive points on the floor to complete a circuit, which triggered the Makey Makey (a microcontroller that responds to human touch). In order to accomplish this, they had to attend to their individual roles in the choreography and to represent the phenomenon, be attuned to where their bodies were in space as related to the other dancers and aware of the audience and negotiating spacing and timing to make sure their hands and feet connected with the foil tape in the right places at the right times to activate the projector. They also had to construct a functional foil tape circuit on the floor so that the trigger point would match up with their choreography. This required spatial thinking and representational thinking, understanding of complete circuits, and artistic and dance skill. Dance-making served as a medium for integrating bodies, movement and technology.

Table 5.1. Examples of Integration of Dance & Technology

Articulating ideas with bodies enhanced by technology *(FOOF, Iteration 2)*	**Example:**	Fast on our Feet (FOOF) created a "nerve signal sock" made with LED lights, batteries, conductive thread and an on/off switch
	Designed to:	Show electrical signals traveling from the foot the brain when the foot came into contact with fire in the choreography
	Required:	Sewing with conductive thread; understanding concepts related to circuitry and wiring; designing and engineering something that was safe to wear and to dance in

Interacting with technology as props/ characters to explain the phenomenon *(CAUTION!, Summer Rain, Iteration 2)*	**Example:** CAUTION! constructed a volcano from cardboard, LED lights, wire, and conductive clay, battery, and a fan motor **Designed to:** "Erupt" at a certain point in the choreography **Required:** Wiring of lights in series; designing a "switch" that could be easily triggered within the timing of the choreography; negotiating spatial arrangements with respect to the volcano prop, the audience, and the aspects of the phenomenon they sought to represent
Technology as a character/prop that signifies a state and change state to signifies a critical point in the explanation *(Kiwi, Chalad, Iteration 3;* *Dreamers, TDD, Iteration 4)*	**Example:** Tie Dye Diamonds (TDD) constructed a supersized mood ring using cardboard, plastic, LED lights and a Lilypad microcontroller **Designed to:** Change colors at different points that corresponded with the changing moods and changing crystal structures reflected in their choreography **Required:** Wiring of LED lights, programming microcontroller, coordinating the microcontroller program with timing of music and choreographic counts
Through choreography that integrates technology into movement phrases *(FOOF, Iteration 2; Fiji, Iteration 3;* *Divaz, Iteration 4)*	**Example:** Fiji used choreography to signal a microcontroller to trigger the projector to play the stop motion video they created **Design:** Created movements that would reflect aspects of the phenomenon while positioning dancers to complete a circuit with their bodies in order to signal the computer **Required:** Spatial thinking and representational thinking, understanding of complete circuits, executing movements to effectively trigger the video at the appropriate time.

Integrating Narrative and Analytical Modes of Thinking

As was discussed earlier in the chapter, many groups enacted representations of the scientific content they were learning through narratives. Narrative, according to Bruner (1986), is one of the two fundamental approaches people use to make sense of and explain the world. An approach used commonly across the arts (Wright, 2003), the narrative mode is concerned with the meaning that is ascribed to experiences through stories that feature "human or human-like intention or action" (Bruner, 1986, p.13). The second approach, the paradigmatic, is logico-scientific or analytical. It seeks to understand the underlying relationships between sets of observable variables and involves thinking about the causes of relations among phenomena. While Bruner argues that the two modes of thought are not reducible one to another, the group projects developed in the dance makerspace show that dance can be a representational medium for both and can provide rich opportunities for integration of these explanatory approaches.

Dance is a particularly powerful medium for bringing together narrative and analytical modes of thinking because it allows for flexibility in storytelling. Movements do not have literal translations, so ideas and representations do not have to be literal. Because stories are not transformed into literal word interpretations, there is room to layer. So, a dance about sickle cell anemia can show the shape of blood cells, the process of sickled cells clotting in a moment of crisis, and the feelings of pain experienced by the person who is experiencing it. Through dance, one can explore many ideas at once. Project groups used their choreography to explore and explain process, cause and effect, and relations among the phenomena they studied in the context of stories.

For example, groups FOOF, Chalad, Fiji and Kiwi all decided to explore body-related phenomena for their projects. Each of their dance representations, focused on activities both inside and outside of the body, took the form of stories that showed the process and cause of a phenomena and also how it affected the people who experience it. Using movement to construct explanations of process, including things like: how sickled blood cells with sharps points get stuck on each other and poke at blood vessel walls; how plaque forms within arteries and causes blockages that restrict blood flow to the heart or to the brain; or how messenger nerves send electrical signals from a body part that is experiencing pain to the brain, showed paradigmatic approaches to thinking. Constructing these explanations with movement required understanding the relationships between different aspects of a phenomenon, what causes what and why. It involved playing around with what representations should look like, how to best show the process, what aspects of the process should be featured and how.

At the same time that the youth dance-makers were thinking about the best ways to represent their phenomena, they were also constructing narratives, placing the phenomena and processes they were representing inside a context that was relatable to them. They created characters in a setting and showed how those characters were impacted by the processes as they took place. This not only required narrative thinking but negotiating how one part of the story (process) mapped on to the other (character and setting). Integrating these modes of explanatory thinking resulted in complex representations that brought the phenomena to life for the dancers. Reflecting on their dance projects, they gave both narrative and paradigmatic explanations of their work, as shown in this post-interview excerpt from Krystle, a member of Kiwi:

> "Um… we did our project about heart attacks and a heart attack is actually a cardiac arrest which means the heart beats fast then slow. [We showed] the process of a heart attack, the heartbeat, um like at its normal tempo and then …it was a blood clot in one of the arteries, like it had too much fat, and then like everything started going slower and then fast... like it was changing tempo. There was also a man having a heart attack. He has chest pains, sweating, nausea, shortness of breath… that part is after the arteries are blocked."

Significance

In this chapter, I explored how representational choices were made as groups collaborated to construct creative representations of science phenomena in the dance makerspace, and the understandings that were developed and enacted through the process. Representational choices were mediated on multiple dimensions, including understanding of science concepts and ideas, technical and artistic skills, and representational competence. Choices and actions were also mediated by the practices groups chose to use to develop and construct their representations. Participants saw their work as a dance-making activity and engaged in practices that utilized dance values to engage with STEM content. This created an interesting opportunity to understand what can be learned from arts-based approaches to STEM learning.

Through their group project work in the dance makerspace, youth demonstrated learning on multiple dimensions – scientific, artistic, technical, and social – even though they framed their project work as a dance-making activity; even though they focused as much on the dance as they did on the science; even though they included things in their representations that would not have been welcomed in science class, including their ways of working. Participants' framing of their project-work as dance-making played an important role in helping them engage with STEM content and practices. They used dance practices to help them investigate and explore aspects of the phenomena they chose to study and to help them organize their representational ideas. Through the process of creating embodied multimodal dynamic representations, or dances that integrated technology to explain science phenomena, they made sense of science content related to the phenomena they studied and developed technical skills related to engineering, circuitry, design, and coding.

Youth, particularly those from low-resourced urban communities, have not typically experienced science in environments of free choice, where they are encouraged to experiment with creative ideas, to raise questions, to be inclusive, or to play (King et al., 2001). As a result, they have developed limited views of what science is and can be, coming to see it as rational, cold, unexciting, and devoid of emotion (Varelas et al., 2010). Perhaps this is why many participants did not associate their project-work or learning with science. Although they could express detailed and accurate explanations of the phenomena they studied and of the technologies used to create their representations, their project work did not align with what past learning experiences have taught them about what science and science learning are. Informal STEM learning spaces can play an important role in broadening perspectives, access, and participation in STEM for youth who typically do not see the connections to science in their activities outside the classroom. If youth can see their practices as relevant and related to the practices of scientists, they can begin to see the STEM in what they do. They can begin to understand that their practices are valuable tools for STEM sense-making and understand the resources they have at their disposal for problem solving.

Chapter 6. Conclusions, Implications and Future Work

The dissertation was an exploratory investigation of a problem space that has not been clearly defined, informal STEAM learning. The broad goal of the work was to further understandings about learning at the intersections of making, STEM, and the arts in informal learning spaces. Through an ethnographic study of a STEAM dance making space where activities were interest-driven and arts-based, I examined how factors related to design and facilitation influenced youth engagement with STEM. I also examined dance as an interest, a representational medium, and a tool for sense-making, using ethnographic descriptions to show how and what youth learned as they engaged in embodied sense-making practices; and the relationships between STEM, art, making and the body when dance was used as a representational medium. This work has attempted to bring readers inside the making process and demonstrate the potential for conceptual learning outcomes in informal STEAM making spaces. The findings have implications for how we theorize about learning and engagement, how we think about the design of informal learning spaces that focus on interest and choice, and the relationship between cognition and embodiment.

Implications

Informal STEM Engagement

Engagement in previous literature has been defined as a stable characteristic of individuals, measured through the self-reporting of factors like classroom behaviors, attention in class, involvement in extra-curricular science activities, homework completed, enthusiasm and persistence, self-perceptions and beliefs. The findings of this study expand prior ways of thinking about STEM engagement by showing that it is not simply a characteristic of individuals, but a choice that is influenced by interactions and the setting. The examples in Chapter 3 show that meaningful engagement – defined as sustained attention, reflection, or problem solving involving interaction with STEM content, tools, or ideas and drawing on, connecting to, questioning, or interpreting knowledge and relationships – was supported and also at times constrained by facilitation and the design of the setting.

The field is currently grappling with questions of how to design informal, interest-driven STEM educational spaces that engage youth while balancing their need for structure and support with the freedom to experiment, explore and play. The findings of this study provide insights into these questions through detailed descriptions of the design and of group making processes. The design of the learning environment supported engagement by providing a structure that was grounded in youths' interest in dance and was consciously designed to link STEM and dance practices. Framing the project as dance was an important design decision as it prompted youth to feel comfortable engaging in dance practices like iteration, revision, and feedback, and embodied exploration to construct their representations. Operating within the structure of the designed environment, youth remained engaged when they had: (1) the freedom to choose their own ways to investigate; (2) opportunities to be creative and iterate on their ideas; (3) opportunities to use one another as just in time resources; (4) opportunities to make meaningful contributions or support others in making meaningful contributions to the activity; and (5) shared or common goals that create a need and a value for the exploration of STEM content.

Open-ended projects in the free-choice environment of the dance makerspace provided opportunities for youth to exercise agency in decision-making about their dance project ideas, to decide on the topics they wanted to explore and on the forms their explorations would take. Given the freedom to decide how they would investigate their chosen topics, youth utilized multiple varied approaches for learning about the phenomena they studied. The freedom to choose their own project roles and to fluidly shift between roles allowed them to continue working without getting frustrated when they found things difficult. This was a practice modeled by facilitators and mentors who also made themselves available when youth experienced frustration, helping them to think about alternative choices without dictating what those choices would be. This allowed for a culture of support to develop in the space, with youth utilizing one another as resources and offering the type of just in time support that allowed them to begin new activities or continue the activities of their investigations and move forward and into deeper exploration. Youth also engaged more deeply in their project work when they found ways to make meaningful contributions or to support one another in making meaningful contributions to group goals and objectives. Whether in the dance space or the makerspace, participants consistently encouraged the participation of everyone in their group. Participation by all is an established practice in dance environments. When doing ensemble work, dancers needed each other to complete the task, not only because they shared a common goal, but because the representational products they were creating required all bodies to participate. I believe this attitude carried over from the dance space to the makerspace and was present in how youth thought about the work of making their electronic components because the electronic component making was part of their dance-making process. Framing the activity as a dance/Making project gave youth the freedom to think creatively about their representations. This creative freedom allowed youth to take ownership of their representational work, to ask authentic questions about the phenomenon, and to engage in discussion and negotiation about their representational choices. The freedom to iterate or to think of their project as a work in progress allowed them to remain open to the possibility that changes might be necessary and kept them from becoming frustrated when changes were necessary.

It is important to think intentionally about these factors when designing STEM informal learning spaces. Another important factor to consider is facilitation. Facilitation either supported or constrained youth engagement depending on the choices made in interactions. Facilitation can be tricky to navigate in informal learning spaces where youth have the freedom to create their own designs and make their own decisions and the pathways to success are not clearly defined or delineated. Facilitators have to grapple with when to support, how to support, and how much to support youth in these spaces. At times in the dance makerspace, facilitator support came in the form of *telling*, providing information or directions that would guide groups toward their project goals. At times, facilitation support meant *working for* youth, helping to complete minor parts of a project so that youth could concentrate on tasks that required more attention. At times, support meant *working with* youth, engaging in exploration, investigation, or construction with youth in order to help them troubleshoot or develop their ideas. Whether facilitators made the choice to *tell*, *work for* or *work with* youth in the construction of their projects, youth were more inclined to meaningfully engage when facilitators positioned themselves as peers in the process, opening the door for youth to do the thinking. An interesting next step might be to examine systematically the knowledge base of effective facilitators in this domain to determine what knowledge and dispositions they draw on making decisions about whether to tell, work for or work with youth. This is an important issue as it may be a critical link between the idea of designing for freedom and choice and determining in such environments when and how direction is needed.

Finally, meaningful engagement was impacted by the responsive nature of the program design. *Responsive design* is a dynamic approach to design that is participant-centered, grounded in a commitment to attending to the needs and interests of those for whom a program is designed as those needs and interests shift and emerge. This is an emerging approach in the field, related other approaches to design that remain open and subject to revision (i.e., social design experiments (Gutierrez & Vossoughi, 2010)) but focused on following participant interests. Utilizing a responsive approach to design that focused on needs and interests and remained flexible within and between each iteration of the program impacted engagement in two ways. First, the freedom to choose their own ways to investigate allowed youth to utilize familiar skills and practices to explore STEM content and develop new skills, to bring in their own interests and incorporate them into their work. In addition to that, the flexible design structure allowed facilitators to track youth interest and group progress in order to ground design changes in participant needs and interests.

STEM + Arts

This work also has implications for thinking about the relationships between STEM and the arts in STEAM education. As a field, we have come to recognize the value of the arts in learning but have struggled to incorporate them into STEM learning environments in ways that stretch beyond the superficial. One way to think about the deep relationships between STEM and dance is to consider the unique affordances dance experiences have for developing science understandings. In Chapter 4, I identified three ways that the construction of dance representations led to STEM sense-making. The first was through embodied re-presentation, the act of interpreting, combining, reformulating, ideas about a phenomenon and translating them in a new embodied form. Utilizing dance as a representational form allowed youth to deepen their understandings of complex dynamic systems by modeling them. This can be particularly useful when thinking about complex phenomena that are hidden from the human eye, like systems operating inside the body; systems that are too small to see, like systems that operate on a microscopic or cellular level; or systems that are too vast to experience in person, like the solar system. It could also be useful for exploring relationships that have to do with time and space. Using dance as a representational form allowed youth to engage with phenomena from multiple perspectives simultaneously, to access and combine narrative and analytical modes of thinking, to think about multiple aspects of a phenomenon, how they relate to each other and how they relate to the whole. Dance also provided a way for youth to physically connect to science content through embodied exploration and kinesthetic experience. Kinesthetic experiences can be especially useful for making physics concepts like gravity, rotational forces, friction salient for dancers because they can feel them operating on their bodies as they move.

These findings should open our minds as educators regarding how we think about bringing young people to science, but they should not be interpreted as promoting "dance in service of science learning." Instead of positioning dance as a way to teach science, I have worked to identify and uncover useful overlaps between dance and STEM practices and to show how the fluid integration of artistic and scientific ways of thinking can lead to deeper, meaningful exploration, and new ways of understanding both disciplines. One example of this is that dancers learned through this process that dance doesn’t have to be about just technical steps as they learned about the science they were representing.

There are other relationships between STEM and dance made salient by this work. Chapter 5 showed how exploring science using dance-making practices heightened youth’s epistemological orientations toward experimentation by providing a useful framing that encouraged testing out ideas, iteration and revision, hypothesizing, and modeling, as well as generally being okay with uncertainty. Engaging in the messiness of making, in both the dance and the technology aspects of the process, allowed youth to grow comfortable learning to say, “I don't know,” asking for help, defining problems and choosing which ones to tackle and which ones to leave on the table. It also encouraged a sense of wonder about the phenomena they explored and a sense of efficacy around STEM exploration more broadly. Much like other work on culturally relevant practices has shown (Lee, 2001, 2003), exploring STEM in the context of their familiar arts practices allowed them to see themselves as competent. As a result, they were willing to dive in to challenging content, and to do what was necessary (or at least what they could) to bring their technological visions to life. It encouraged them to think big and provided opportunities for them to learn to scale down their ideas and engage in problem solving. Problem solving, which centered around choreography, troubleshooting technology, integrating technology into the choreography, planning project work, and translating ideas from one modality to another was an important part of the creative process. Problem solving in the context of their creative, artistic work still aligns with NGSS standards, which stress the value of "defining problems, specifying criteria and constraints for acceptable solutions, generating and evaluating multiple solutions; building and testing prototypes; and optimizing solutions" for STEM learning (NGSS, 2013).

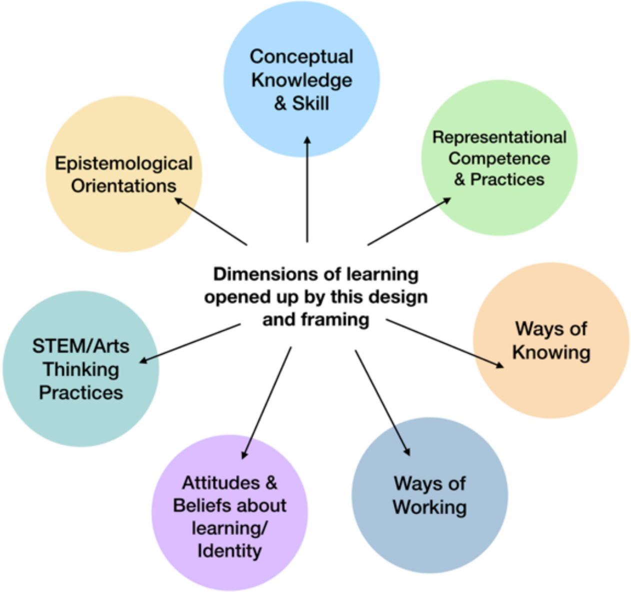


Figure 6.1. Dimensions of learning experienced by participants in the context of the dance makerspace

This work meaningfully integrates art and STEM by infusing dance into science and infusing science into dance, complicating how we think about leveraging relationships between the two. When science and dance are considered as different but equally respected domains of thinking, it creates a legitimate sense of integration. Another aspect of leveraging in this work is utilizing youth's authentic interests as a bridge to understanding. Dance interest was a critical factor in the design of this STEM learning experience. However, the uniqueness of a context focused on dance interest raises questions about the generalizability of the findings from this context, specifically, how leveraging interests would work or what it might look like if youth are not interested in dance, but in something else (i.e., sports, sewing, cooking) or if the interests of a group are diverse. Leveraging interest in this context was not only about identifying youth interests but designing for utility. In other words, a critical factor in integrating STEM and arts activities was creating a need for STEM within the activity of interest. This is a principle that can be translated to a variety of interests and contexts. For example, if youth had an interest in baseball, it would not be enough to say, "Let's calculate the trajectories of balls that are hit into the outfield" or "What angle would I need to hit a ball to get it to first base?" because you don't need to do or know those things to play baseball. But if instead, you said, "We are going to create a new sport. What kind of ball would we need? What size, what material, what weight would it need to be in order for it to function the way that we will need it to in the game?" then it would likely become necessary to understand trajectory. The making would be tied to interest and the STEM would be useful to the making, and participants could pull from and utilize their embodied experiences to make decisions and design choices. The same applies when youth's interest are diverse. Research on interest-based informal STEM making has shown that youth engage with challenges when the

STEM has a functional utility in the making and the making is based on what is interesting to them (Stevens, Jona, Champion, Echevarria, Hilppö, Penney, & Ramey, K., 2016; Ramey, K., 2017).

Makerspace Research

This study also has theoretical implications for understanding STEAM learning in makerspaces. It lends empirical support to research on making to learn by demonstrating how STEAM making leads to conceptual understanding and shows the potential richness of learning environments where children are allowed and encouraged to use diverse practices and multiple languages as tools in their problem solving. It also pushes the boundaries of how we characterize the value of making in STEM education. Research on STEM learning and making has focused heavily on preparing youth for future success in high school and college STEM courses or STEM careers by exposing learners to the tools and practices of engineers and scientists. This work shows the value of exploration and creativity for science learning and demonstrates that making to learn activities can support youth in exploring their current interests, not just prepare them to follow a STEM career path. Finally, this study pushes the boundaries of what has been considered making by positioning youth's bodies as materials and tools for exploration.

Embodied Cognition

Research on cognition has not given much consideration to the artistic expressive form of dance as a mode of thinking and knowing. Yet, dance-making possesses multiple features that make it a powerful meaning-making activity that can expand how we understand cognition and the body's role in sense-making. This study showed how exploring in embodied ways provided opportunities to examine science phenomena from multiple simultaneous perspectives, to work through developing representational ideas and construct shared understandings by creating embodied dynamic artifacts that could be easily manipulated and evaluated as understandings evolved, and to practice abstracting to get to the essence of ideas. The findings on STEM embodiment can be synthesized into a set of design principles that consider embodiment in the design of STEAM making environments and activities. Principles for utilizing dance as a tool for STEM exploration would include: creating opportunities for learners to move early and move often as they engage in exploration of STEM content and ideas, before their ideas are settled; creating a context through which authentic questions and problems to solve can emerge as dancers engage in inquiry and investigation; providing opportunities for youth to develop their movement vocabularies and to learn tools for embodied expression (dance composition tools); and providing opportunities for learners to develop and work out ideas collaboratively, with multiple sources and chances for feedback and iteration.

While these design principles were developed from analysis of a setting that was focused on a population of dancers and on dance as an embodied making activity, they can be applied more generally. The fact that the vast majority of participants were dancers could be considered a limitation of the study, making it difficult to generalize the findings about the usefulness of dance as an integrating practice for other populations. It is true that this program may have looked different had it been implemented in a setting where youth did not self-identify as dancers. However, it is necessary in implementing programs that focus on expressive art forms for making and STEM exploration to go beyond thinking of them as high art or even as a set of technical skills that must be mastered in order to effectively create. It was important even designing for a population of dancers to be clear with youth that dance could be defined as their own forms of movement, which every body has (even those bodies that don’t consider themselves to be dancers). Dancing in the context of STEM exploration does not have to mean ballet technique or some other kind of formal training. It is important to welcome youth to bring their own forms of movement, things they feel comfortable with, to provide tools for dance-making, but not judge them on the "quality" of what they are calling dance. In a classroom or a setting where students may not necessarily identify as dancers, these embodied investigative activities may be able to be used without calling them dance. This is an open question to be explored, perhaps in future research. The task is open enough that learners can move in ways they feel comfortable and groups can decide who does what. The thing to take away is not that dancing is the way to learn science, but that embodied explorations can lead to new ways of thinking; that developing tasks that create a utility and value for STEM learning gives youth a reason to get deeply engaged; that understandings are expressed multimodally; and given opportunities to engage with content using a range of modalities, youth can develop complex representations.

Limitations

While it is true that creating embodied multimodal representations can allow youth to develop and express complex representations of science phenomena, a limitation to studying dance as an expressive modality is that it is a non-verbal form of communication. Meanings must be interpreted by observers, which is not always an easy or straight-forward task. While I went through great pains to do member checking, asking youth to review footage of their making processes, to give their interpretations of choreographed movement phrases and to evaluate my interpretations, the children in hindsight did not always remember or could not always express verbally what the intermediary movements and phrases they constructed as they moved toward their final representations meant. Like most creative processes, the process of dance-making can be amorphous. Often, in constructing these types of collaborative representations, meanings shift throughout the making process and are not clear until a dance is complete.

My role as participant observer allowed me to watch groups' dance-making processes unfold, which gave me some insight into the meanings they were making and how they were evolving. I was able to rely on the conversations they had with one another as and the vocabulary they used as they worked to make connections between what they were thinking and the ideas they expressed through movement. But it also required me to balance facilitation, observation, and data collection. While playing these three roles allowed me to see and make sense of the program from three different perspectives, it also meant that the video data were often recorded with minimal oversight. The whole room camera was stationary, placed either in the studio upstairs or in the makerspace downstairs while multiple groups were working in the space during *make time*. Participants moved around the room and around the building a lot, often moving in and out of camera range, and the whole room cameras could also only capture the groups working closest to it with good sound quality. Although the children wore point-of-view cameras as they worked in the makerspace, they often took them off because they were uncomfortable or getting in the way of their work. They could not wear them at all when they were dancing. Because many of their movements involved jumping, spinning, quick level changes, and rolling on the floor, it was not possible to safely dance with the visor cameras on.

I did not collect any data outside the context of the program. The focus of this study was on understanding the experiences of STEM inside the camp. However, it would be interesting to think about how the summer making experiences may have influenced subsequent STEM participation and interest. This is one potential line of research for future work. It includes questions about relationships between meaningful engagement in the space and engagement in

STEM outside the space (in school, in community); the ways that engagement in the space impacts future STEM engagement; and whether and how integrated STEAM practices can be implemented in formal learning contexts. Another potential line of future research related to interest is understanding how experiences driven by interest in dance and interest in making can lead to interest in STEM, and specifically which dance skills and practices are most closely linked to STEM skill and practice development. This work could potentially lead to the development of models for designing and assessing learning in informal spaces that focus on multiple understandings and the ways they are enacted.

An important question raised by this work but not taken on by this study – a line of research that emerged but I did not follow in this work – involves how parents' and children's values differ from mainstream narratives about the value of STEM. The youth and parents interviewed in this study expressed a different value of STEM that is not tied to mainstream narratives of upward mobility, college success, and future STEM careers, but instead has a utilitarian value. Parents relate the importance of STEM to the need for their children to understand how to solve problems for themselves, to be independent and take care of themselves. The youth participants related the value of STEM to the importance of understanding how the world works. In future work, I would like to understand how these values play a role in the ways that youth situate their STEM learning experiences in the larger context of their lives, to interrogate the meanings that science holds for participants, how it is framed by parents and the larger community, and how that affects the ways that youth think about the work they are doing and the value of STEM.

Conclusion

The dance makerspace provided opportunities for a group of urban youth to learn through and about science and dance in an environment that positioned them as knowledgeable STEM thinkers and that valued their practices. By focusing on youth that were predominantly girls and students of color, both underrepresented populations in STEM, this study can contribute to research on ways to broaden STEM participation for underrepresented youth who typically do not see the connection to science in what they do. This work provides insights on how to integrate interest in STEM work, especially important for youth who identify as dancers because both arts and the body are so often positioned in opposition to scientific thinking and practices. This work shows how the arts and the body can be integrated with STEM exploration. Seeing STEM as an integrated part of their practices provides different kinds of access to science. While the study looked at learners from underrepresented ethnic backgrounds, lessons could be applied generally, used to create new mechanisms for designing for STEM learning, and environments that encourage and broaden participation.

I had the privilege of guiding these young artist/scientists through an experience of interdisciplinary exploration, and I learned as much from them as they learned from me. Watching their faces light up with anticipation each new day, seeing them grapple with complex ideas and work together to make sense of challenging concepts – the same children who struggle to maintain focus in their science classrooms, who are quick to proclaim that "science is boring" or that they are "not good with technology because it's hard" – I was excited by the ways that they jumped into their projects without hesitation, willing to engage and try new things. I was inspired by their hunger and eagerness to learn and also reminded of the critical importance of our work as education researchers and learning scientists. As designers of STEM learning environments, it is important that we develop designs that engage learners where they are, taking their knowledge, skills, practices, and values as a starting point. We must create opportunities for youth to learn, create and explore (1) in settings that value what learners bring to the table and (2) in ways that allow them to express their understandings with the full multimodal range of their communicative abilities. Given these types of opportunities, our children can develop the confidence and competencies that will delimit their future pathways, allowing them to become the scientists, the artists, or the interdisciplinary thinkers that will drive innovation and solve the problems of the future.

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Appendix A. STEAM Makerspace Pilot Design Document

STEAM Makerspace
DESIGN DOCUMENT

Dionne N. Champion
Design of Learning Environments

Design of Learning Environments Project Brief

FOCUS STATEMENT

Title: STEAM "Makerspace" Project
Team: Dionne N. Champion

Client Profile: [redacted] Creative Arts Center
The client is my own dance center, [redacted] a creative arts center in [redacted]. [redacted] offers an academic-infused arts summer camp program every year for children ranging in age from 7-18. This summer, the school is interested in offering a unique program that infuses STEM (Science, Technology, Engineering, and Mathematics) activities into an arts-based curriculum, and that helps develop interest in science and engineering among inner-city kids who don't usually have exposure to engineering activities.

Program Summary: The 3-week summer intensive program is designed to immerse participants in a creative environment that provides technical training and hands-on learning experiences, and that introduces them to creative problem solving strategies. The developed curriculum will teach students to apply both scientific and creative thinking tools as they explore the fundamental concepts of electric circuitry in a process of "making." Participants will work on small group projects that creatively combine the use of choreography, art, and a "Makey Makey" circuit board to express an idea, allowing them to apply their developing technical and artistic skills. These projects will be documented and presented.

Personal Motivation: My background in engineering and dance has led me to develop an interest in polymathic learning environments and ways to help children develop into creative thinkers and learners. I have begun looking at the "Maker Movement" as a research topic, and I am interested in the concept of "making-to-learn," studying how "Makerspaces" can help children develop 21st century learning skills. Makerspaces, sometimes also referred to as hackerspaces, and fablabs are creative, DIY spaces where people can gather to create, invent, and learn. My specific interest is in spaces that allow for multimodal learning, where learners not only have access to physical and technological tools, but are also given space to develop ideas through movement, music, and art.

CONTEXT

Student "Makers":

- Young dancers, ages 9-14
- Upper elementary and middle school students (4th-8th graders)
- Novice "makers"
- Limited exposure to hands-on science and engineering activities
- Varying levels of dance experience and formal dance training
- Approximately 10-15 participants

The program will be will geared toward participants in the DancExcel summer program who range in age from 9 to 14, upper elementary and middle school (4th-8th grade) students. Program participants will be mostly novices. Even those who may consider themselves to be tinkerers or crafters will not have been introduced to the concept of "making" as a formal form of education, so the ideas presented and ways of working will mostly be new to them, although they should incorporate some things that they are used to doing. Most of the children will be students who I have worked with before (or work with presently) as dance students at [redacted]. Children (or their parents) sign up for the program based on interest.

Setting: The program will take place at [redacted] Creative Arts Center for three weeks in the month of July. Participants will come five days a week (Monday-Friday) from 9:00-4:00 pm, working on a variety of related learning activities during that period.

RATIONALE

The goal of this project is to design a program that allows children to build on their ability to think, problem solve, and persevere through a scaffolded process of "making." Dance students (ages 10-14) will be immersed in a creative environment for three weeks (5 days a week, 7 hours a day) where they will use developing skills in the arts and sciences to solve an open-ended problem. The challenge will focus on the use of kid-friendly electronic elements and other available tools and materials, which participants will use to create something that expresses an original idea. These projects will be documented, published, and presented.

The process of making is different from the design process in a few critical ways. In making, the focus is not necessarily on designing an end product. The goal is to discover as much as you can through the process – to learn how things work by playing around with ideas, to think and learn about things by DOING, and to make something creative in the process. Children should complete the program with a better sense of how to make things than when they began, but they should also leave with a deeper realization that they can be creators and producers, not merely consumers, of content. While students will engage in dance/choreographic and circuit building activities, the primary learning goals are not about dance or about circuits. The main goals are that students

(1) learn to use what they know to create something original;
(2) learn how to get the information that they need in order to create; and
(3) learn to express their ideas in multiple formats.

Making results in self-directed learning. Building your own project can be a motivator to engage in engineering. The purpose of this program, however, is not to create expert engineers, electricians or choreographers, but to help children use those developing skills to gain confidence and proficiency at making. What I'm suggesting is more of a bootstrapping concept – that they use the practice of making something (practically applying new knowledge) to build on understanding and/or develop expertise in a knowledge domain (or in several knowledge domains). Meaning-making through this type of process is more social and engaging, as children learn to communicate effectively in teams and share their thoughts and ideas. While they might not become expert presenters by the end of the program, the project offers students an opportunity to develop and improve their fluency as presenters by given them a chance to reflect on their experiences, organize their ideas, and share their process and the products of their learning.

INITIAL RESOURCES

Personal Qualifications: I am an experienced dance educator and have spent the last nine years developing an arts program that integrates dance skills with education in science, math, history and writing. While I am not an expert "maker," I do possess many of the skills needed to guide students in the process of creation. These include experience in engineering and design, choreography, basic computer skills, basic building and tinkering. One of the fundamental characteristics of the Maker Movement is that anyone can be a maker, and it is not necessary to be an expert in order to coach and guide students in the process. It is only necessary that one be open and willing to learn along with them and model learning for them.

Educational Standards:

The Corporate Member Council lists several K-12 STEM Guidelines for All Americans that align with program goals:

- STEM Dimension 2: Connecting Engineering to Science, Math and Technology
  Understand how knowledge acquired in one context can be applied in another.
- STEM Dimension 3: Nature of Engineering
  All American will be creative and innovative in their thought process and actions.
  Use a logical process for inquiry, solving practical problems, critical thinking, and innovation.
- STEM Dimension 4: Communication and Teamwork
  Students will understand that engineers need to communicate effectively as individuals and as members of a team.

In addition to these standards, students will understand that:

- Complex problems, such as those faced by engineers, are often better solved by teams rather than by individuals.
- Effective individual and group communication skills are learned attributes.
- Roles of team members are an important aspect in learning to work collaboratively and cooperatively.
- Communication of ideas is effective when appropriate media is used and knowledge of your audience considered.
- Multidisciplinary and cross-functional teams bring a variety of skills and perspectives that enhance the engineering design and problem solving processes.

Students will be also able to:

- Use appropriate communication procedures, including oral presentations and written documentation using guidelines and style standards.
- Communicate effectively using multiple media.
- Practice interpersonal and group dynamic skills, such as: cooperate with others, advocate, influence, resolve conflict, and negotiate.
- Function on multidisciplinary and cross-functional teams.

Activities will also align with Indiana process and content Math and Science Standards:
Indiana State Standard - Standard 7—Mathematics Problem Solving (Process Standards)

- Students make decisions about how to approach problems and communicate their ideas.
- Apply and adapt a variety of appropriate strategies to solve problems

Indiana State Standards - Physical Science/Electricity (Content Standards)

- Provide evidence that heat and electricity are forms of energy
- Design and assemble electric circuits that provide a means of transferring energy from one place to another (4.1.3; 4.1.4; 4.1.5)

Performing Arts Standards - Standard 11

- Students identify and make connections between theatre/dance and other disciplines, such as language arts, social studies, humanities, science, and technology.

Educational Materials:

The concept of making to learn is a new and growing idea in education. There is an online community of resources that is continuing to grow and evolve as "makers" contribute to it. Resources include:

- The Makerspace Playbook, an online resource that guides potential makers on how to create a Makerspace. (Published in 2012)
- MAKE Magazine
- Make: Magazine's special issue, the *2011 Ultimate Workshop and Tool Guide*
- Dr. Stuart Brown, *Play: How it Shapes the Brain, Opens the Imagination and Invigorates the Soul*

- Maker Faire Events
- Makerspaces (21st Century Skills Innovation Library: Makers as Innovators), Emily Puckett Rodgers
- Leaving to Learn: How Out-of-School Learning Increases Student Engagement and Reduces Dropout Rates, Elliot Washor
- School Library Makerspaces: Grades 6-12, Leslie Preddy
- Hack This: 24 Incredible Hackerspace Projects from the DIY Movement, John Baichtal
- Design, Make, Play: Growing the Next Generation of STEM Innovators, Margaret Honey
- Maketolearn.org http://maketolearn.org/explore/
- Teaching with Makey Makey http://www.makeymakey.com/forums/index.php?topic=530.0
- Squishy Circuits http://courseweb.stthomas.edu/apthomas/SquishyCircuits/buildingCircuits.htm
- Curriculum of Creativity http://www.scoop.it/t/curriculum-of-creativity
- Classroots.org http://classroots.org/blog/
- Teaching Creative Problem Solving in Science http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2736021/
- Creative Problem Solving in the Classroom http://www.amazon.com/Creative-Problem-Solving-Classroom-Effectively/dp/1882664000

INITIAL SKETCH

Learning Goals

Participants should learn that they are makers; that they can be producers of content; that they can be creators and not just consumers; that the creative process is messy and not magic; that they can apply the same problem solving methods to many different types of problems; and that math and science can be useful and are related to their everyday lives.

They should develop a multi-modal understanding of circuits and understand the relationship between the creative process and the scientific thinking, technical skills in dance, knowledge of choreographic composition tools, and an understanding of how and when to apply these skills.

Assessments

They will have a final product to show at the end of the summer. Each student will present their project in front of an audience, explaining what they did and what they learned. They will also document their work on a maker site, creating a step-by-step guide to the creation of their product.

Learning Plans

Give them an open-ended problem to solve... let them come up with a creative solution

1. Skill elements – dance/choreography tools, dance technique, problem solving strategies
2. Creativity Training – "playing" with tools and ideas, open "make" opportunities, toy hacking, upcycling/repurposing projects, 3D Printing
3. Science/Tech Elements – Circuits, analogy to energy transfer in dance, activity with the energy stick
4. Creative Process versus Scientific Process (Creative Thinking versus Scientific Thinking) – creatively answer a question or solve a problem about circuits using different modalities
5. Organizing Ideas –tools for storyboarding, documenting the process of project design
6. Practical Application of new skills: Makey Makey Culminating Project – Introduce Makey Makey, Introduce open-ended creativity challenge, express yourself using what you've learned

Expert CTA Report

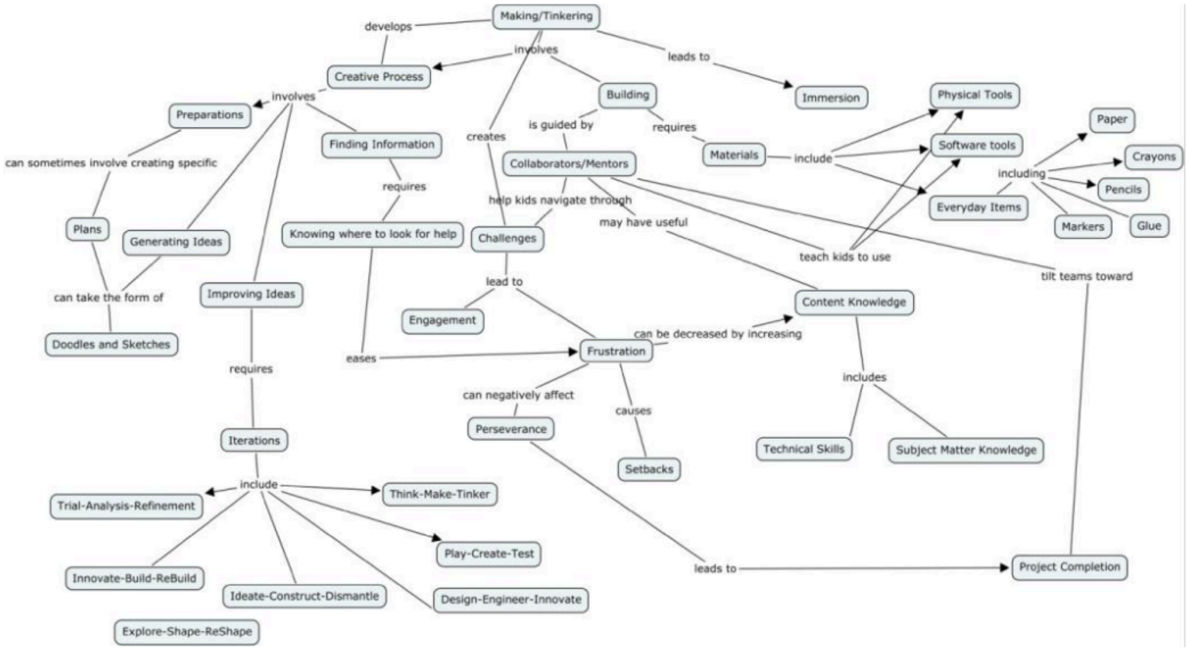
CTA FRAMING STATEMENT

The goal of the cognitive task analysis was to understand the full scope of strategies, skills, and procedures involved in the process of making. Through expert interview and observation, I sought to capture the knowledge and skills (expertise) required to generate ideas, persevere through points of frustration, and see an open-ended project through from its starting point to completion.

Initial Resources

I am an engineer and experienced dance educator and have spent the last nine years developing an arts program that integrates dance skills with education in science, math, history and writing. While I do not profess to be an expert "maker," I do possess many of the skills needed to understand the process of creation, including experience in engineering and design, choreography, basic computer skills, basic building, and tinkering. I am familiar with some literature on the design process, including the IDEO and Frog Collection Action Toolkits for design, as well as the process of Learning by Design Distributed Scaffolding. This literature provides an understanding of the design process, but mostly focuses on project planning, a less crucial aspect of making. I have become familiar with the work of Gever Tulley and his Tinkering School program, where children are given abstract open-ended building projects and problems and trained to use the tools required for success. I am also familiar with some resources for developing Makerspaces and projects, including the Makerspace Playbook, and the littleBits, and Instructables websites. The concept below map was created based on all initial resources.

Bootstrapping



Problem(s)

What are the steps in the process of making? What key skills are needed to be successful in completing an open-ended project through a process of "making"? How do makers gain the skills and information necessary for project completion? What is project completion in the context of making?

Expert Interview and Observation

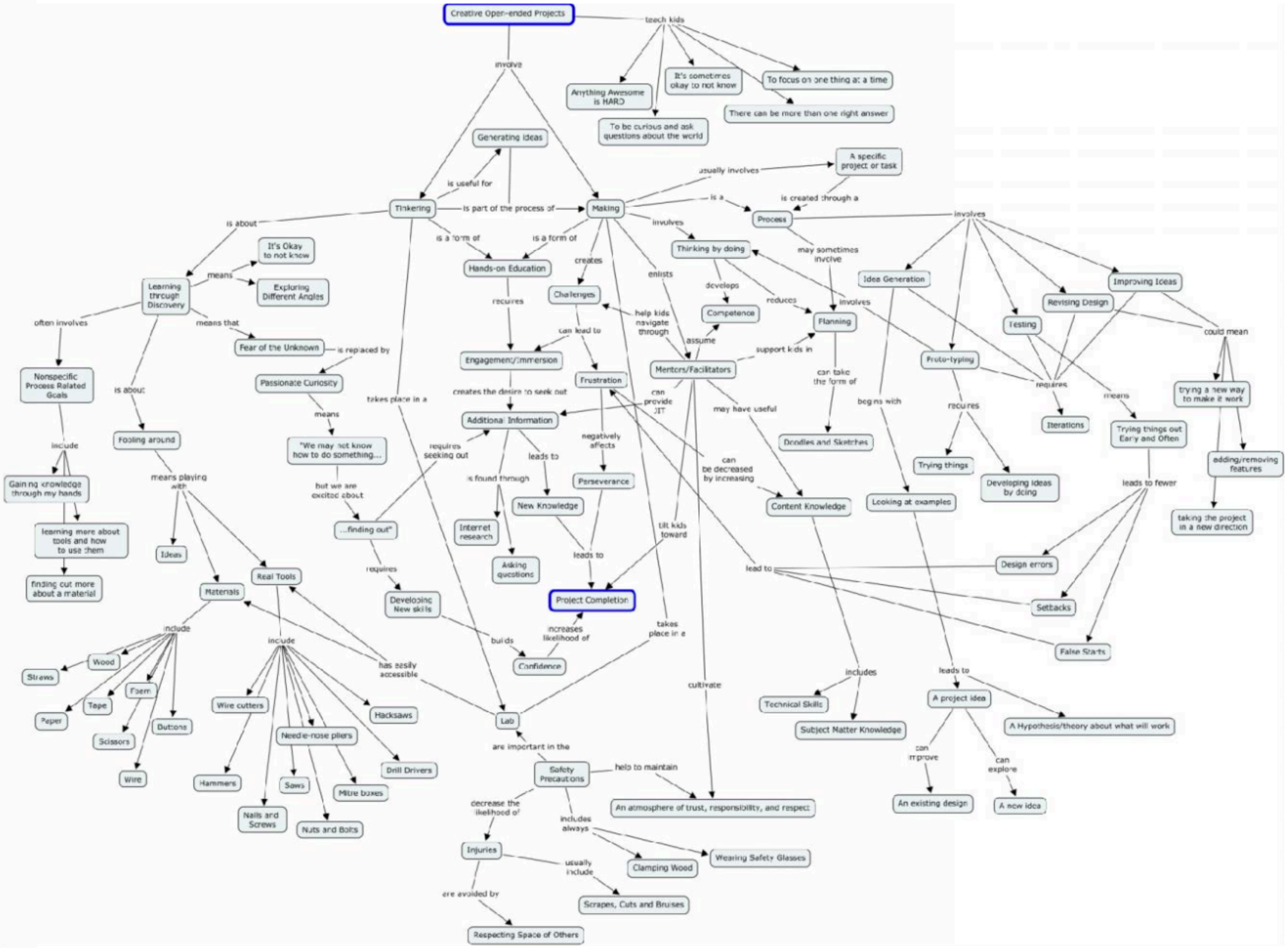
In order to address these questions, I chose to conduct an expert interview as well as to observe the expert in practice. The expert I chose, [redacted] is the lead educator for Tinkering Lab and director of Tinkering School [redacted]. [redacted] is an expert maker who has completed many individual and group projects and presented them at Maker Faires across the region. He is also an expert on engaging kids in "tinkering" and can elaborate on the process of helping kids get through an idea. The Tinkering Lab [redacted] has a "Tinkering in Residence" program every Thursday from 5:30-7:30 (Kraft Family Free Night).

I met [redacted] at the Museum and did a GEL interview prior to the start of his program, then observed him in the process of working with children during the residence program. I chose these methods because of the multi-faceted nature of the making process. The interview provided access to expert knowledge and practices that are highly internalized and rarely made public. However, the interview alone was insufficient for understanding the complex nature of the process, so observation was necessary. While observing the expert in practice was a necessary component in understanding all aspects of the process, the process was far too complex to lend itself well to a talk-aloud. The interview was video recorded and transcribed.

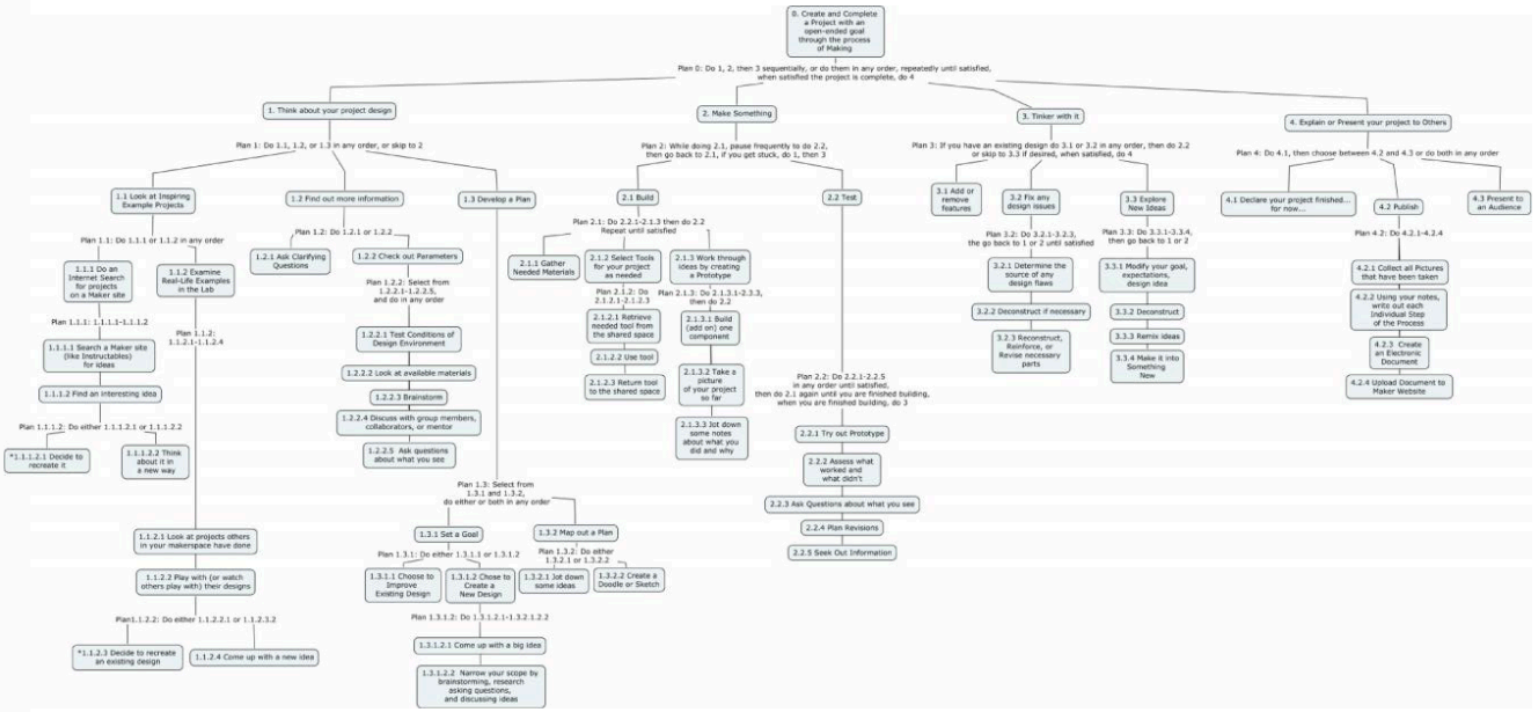
Insights

The process of making is complex and highly iterative. It can begin and end at any point in the process. Helping kids to understand and embrace the cycle (i.e. explore, shape, re-shape) can create a failure positive atmosphere that encourages innovative ideas, risk-taking, and perseverance.

Expert Concept Map



Expert Hierarchical Task Chart



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*Parts 1.1.2.2.1 and 1.3.1.1 lead into 3

Create and Complete a Project with an open-ended goal through the process of Making

Step	Type	Description
Plan 0: Do 1, 2, then 3 sequentially, or do them in any order, repeatedly until satisfied, when satisfied the project is complete, do 4		
1. Think about your project design	A	Concept: Generating lots of ideas can help get creative juices flowing
Plan 1: Do 1.1, 1.2, or 1.3 in any order, or skip to 2		
1.1 Look at Inspiring Example Projects	A	Concept: Looking at others' work helps one imagine the possibilities, opening mind to new ideas
Plan 1.1: Do 1.1.1 or 1.1.2 in any order		
1.1.1 Do an Internet Search for projects on a Maker site	A	Process: Using a computer and conduct internet search
Plan 1.1.1: 1.1.1.1-1.1.1.2		
1.1.1.1 Search a Maker site (like Instructables) for ideas	A	
1.1.1.2 Find an interesting idea	A	Process: Knowledge of where to find relevant information
Plan 1.1.1.2: Do either 1.1.1.2.1 or 1.1.1.2.2		
1.1.1.2.1 Decide to recreate it	D	Process: Ability to synthesize information, and draw conclusions about feasibility and scope
1.1.1.2.2 Think about it in a new way	A	Process: Ability to generate alternate ideas
1.1.2 Examine Real-Life Examples in the Lab		Concept: Looking at others' work helps one imagine the possibilities, opening mind to new ideas
Plan 1.1.2: 1.1.2.1-1.1.2.4		
1.1.2.1 Look at projects others in your makerspace have done	A	Process: Access to other projects,
1.1.2.2 Play with (or watch others play with) their designs	A	Process: Respect for the space and work of others, Communication Skills
1.1.2.3 Decide to recreate an existing design	D	Process: Ability to synthesize information, and draw conclusions about feasibility and scope
1.1.2.4 Come up with a new idea	A	Process: Ability to imagine new possibilities based on material and skill constraints
1.2 Find out more information		Concept: Additional information can facilitate project completion and lead to new conceptual understandings
Plan 1.2: Do 1.2.1 or 1.2.2		
1.2.1 Ask Clarifying Questions	A	Process: Ability to communicate to team members and/or mentors
1.2.2 Check out Parameters	A	Concept: Understanding physical limitations of project is useful to design
Plan 1.2.2: Select from 1.2.2.1-1.2.2.5, and do in any order		
1.2.2.1 Test Conditions of Design Environment	A	Process: Ability to discern which factors play a key role and how
1.2.2.2 Look at available materials	A	Process: Pick up, play with or test out building materials to generate ideas about

Plan 2.1.2: Do 2.1.2.1-2.1.2.3		
2.1.2.1 Retrieve needed tool from the shared space	A	Process: Knowledge of the work space, where tools are located, how to access
2.1.2.2 Use tool	A	Process: Knowledge of how to use tool
2.1.2.3 Return tool to the shared space	A	Concept: Sharing creates an atmosphere of trust, responsibility, and respect
2.1.3 Work through ideas by creating a Prototype	A	Concept: Develop ideas by doing, try lots of things and see what works
Plan 2.1.3: Do 2.1.3.1-2.3.3, then do 2.2		
2.1.3.1 Build (add on) one component	A	Concept: Add on in small increments and test them out, know what works (or how things work) before you add on, Specific content knowledge required to make it do what you want it to do
2.1.3.2 Jot down some notes about what you did and why	A	Process: Keep a record of your process, Take notes about the important choices that you made, the materials you used, what worked and what didn't
2.1.3.3 Take a picture of your project so far	A	Process: Keep a record of your process
2.2 Test	A	Concept: Carry out tests and evaluations early and often
Plan 2.2: Do 2.2.1-2.2.5 in any order until satisfied, then do 2.1 again until you are finished building, when you are finished building, do 3		
2.2.1 Try out Prototype	A	Process: Understand what you want it to be able to do
2.2.2 Assess what worked and what didn't	A	Process: Ability to draw conclusions about functionality
2.2.3 Ask Questions about what you see	A	Process: Communication skills, ability to discern points of potential confusion ad identify what needs to be learned
2.2.4 Plan Revisions	A	Process: Imagination and Creativity, Specific content knowledge and understanding of how that knowledge relates to your project, Consider tradeoff and justify choices
2.2.5 Seek Out Information	A	Process: Research similar ideas, relevant concepts, any other information that might help bridge understanding
3. Tinker with it		Concept: Fooling around with ideas leads to discovery and sometimes brilliant ideas that work
Plan 3: If you have an existing design do 3.1 or 3.2 in any order, then do 2.2 or skip to 3.3 if desired, when satisfied, do 4		
3.1 Add or remove features	A	Process: Ability to keep an open mind, willingness to continue to improve design
3.2 Fix any design issues	A	Process: Ability to discern origin of issues, creativity
Plan 3.2: Do 3.2.1-3.2.3, the go back to 1 or 2 until satisfied		
3.2.1 Determine the source of any design flaws	A	Process: Ability to discern origin of issues,

		they can work
1.2.2.3 Brainstorm	A	Process: Generate as many ideas as you can think of
1.2.2.4 Discuss with group members, collaborators, or mentor	A	Process: Communication skills, Feed off of one another's ideas
1.2.2.5 Ask questions about what you see	A	Process: Understanding what you don't know and what you will need to understand
1.3 Develop a Plan	A	Concept: Understanding where you are going can help you get there
Plan 1.3: Select from 1.3.1 and 1.3.2, do either or both in any order		
1.3.1 Set a Goal	A	Process: Understanding what you want to accomplish and elements are most important
Plan 1.3.1: Do either 1.3.1.1 or 1.3.1.2		
1.3.1.1 Choose to Improve Existing Design	D	Process: Understanding how to draw conclusions about feasibility and scope
1.3.1.2 Chose to Create a New Design	D	Process: Understanding how to draw conclusions about feasibility and scope
Plan 1.3.1.2: Do 1.3.1.2.1-1.3.2.1.2.2		
1.3.1.2.1 Come up with a big idea	A	Process: Imagination and creativity, Specific content knowledge and understanding of how that knowledge relates to your project
1.3.1.2.2 Narrow your scope by brainstorming, research asking questions, and discussing ideas	A	Process: Ability to synthesize information, communicate, and draw conclusions about feasibility and scope
1.3.2 Map out a Plan	A	Process: Imagination and creativity, Specific content knowledge and understanding of how that knowledge relates to your project
Plan 1.3.2: Do either 1.3.2.1 or 1.3.2.2		
1.3.2.1 Jot down some ideas	A	Process: Specific content knowledge and understanding of how that knowledge relates to your project
1.3.2.2 Create a Doodle or Sketch	A	Process: Generate ideas through free drawing of whatever comes to mind
2. Make Something	A	Concept: Thinking by doing – We learn by doing and seeing it done
Plan 2: While doing 2.1, pause frequently to do 2.2, then go back to 2.1, if you get stuck, do 1, then 3		
2.1 Build	A	Process: start putting pieces together, build small components at a time
Plan 2.1: Do 2.2.1-2.1.3 then do 2.2 Repeat until		
2.1.1 Gather Needed Materials	A	Process: Understand which materials might be useful and how certain materials might work well together
2.1.2 Select Tools for your project as needed	D, A	Process: Understand which tools might be useful and which are required for certain materials

Novice (Student) Interviews

Problem

I presented my novices with an open-ended creative problem solving task:

> *"Create some kind of vehicle, craft or carrier that can travel from one place to another using the available materials. As you work, think about how will present your design at the upcoming maker faire."*

I made the computer available for their use. Other available materials included: scissors, cellophane tape, duct tape, paper, cardboard, water bottles and caps, glue, pencils, straws, toothpicks, popsicle sticks, string, and colored styrofoam.

Choice of method(s)

I decided to do two sets of interviews – an individual interview so that I could get a feel for a novice's understanding of the process of making, and another small group observation so that I could see how interactions between novices affect each individual's process. I started by talking to the children about the purpose of the interview, and then I explained the talk-aloud procedure.

For the first interview, I demonstrated the talk-aloud procedure with a simple math problem, then had my interviewee practice talking-aloud while working to recreate a simple (four-block) Lego structure. After that, I presented the problem as stated above. I observed and took notes, only prompting her once with "Please keep talking." I followed the same procedure for the group interview only in that interview, I observed the children talking to one another as they worked together to complete the task.

The process of making is long and complex. I tried to choose a challenging yet simple task that would allow me to observe some parts of the process; however, I realized that the information I got would not be complete, as the task was extremely limited by time and available materials. In order to round out my data and learn more about my subjects' understanding of other stages of the process, I prepared a few interview questions to ask after they had completed their talk-aloud task. I wanted to find out if they felt limited by the materials that were available and asked them about other things they might want to use. I asked questions about how would document their process and how they would present their project to an audience. All interviews were video recorded.

Students

Four students participated in this process – one in the individual interview, and three as a part of the group. The students, all girls, ranged from 9-12 years old and all were dance students. Their interests and academic skill levels ranged. The individual interviewee was a fourth grade student at a public elementary school. She is an average to above average student at her school, which has a gifted and talented program. The small group subjects were in fourth, fifth, and seventh grade. These students are also considered academically above average although they each admit to struggles in some academic areas (namely math, science, and social studies).

Student Misconceptions

Unlike the expert, who played around with many ideas before committing to one, and even then, continued to tinker, constantly reassessing choices and revising the design, my novices tended to stay focused on one idea. This made it difficult for them to move beyond stuck points. For example, in the individual interview, the novice seemed quite determined to create a "water bottle wheel" by using duct tape to attach a piece of cardboard. Although given the option of using a number of other materials, she continued to pursue the duct tape-water bottle solution even though it was clearly not working for her. Although she did attempt to think about multiple solutions, she kept coming back to the same one.

> *"Okay so what I was thinking... I see this (cardboard) kinda looks like a vehicle or something. And I see these two water bottles, and I'm gonna try to like tape them to the bottom, so it could like kinda make wheels, but not actual wheels, so when I tape them it could like move with the water bottles and the water bottle could like turn, so I wanna try to tape the two water bottles to the bottom of the cardboard that is a vehicle..."*
> *(tears about 4 inches of duct tape)*
>
> *"Okay, so I guess... that's... not really how I planned it. Um... What I'm doing wrong is... I need like the even sides of duct tape on each side... put the bottle in the middle and then (tapes it the same way as before). Okay, so I guess... that's really not how I'm trying to make it, but... um... I'm gonna try it with the other water bottle... (tears more duct tape) and hope that could make it move..."*

Once the novices started down a path, they did not really consider alternatives. They committed to the very first idea, whether it was good or bad, and this led to problems when things were not working out. They didn't begin with any initial goal or plan either, which is not a problem in itself. The real issue seemed to be the lack of strategies for ideation, evaluation, and seeking out new knowledge.

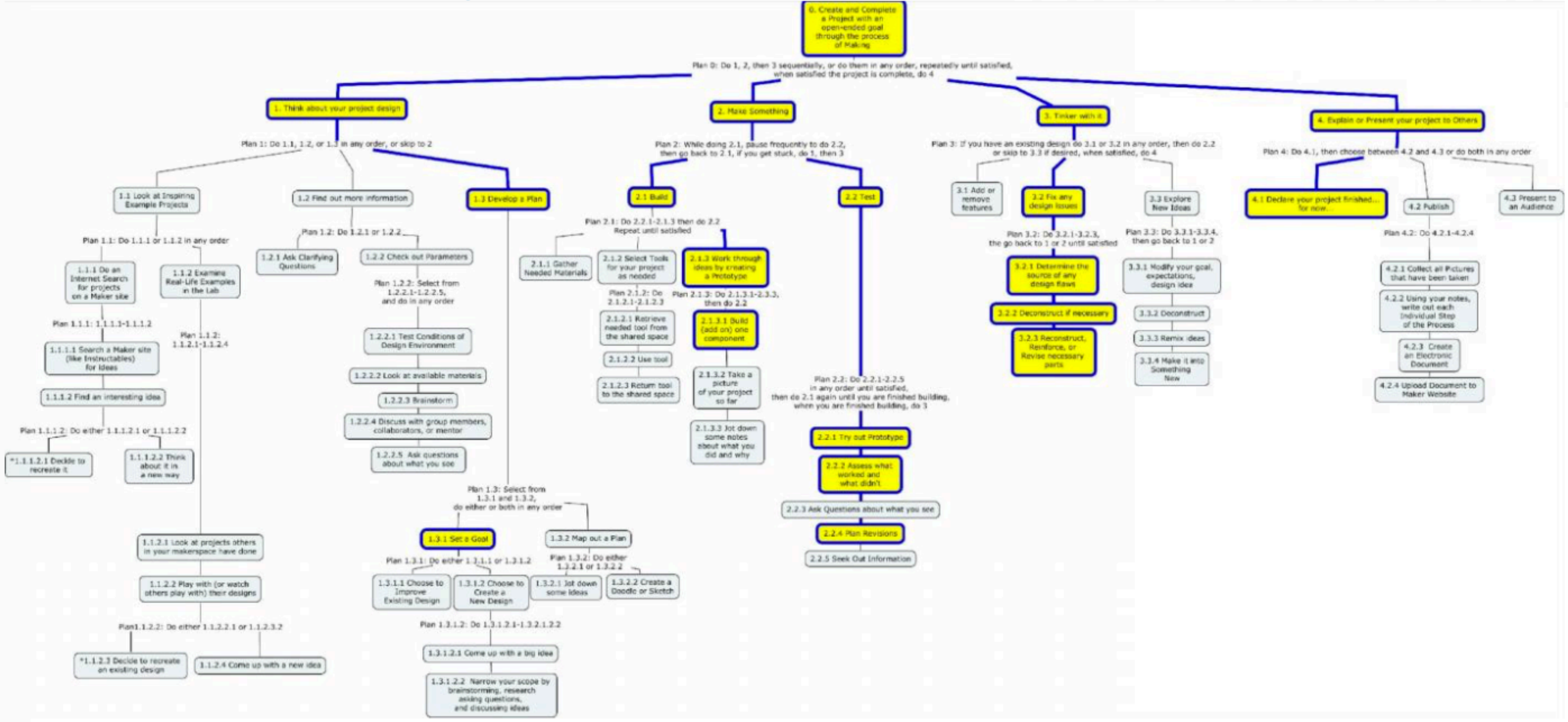
The novice process was incredibly streamlined. It touched on elements of each stage of the expert process, but did not fully explore any stage. The novice goal evolved out of building; building happened first, then once the vehicle started taking shape, the novice declared, "this is what I'm trying to build." This was especially apparent in the group interaction. Novices were also definitely limited by the materials that were in front of them. They remained focused on the given materials, wanted to use them all, and even when prompted, didn't consider anything else. Novice comments revealed that the girls felt like they were "supposed to" use what was given in order to get the right answer. They did not consider outside resources, tools, people, or materials. They did not consider documenting their process as they worked. When asked about how they could document the process and how they would present their idea, they didn't have very many ideas, other than posting a final picture on Facebook.

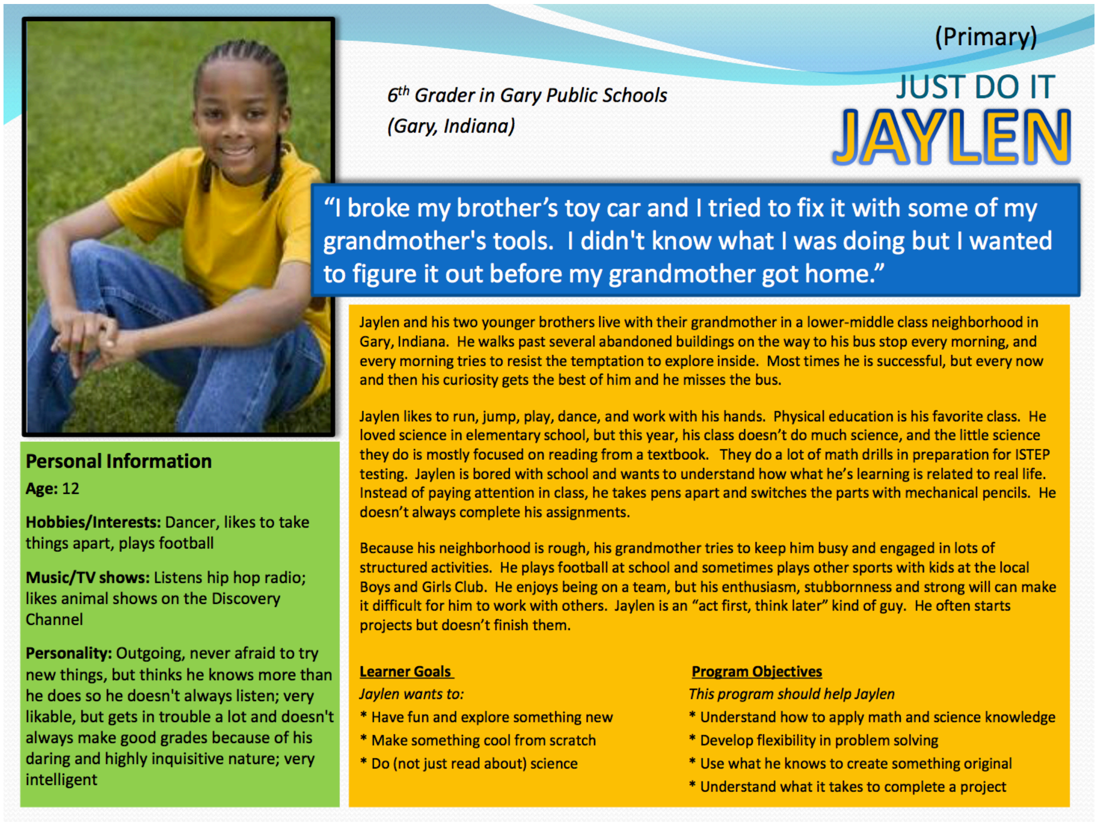
My goal is to help students to learn how to use all possible steps in the process; to give them more options and paths to take when they get stuck, and help them think outside the box. This project should also help young makers learn how to locate relevant resources, use those resources to more systematically construct their projects, and become more self-directed learners.

Key Takeaways from the Expert/Novice Interviews

There are several key takeaways from this analysis that will be used to inform the design of the STEAM Makerspace learning environment. While experts remain open to new ideas throughout the process of making, novice makers may need to reminded or possibly even coached through activities like brainstorming, iterating, and exploring alternate solutions. Experts, because they have more experiences developing projects, working with materials, and thinking through solutions, have access to a larger toolbox when making. It will be important to consider ways to scaffold for novices so that they can increase their toolkit while without being restricted by their limited knowledge base and inexperience.

Student Model – Hierarchical Task Analysis Chart





(Primary)

JUST DO IT

JAYLEN

6th Grader in Gary Public Schools
(Gary, Indiana)

> "I broke my brother's toy car and I tried to fix it with some of my grandmother's tools. I didn't know what I was doing but I wanted to figure it out before my grandmother got home."

Jaylen and his two younger brothers live with their grandmother in a lower-middle class neighborhood in Gary, Indiana. He walks past several abandoned buildings on the way to his bus stop every morning, and every morning tries to resist the temptation to explore inside. Most times he is successful, but every now and then his curiosity gets the best of him and he misses the bus.

Jaylen likes to run, jump, play, dance, and work with his hands. Physical education is his favorite class. He loved science in elementary school, but this year, his class doesn't do much science, and the little science they do is mostly focused on reading from a textbook. They do a lot of math drills in preparation for ISTEP testing. Jaylen is bored with school and wants to understand how what he's learning is related to real life. Instead of paying attention in class, he takes pens apart and switches the parts with mechanical pencils. He doesn't always complete his assignments.

Because his neighborhood is rough, his grandmother tries to keep him busy and engaged in lots of structured activities. He plays football at school and sometimes plays other sports with kids at the local Boys and Girls Club. He enjoys being on a team, but his enthusiasm, stubbornness and strong will can make it difficult for him to work with others. Jaylen is an "act first, think later" kind of guy. He often starts projects but doesn't finish them.

Learner Goals

Jaylen wants to:

* Have fun and explore something new
* Make something cool from scratch
* Do (not just read about) science

Program Objectives

This program should help Jaylen

* Understand how to apply math and science knowledge
* Develop flexibility in problem solving
* Use what he knows to create something original
* Understand what it takes to complete a project

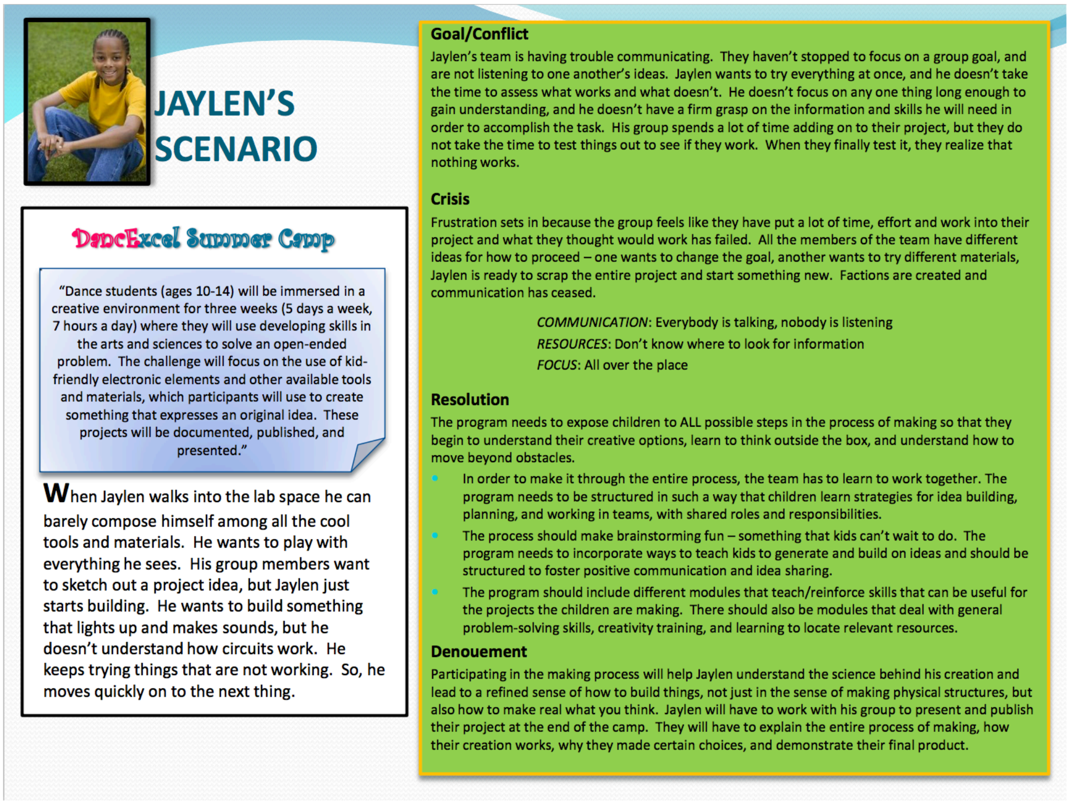
Personal Information

Age: 12

Hobbies/Interests: Dancer, likes to take things apart, plays football

Music/TV shows: Listens hip hop radio; likes animal shows on the Discovery Channel

Personality: Outgoing, never afraid to try new things, but thinks he knows more than he does so he doesn't always listen; very likable, but gets in trouble a lot and doesn't always make good grades because of his daring and highly inquisitive nature; very intelligent



JAYLEN'S SCENARIO

DanceExcel Summer Camp

"Dance students (ages 10-14) will be immersed in a creative environment for three weeks (5 days a week, 7 hours a day) where they will use developing skills in the arts and sciences to solve an open-ended problem. The challenge will focus on the use of kid-friendly electronic elements and other available tools and materials, which participants will use to create something that expresses an original idea. These projects will be documented, published, and presented."

When Jaylen walks into the lab space he can barely compose himself among all the cool tools and materials. He wants to play with everything he sees. His group members want to sketch out a project idea, but Jaylen just starts building. He wants to build something that lights up and makes sounds, but he doesn't understand how circuits work. He keeps trying things that are not working. So, he moves quickly on to the next thing.

Goal/Conflict

Jaylen's team is having trouble communicating. They haven't stopped to focus on a group goal, and are not listening to one another's ideas. Jaylen wants to try everything at once, and he doesn't take the time to assess what works and what doesn't. He doesn't focus on any one thing long enough to gain understanding, and he doesn't have a firm grasp on the information and skills he will need in order to accomplish the task. His group spends a lot of time adding on to their project, but they do not take the time to test things out to see if they work. When they finally test it, they realize that nothing works.

Crisis

Frustration sets in because the group feels like they have put a lot of time, effort and work into their project and what they thought would work has failed. All the members of the team have different ideas for how to proceed – one wants to change the goal, another wants to try different materials, Jaylen is ready to scrap the entire project and start something new. Factions are created and communication has ceased.

COMMUNICATION: Everybody is talking, nobody is listening
RESOURCES: Don't know where to look for information
FOCUS: All over the place

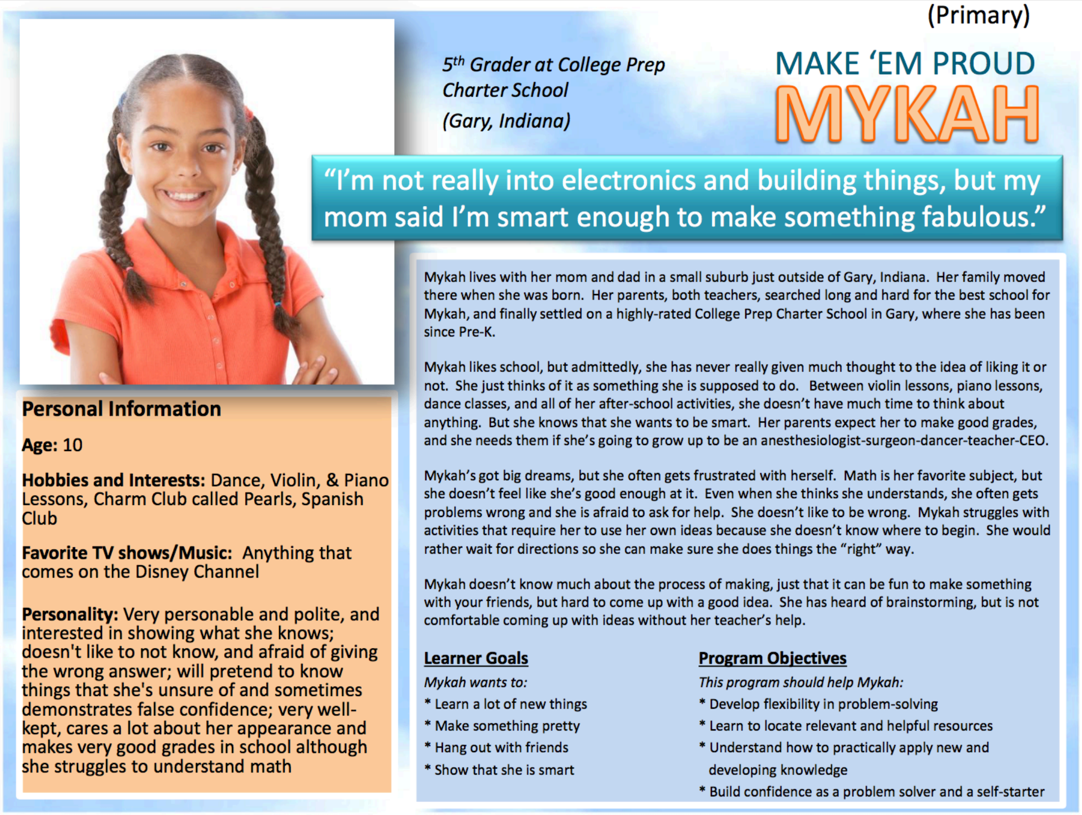
Resolution

The program needs to expose children to ALL possible steps in the process of making so that they begin to understand their creative options, learn to think outside the box, and understand how to move beyond obstacles.

- In order to make it through the entire process, the team has to learn to work together. The program needs to be structured in such a way that children learn strategies for idea building, planning, and working in teams, with shared roles and responsibilities.
- The process should make brainstorming fun – something that kids can't wait to do. The program needs to incorporate ways to teach kids to generate and build on ideas and should be structured to foster positive communication and idea sharing.
- The program should include different modules that teach/reinforce skills that can be useful for the projects the children are making. There should also be modules that deal with general problem-solving skills, creativity training, and learning to locate relevant resources.

Denouement

Participating in the making process will help Jaylen understand the science behind his creation and lead to a refined sense of how to build things, not just in the sense of making physical structures, but also how to make real what you think. Jaylen will have to work with his group to present and publish their project at the end of the camp. They will have to explain the entire process of making, how their creation works, why they made certain choices, and demonstrate their final product.



(Primary)

5th Grader at College Prep Charter School
(Gary, Indiana)

MAKE 'EM PROUD
MYKAH

"I'm not really into electronics and building things, but my mom said I'm smart enough to make something fabulous."

Personal Information

Age: 10

Hobbies and Interests: Dance, Violin, & Piano Lessons, Charm Club called Pearls, Spanish Club

Favorite TV shows/Music: Anything that comes on the Disney Channel

Personality: Very personable and polite, and interested in showing what she knows; doesn't like to not know, and afraid of giving the wrong answer; will pretend to know things that she's unsure of and sometimes demonstrates false confidence; very well-kept, cares a lot about her appearance and makes very good grades in school although she struggles to understand math

Mykah lives with her mom and dad in a small suburb just outside of Gary, Indiana. Her family moved there when she was born. Her parents, both teachers, searched long and hard for the best school for Mykah, and finally settled on a highly-rated College Prep Charter School in Gary, where she has been since Pre-K.

Mykah likes school, but admittedly, she has never really given much thought to the idea of liking it or not. She just thinks of it as something she is supposed to do. Between violin lessons, piano lessons, dance classes, and all of her after-school activities, she doesn't have much time to think about anything. But she knows that she wants to be smart. Her parents expect her to make good grades, and she needs them if she's going to grow up to be an anesthesiologist-surgeon-dancer-teacher-CEO.

Mykah's got big dreams, but she often gets frustrated with herself. Math is her favorite subject, but she doesn't feel like she's good enough at it. Even when she thinks she understands, she often gets problems wrong and she is afraid to ask for help. She doesn't like to be wrong. Mykah struggles with activities that require her to use her own ideas because she doesn't know where to begin. She would rather wait for directions so she can make sure she does things the "right" way.

Mykah doesn't know much about the process of making, just that it can be fun to make something with your friends, but hard to come up with a good idea. She has heard of brainstorming, but is not comfortable coming up with ideas without her teacher's help.

Learner Goals

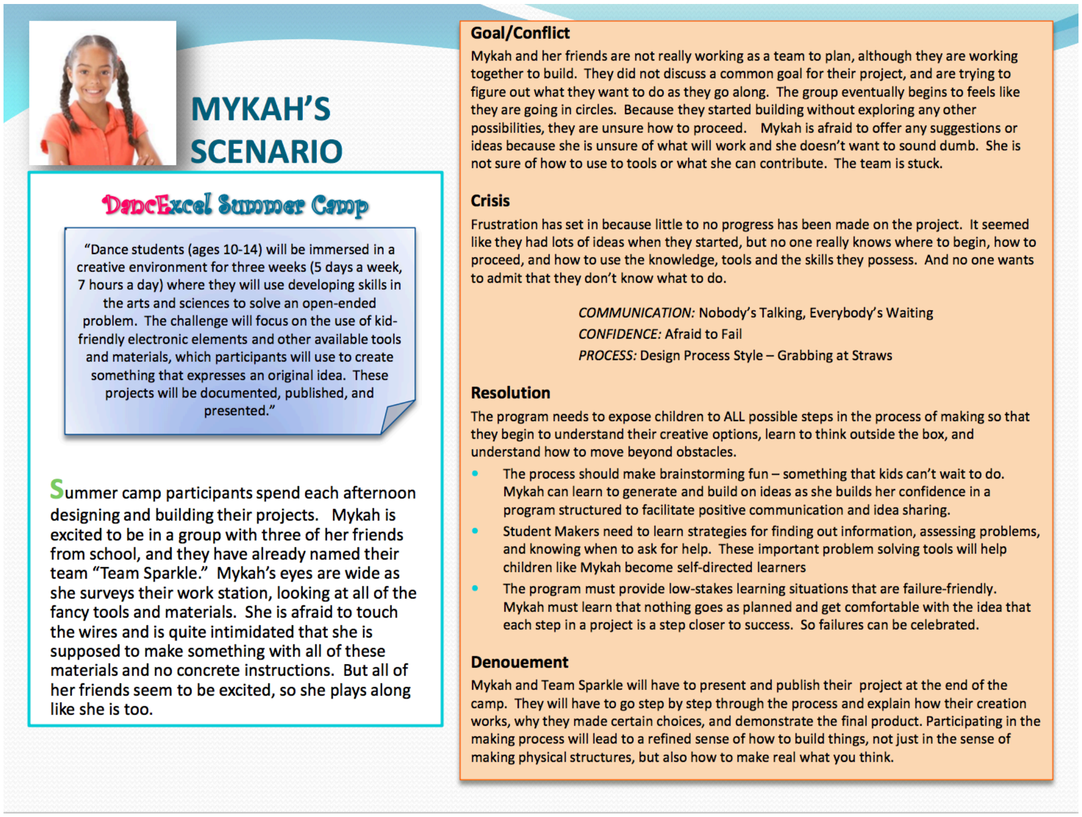
Mykah wants to:

* Learn a lot of new things
* Make something pretty
* Hang out with friends
* Show that she is smart

Program Objectives

This program should help Mykah:

* Develop flexibility in problem-solving
* Learn to locate relevant and helpful resources
* Understand how to practically apply new and developing knowledge
* Build confidence as a problem solver and a self-starter



MYKAH'S SCENARIO

DancExcel Summer Camp

"Dance students (ages 10-14) will be immersed in a creative environment for three weeks (5 days a week, 7 hours a day) where they will use developing skills in the arts and sciences to solve an open-ended problem. The challenge will focus on the use of kid-friendly electronic elements and other available tools and materials, which participants will use to create something that expresses an original idea. These projects will be documented, published, and presented."

Summer camp participants spend each afternoon designing and building their projects. Mykah is excited to be in a group with three of her friends from school, and they have already named their team "Team Sparkle." Mykah's eyes are wide as she surveys their work station, looking at all of the fancy tools and materials. She is afraid to touch the wires and is quite intimidated that she is supposed to make something with all of these materials and no concrete instructions. But all of her friends seem to be excited, so she plays along like she is too.

Goal/Conflict

Mykah and her friends are not really working as a team to plan, although they are working together to build. They did not discuss a common goal for their project, and are trying to figure out what they want to do as they go along. The group eventually begins to feels like they are going in circles. Because they started building without exploring any other possibilities, they are unsure how to proceed. Mykah is afraid to offer any suggestions or ideas because she is unsure of what will work and she doesn't want to sound dumb. She is not sure of how to use to tools or what she can contribute. The team is stuck.

Crisis

Frustration has set in because little to no progress has been made on the project. It seemed like they had lots of ideas when they started, but no one really knows where to begin, how to proceed, and how to use the knowledge, tools and the skills they possess. And no one wants to admit that they don't know what to do.

COMMUNICATION: Nobody's Talking, Everybody's Waiting
CONFIDENCE: Afraid to Fail
PROCESS: Design Process Style – Grabbing at Straws

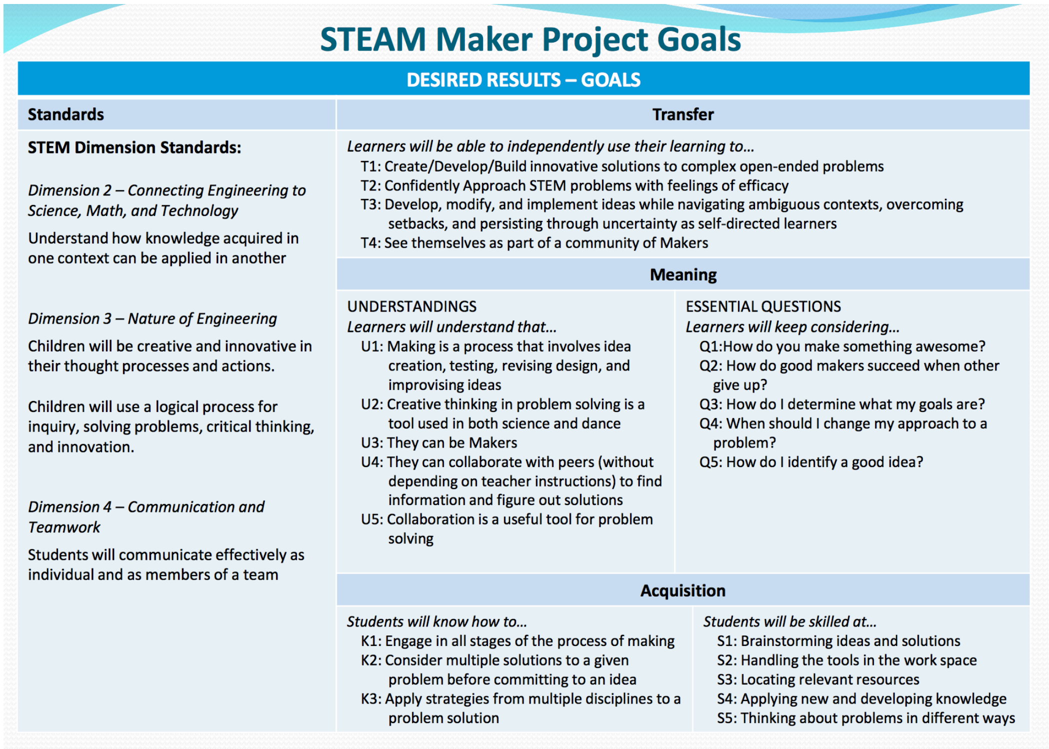
Resolution

The program needs to expose children to ALL possible steps in the process of making so that they begin to understand their creative options, learn to think outside the box, and understand how to move beyond obstacles.

- The process should make brainstorming fun – something that kids can't wait to do. Mykah can learn to generate and build on ideas as she builds her confidence in a program structured to facilitate positive communication and idea sharing.
- Student Makers need to learn strategies for finding out information, assessing problems, and knowing when to ask for help. These important problem solving tools will help children like Mykah become self-directed learners
- The program must provide low-stakes learning situations that are failure-friendly. Mykah must learn that nothing goes as planned and get comfortable with the idea that each step in a project is a step closer to success. So failures can be celebrated.

Denouement

Mykah and Team Sparkle will have to present and publish their project at the end of the camp. They will have to go step by step through the process and explain how their creation works, why they made certain choices, and demonstrate the final product. Participating in the making process will lead to a refined sense of how to build things, not just in the sense of making physical structures, but also how to make real what you think.



STEAM Maker Project Goals

DESIRED RESULTS – GOALS

Standards

STEM Dimension Standards:

Dimension 2 – Connecting Engineering to Science, Math, and Technology

Understand how knowledge acquired in one context can be applied in another

Dimension 3 – Nature of Engineering

Children will be creative and innovative in their thought processes and actions.

Children will use a logical process for inquiry, solving problems, critical thinking, and innovation.

Dimension 4 – Communication and Teamwork

Students will communicate effectively as individual and as members of a team

Transfer

Learners will be able to independently use their learning to…

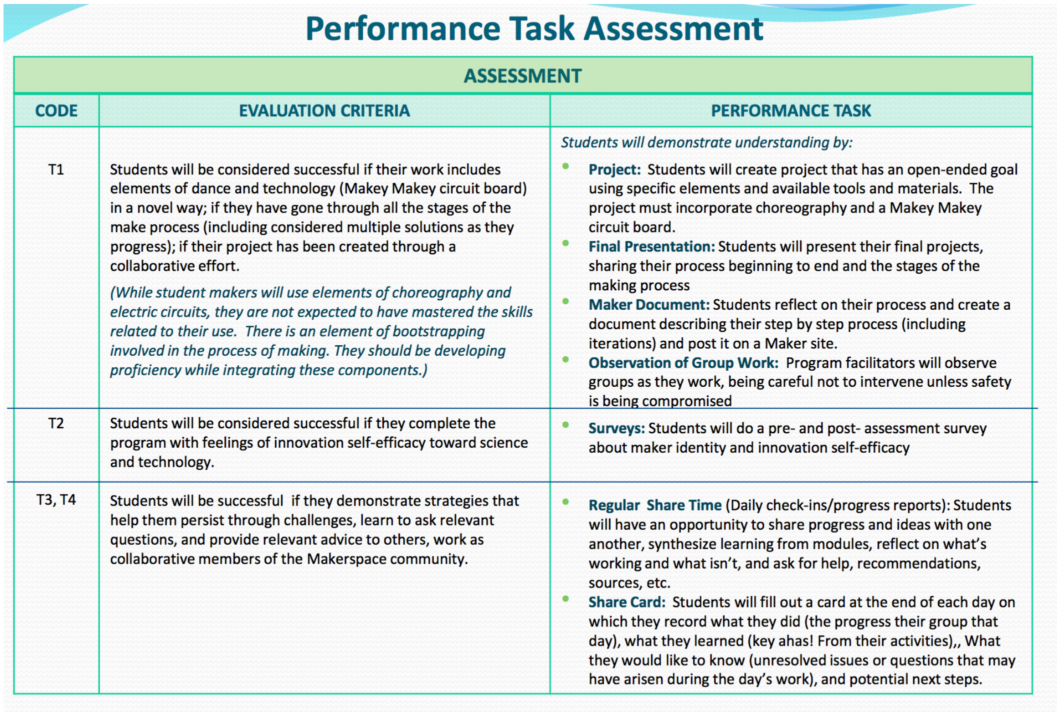
T1: Create/Develop/Build innovative solutions to complex open-ended problems
T2: Confidently Approach STEM problems with feelings of efficacy
T3: Develop, modify, and implement ideas while navigating ambiguous contexts, overcoming setbacks, and persisting through uncertainty as self-directed learners
T4: See themselves as part of a community of Makers

Meaning

UNDERSTANDINGS	ESSENTIAL QUESTIONS
Learners will understand that…	*Learners will keep considering…*
U1: Making is a process that involves idea creation, testing, revising design, and improvising ideas	Q1:How do you make something awesome?
U2: Creative thinking in problem solving is a tool used in both science and dance	Q2: How do good makers succeed when other give up?
U3: They can be Makers	Q3: How do I determine what my goals are?
U4: They can collaborate with peers (without depending on teacher instructions) to find information and figure out solutions	Q4: When should I change my approach to a problem?
U5: Collaboration is a useful tool for problem solving	Q5: How do I identify a good idea?

Acquisition

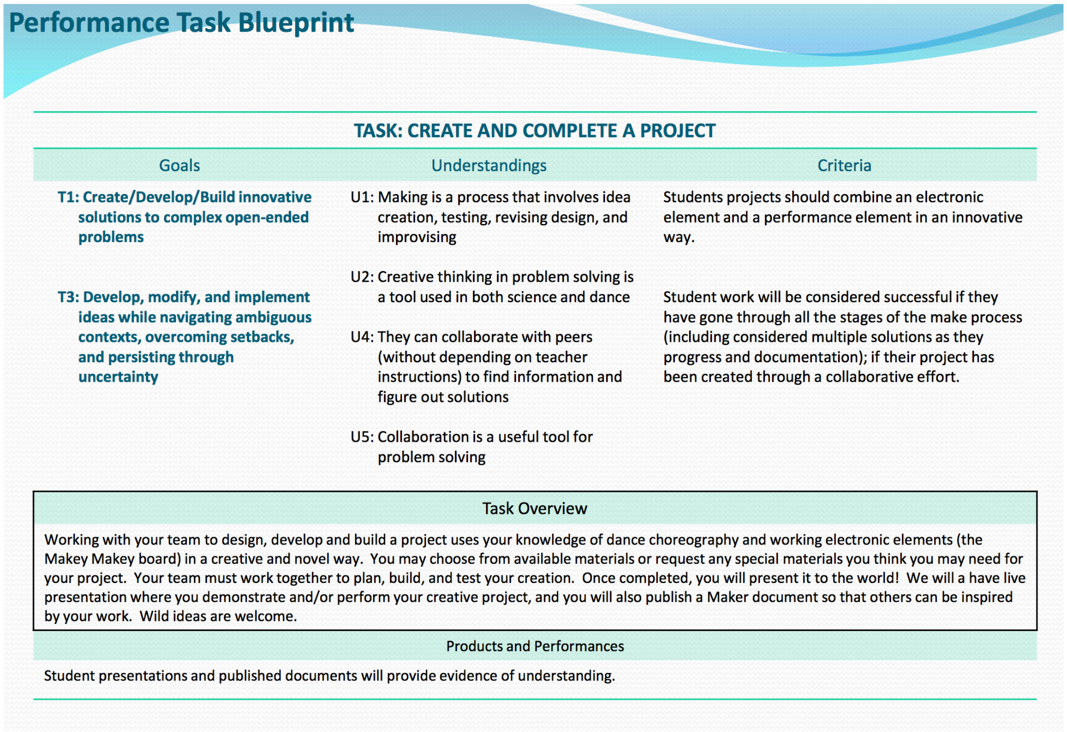
Students will know how to…	*Students will be skilled at…*
K1: Engage in all stages of the process of making	S1: Brainstorming ideas and solutions
K2: Consider multiple solutions to a given problem before committing to an idea	S2: Handling the tools in the work space
K3: Apply strategies from multiple disciplines to a problem solution	S3: Locating relevant resources
	S4: Applying new and developing knowledge
	S5: Thinking about problems in different ways



Performance Task Assessment

ASSESSMENT

CODE	EVALUATION CRITERIA	PERFORMANCE TASK
		Students will demonstrate understanding by:
T1	Students will be considered successful if their work includes elements of dance and technology (Makey Makey circuit board) in a novel way; if they have gone through all the stages of the make process (including considered multiple solutions as they progress); if their project has been created through a collaborative effort. *(While student makers will use elements of choreography and electric circuits, they are not expected to have mastered the skills related to their use. There is an element of bootstrapping involved in the process of making. They should be developing proficiency while integrating these components.)*	• **Project:** Students will create project that has an open-ended goal using specific elements and available tools and materials. The project must incorporate choreography and a Makey Makey circuit board. • **Final Presentation:** Students will present their final projects, sharing their process beginning to end and the stages of the making process • **Maker Document:** Students reflect on their process and create a document describing their step by step process (including iterations) and post it on a Maker site. • **Observation of Group Work:** Program facilitators will observe groups as they work, being careful not to intervene unless safety is being compromised
T2	Students will be considered successful if they complete the program with feelings of innovation self-efficacy toward science and technology.	• **Surveys:** Students will do a pre- and post- assessment survey about maker identity and innovation self-efficacy
T3, T4	Students will be successful if they demonstrate strategies that help them persist through challenges, learn to ask relevant questions, and provide relevant advice to others, work as collaborative members of the Makerspace community.	• **Regular Share Time** (Daily check-ins/progress reports): Students will have an opportunity to share progress and ideas with one another, synthesize learning from modules, reflect on what's working and what isn't, and ask for help, recommendations, sources, etc. • **Share Card:** Students will fill out a card at the end of each day on which they record what they did (the progress their group that day), what they learned (key ahas! From their activities),, What they would like to know (unresolved issues or questions that may have arisen during the day's work), and potential next steps.



Performance Task Blueprint

TASK: CREATE AND COMPLETE A PROJECT

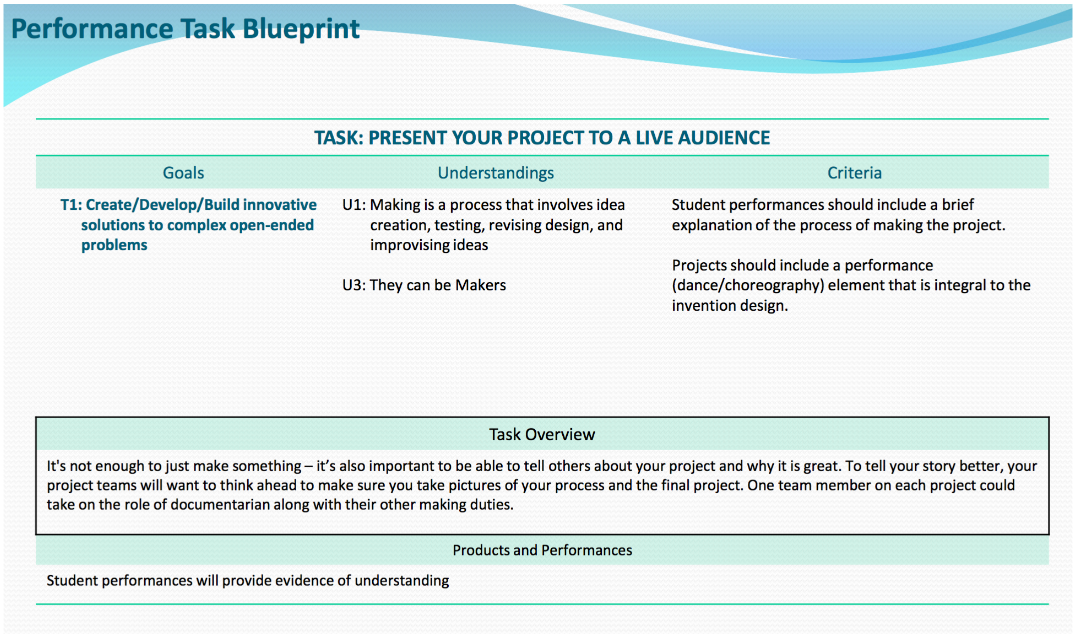
Goals	Understandings	Criteria
T1: Create/Develop/Build innovative solutions to complex open-ended problems	U1: Making is a process that involves idea creation, testing, revising design, and improvising	Students projects should combine an electronic element and a performance element in an innovative way.
T3: Develop, modify, and implement ideas while navigating ambiguous contexts, overcoming setbacks, and persisting through uncertainty	U2: Creative thinking in problem solving is a tool used in both science and dance U4: They can collaborate with peers (without depending on teacher instructions) to find information and figure out solutions	Student work will be considered successful if they have gone through all the stages of the make process (including considered multiple solutions as they progress and documentation); if their project has been created through a collaborative effort.
	U5: Collaboration is a useful tool for problem solving	

Task Overview

Working with your team to design, develop and build a project uses your knowledge of dance choreography and working electronic elements (the Makey Makey board) in a creative and novel way. You may choose from available materials or request any special materials you think you may need for your project. Your team must work together to plan, build, and test your creation. Once completed, you will present it to the world! We will a have live presentation where you demonstrate and/or perform your creative project, and you will also publish a Maker document so that others can be inspired by your work. Wild ideas are welcome.

Products and Performances

Student presentations and published documents will provide evidence of understanding.



Performance Task Blueprint

TASK: PRESENT YOUR PROJECT TO A LIVE AUDIENCE

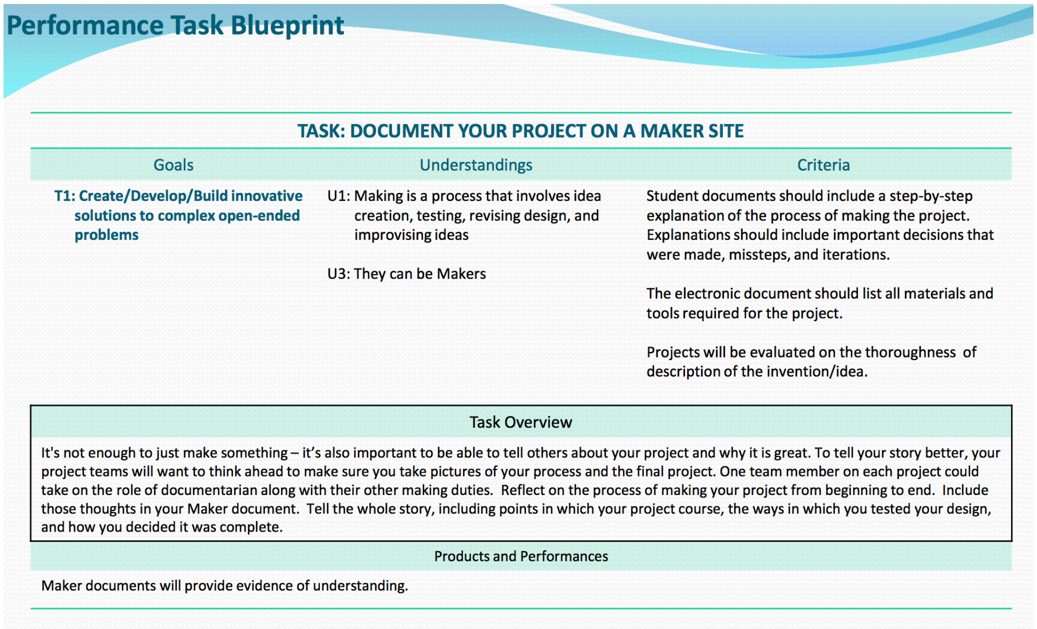
Goals	Understandings	Criteria
T1: Create/Develop/Build innovative solutions to complex open-ended problems	U1: Making is a process that involves idea creation, testing, revising design, and improvising ideas	Student performances should include a brief explanation of the process of making the project.
	U3: They can be Makers	Projects should include a performance (dance/choreography) element that is integral to the invention design.

Task Overview

It's not enough to just make something – it's also important to be able to tell others about your project and why it is great. To tell your story better, your project teams will want to think ahead to make sure you take pictures of your process and the final project. One team member on each project could take on the role of documentarian along with their other making duties.

Products and Performances

Student performances will provide evidence of understanding



Performance Task Blueprint

TASK: DOCUMENT YOUR PROJECT ON A MAKER SITE

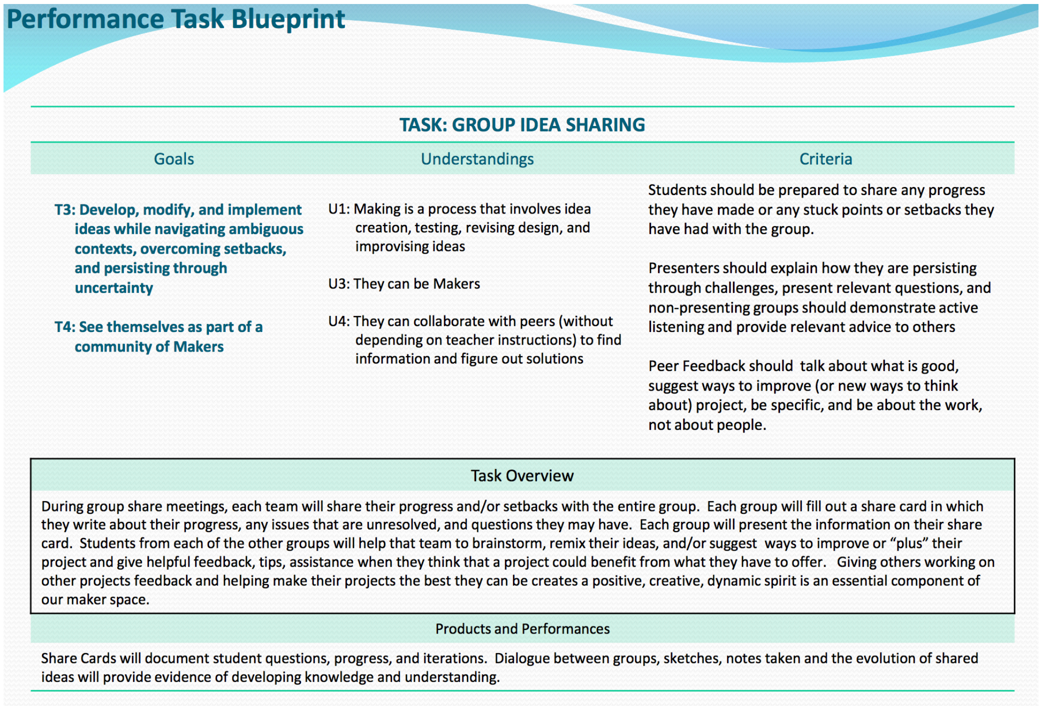
Goals	Understandings	Criteria
T1: Create/Develop/Build innovative solutions to complex open-ended problems	U1: Making is a process that involves idea creation, testing, revising design, and improving ideas U3: They can be Makers	Student documents should include a step-by-step explanation of the process of making the project. Explanations should include important decisions that were made, missteps, and iterations. The electronic document should list all materials and tools required for the project. Projects will be evaluated on the thoroughness of description of the invention/idea.

Task Overview

It's not enough to just make something – it's also important to be able to tell others about your project and why it is great. To tell your story better, your project teams will want to think ahead to make sure you take pictures of your process and the final project. One team member on each project could take on the role of documentarian along with their other making duties. Reflect on the process of making your project from beginning to end. Include those thoughts in your Maker document. Tell the whole story, including points in which your project course, the ways in which you tested your design, and how you decided it was complete.

Products and Performances

Maker documents will provide evidence of understanding.



Performance Task Blueprint

TASK: GROUP IDEA SHARING

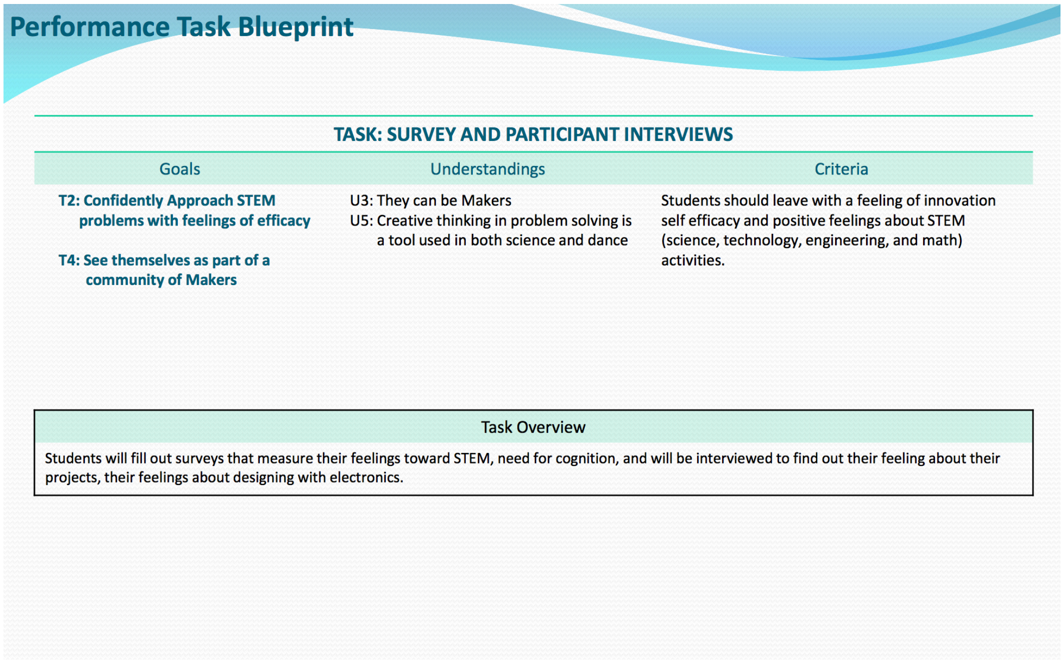
Goals	Understandings	Criteria
T3: Develop, modify, and implement ideas while navigating ambiguous contexts, overcoming setbacks, and persisting through uncertainty **T4: See themselves as part of a community of Makers**	U1: Making is a process that involves idea creation, testing, revising design, and improving ideas U3: They can be Makers U4: They can collaborate with peers (without depending on teacher instructions) to find information and figure out solutions	Students should be prepared to share any progress they have made or any stuck points or setbacks they have had with the group. Presenters should explain how they are persisting through challenges, present relevant questions, and non-presenting groups should demonstrate active listening and provide relevant advice to others Peer Feedback should talk about what is good, suggest ways to improve (or new ways to think about) project, be specific, and be about the work, not about people.

Task Overview

During group share meetings, each team will share their progress and/or setbacks with the entire group. Each group will fill out a share card in which they write about their progress, any issues that are unresolved, and questions they may have. Each group will present the information on their share card. Students from each of the other groups will help that team to brainstorm, remix their ideas, and/or suggest ways to improve or "plus" their project and give helpful feedback, tips, assistance when they think that a project could benefit from what they have to offer. Giving others working on other projects feedback and helping make their projects the best they can be creates a positive, creative, dynamic spirit is an essential component of our maker space.

Products and Performances

Share Cards will document student questions, progress, and iterations. Dialogue between groups, sketches, notes taken and the evolution of shared ideas will provide evidence of developing knowledge and understanding.

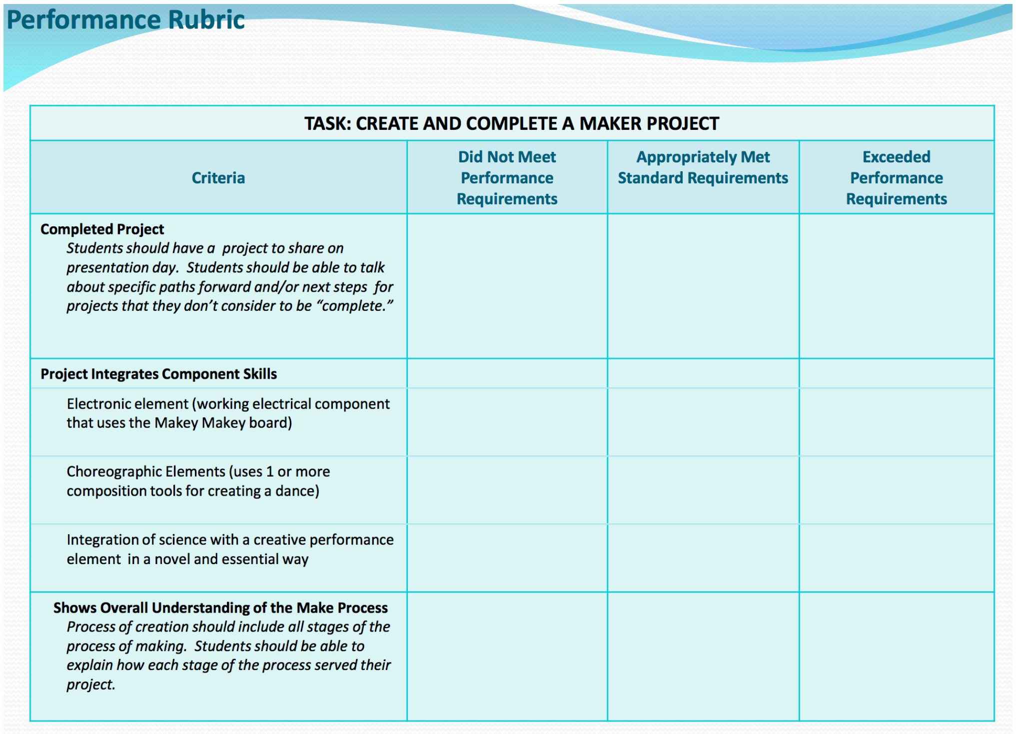


Performance Task Blueprint

TASK: SURVEY AND PARTICIPANT INTERVIEWS

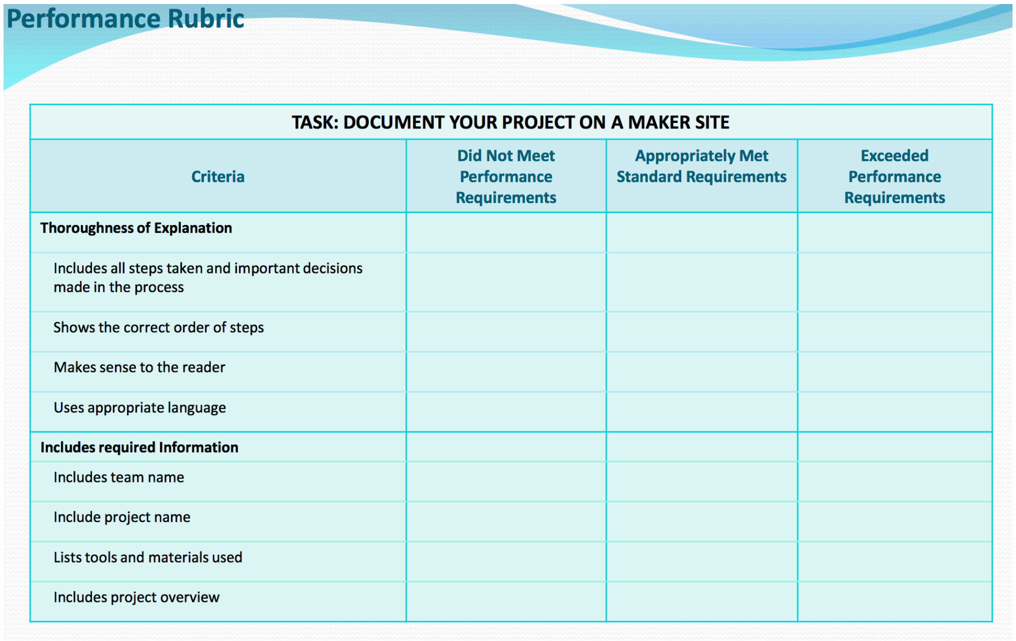
Goals	Understandings	Criteria
T2: Confidently Approach STEM problems with feelings of efficacy **T4: See themselves as part of a community of Makers**	U3: They can be Makers U5: Creative thinking in problem solving is a tool used in both science and dance	Students should leave with a feeling of innovation self efficacy and positive feelings about STEM (science, technology, engineering, and math) activities.

Task Overview
Students will fill out surveys that measure their feelings toward STEM, need for cognition, and will be interviewed to find out their feeling about their projects, their feelings about designing with electronics.



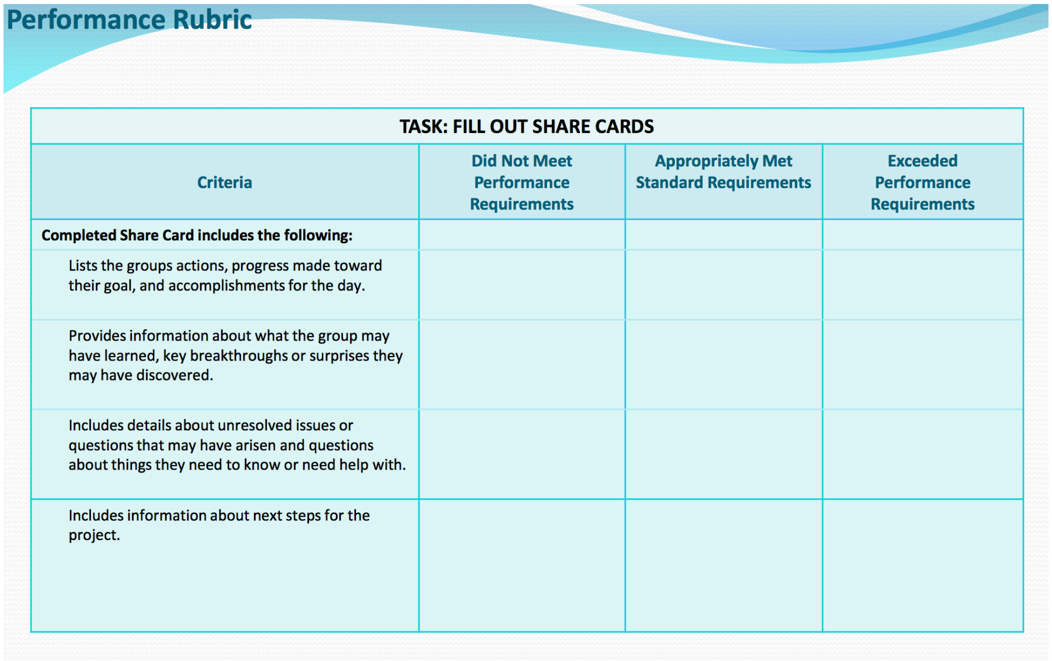
Performance Rubric

TASK: CREATE AND COMPLETE A MAKER PROJECT			
Criteria	Did Not Meet Performance Requirements	Appropriately Met Standard Requirements	Exceeded Performance Requirements
Completed Project *Students should have a project to share on presentation day. Students should be able to talk about specific paths forward and/or next steps for projects that they don't consider to be "complete."*			
Project Integrates Component Skills			
Electronic element (working electrical component that uses the Makey Makey board)			
Choreographic Elements (uses 1 or more composition tools for creating a dance)			
Integration of science with a creative performance element in a novel and essential way			
Shows Overall Understanding of the Make Process *Process of creation should include all stages of the process of making. Students should be able to explain how each stage of the process served their project.*			



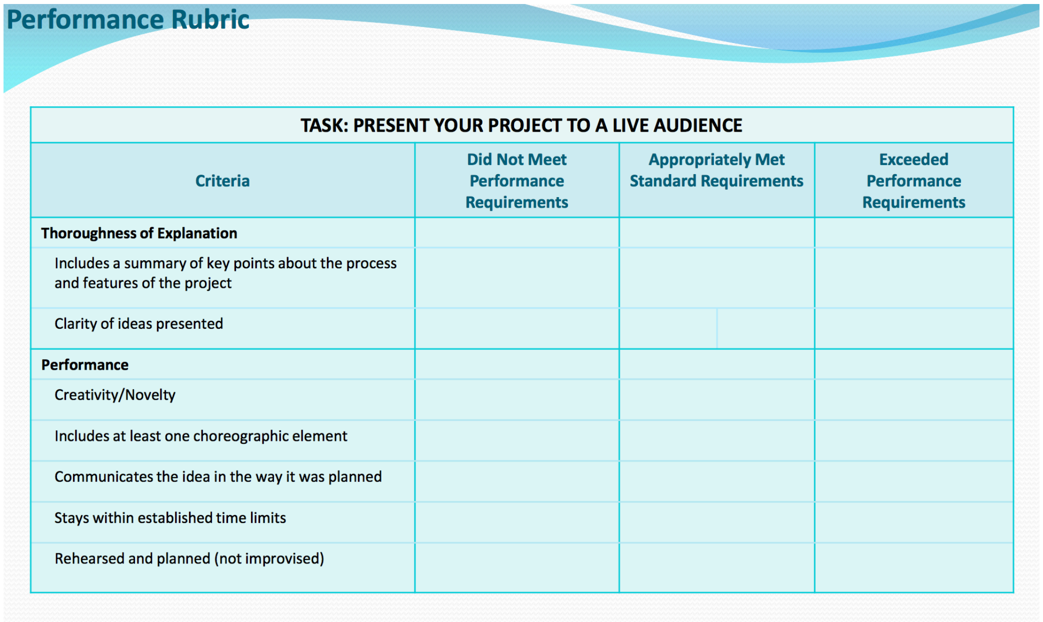
Performance Rubric

TASK: DOCUMENT YOUR PROJECT ON A MAKER SITE			
Criteria	Did Not Meet Performance Requirements	Appropriately Met Standard Requirements	Exceeded Performance Requirements
Thoroughness of Explanation			
Includes all steps taken and important decisions made in the process			
Shows the correct order of steps			
Makes sense to the reader			
Uses appropriate language			
Includes required Information			
Includes team name			
Include project name			
Lists tools and materials used			
Includes project overview			



Performance Rubric

TASK: FILL OUT SHARE CARDS			
Criteria	**Did Not Meet Performance Requirements**	**Appropriately Met Standard Requirements**	**Exceeded Performance Requirements**
Completed Share Card includes the following:			
Lists the groups actions, progress made toward their goal, and accomplishments for the day.			
Provides information about what the group may have learned, key breakthroughs or surprises they may have discovered.			
Includes details about unresolved issues or questions that may have arisen and questions about things they need to know or need help with.			
Includes information about next steps for the project.			



Performance Rubric

TASK: PRESENT YOUR PROJECT TO A LIVE AUDIENCE			
Criteria	**Did Not Meet Performance Requirements**	**Appropriately Met Standard Requirements**	**Exceeded Performance Requirements**
Thoroughness of Explanation			
Includes a summary of key points about the process and features of the project			
Clarity of ideas presented			
Performance			
Creativity/Novelty			
Includes at least one choreographic element			
Communicates the idea in the way it was planned			
Stays within established time limits			
Rehearsed and planned (not improvised)			

Unit Design

The Maker movement and Do-It-Yourself (DIY) culture celebrates innovation, creativity, and community engagement centered on hands-on creation. The purpose of this Makerspace summer intensive program is to get children engaged in the process of making with circuit boards in order to help them explore and deepen their understanding of the relationships between science, technology and dance. By studying this designed environment, I hope to determine the characteristics of a Makerspace for the purposes of developing interest in STEM in the context of an informal arts-based learning environment.

Design Question:
What are the characteristics of a Makerspace designed for the purposes of teaching young dancers to build innovative STEM solutions to complex open-ended problems in the context of an informal arts-based environment?

Design Argument:
In order to design a Maker-focused program for the purposes of teaching kids to build innovative STEM solutions to complex problems in the context of a dance (arts program):

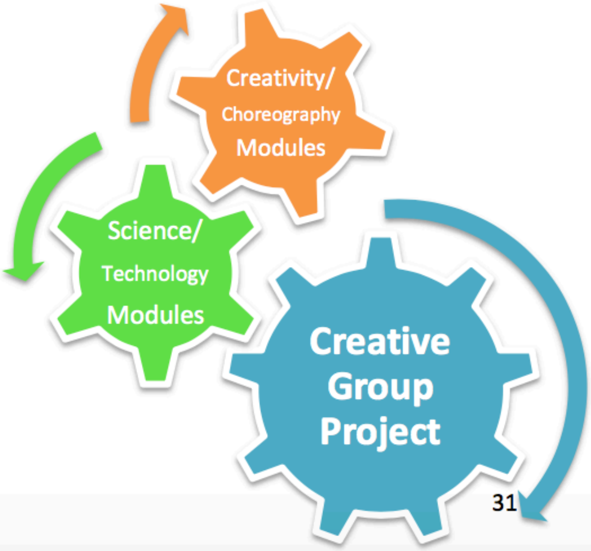
- Immerse learners in an engaging environment that provides hands-on opportunities for learning and opportunities to construct their own ideas by playing with ideas, materials, and tools;
- Provide opportunities to not only learn component skills, but to practice integrating them, and to make choices about how and when to apply what they have learned;
- Make learning relevant to students' needs and wants.
- Provide lots of opportunities to iterate in an environment in which failure is embraced as a part of the process;
- Create an integrated learning system in which facilitators and students can collaborate, pooling their skills and knowledge and sharing in the tasks of teaching and learning;

General Approach
The program goals are grounded in an open-ended problem solving context and centered around learning the process of making and also learning *through* the process of making. Student work will focus on the tasks of designing, building, improving, and revising ideas until projects are complete. The general approach is to guide children through their own processes of discovery, providing supplemental support in the form of modules that allow them to construct and extract understandings and apply them to the projects they create.

Daily schedule
Students will participate in two modules each morning, one devoted to science/technology concepts and the other devoted to creativity and choreography. The modules will provide basic information and examples of concepts that might be useful to makers as they design and build their projects. Afternoon activities will include group share time and make time.

9:00-9:45	**Dance Warm Up/Technique (Focus on few usable skills)**
9:50-10:35	**Science/Technology Module**
10:35-10:45	SNACK
10:45-11:30	**Choreography/Creativity Module**
11:30-12:15	LUNCH
12:15-1:00	**Group Share/Progress Report**
1:00-1:45	**Make Time***
1:45-2:30	**Make Time***
2:30-2:45	SNACK
2:45-4:00	**Make Time***
4:00	Dismissal

* Each team will have a specific time allotted during one of these periods to work on the computer (have access to the Internet). Children are free to access their own Internet-ready devices at any time, but an equal amount of computer time will be given to each group to ensure that they have the time and space to search for ideas and information if needed.



Immersion in an Engaging Environment

Motivation is a key factor in determining what students learn, how they engage in a learning environment, and the length and depth of their participation. Educational researchers propose that engagement is a multidimensional construct including behavioral engagement (actively performing learning activities), cognitive engagement (using cognitive strategies to foster deep learning), and affective engagement (expressing enjoyment about learning) (Fredericks, Blumenfeld & Paris, 2004). Makerspaces offer opportunities for all three facets of engagement by providing authentic, real-world challenges that connect to students' interests and require complex problem solving. The designed environment should provide opportunities for learning through meaningful play and experimentation, to solve problems using a variety of media and tools. Educators and students need to give themselves time and space to play. According to the framework for Participatory Learning (2012) a "magic circle" is created around play exercises, which suspends real world consequences and allows participants to take chances, and supports trial and error, believed valuable for learning. Play is not simply something we do; it also describes the mental attitude we bring with us to the activity. According to learning research, motivated behavior is a result of positive outcome and efficacy expectancies (Reilly et al. 2012).

Learning Component Skills

In order to constructively engage in the process of making, students will need to apply prior knowledge and may need to apply new knowledge and understandings. Research has shown that it is beneficial for students working toward domain mastery to develop "key component skills, practice them to the point where they can be combined fluently and used with a fair degree of automaticity, and know when and where to apply them appropriately" (Ambrose, 2010). Modules are designed to give students opportunities to develop and reinforce relevant component skills in a simpler context than is provided during "Make time." The modules should serve as a solid introduction to important concepts and provide early opportunities for success with activities that require using these concepts, which will be reintegrating during "Make time" with help from mentors, older and more experienced makers who also going through the process of project making integrated into the working groups as "knowledgeable peers" (Cole, 2009).

Modules Feed into the Make Time Activities

Relevant to Student Wants and Needs

When students find school meaningful, they tend to do well. When students are interested in something, they tend to pursue it and excel at it. The program design needs to incorporate students' interests, and provide opportunities for flexibility, and allow them to chart their own course. Makers will be provided with a suggested end point, and then, along with their groups members, create a plan for achieving their goal. Students will be encouraged to seek out information, help and guidance as they need it, include ideas and materials that reflect their interests, and bring their projects to completion through their own chosen strategies.

Fail-Safe Environment

According to the Participatory learning framework for informal learning environments (2012), making requires that children be given opportunities to "experiment creatively and fail productively." Participants in a Makerspace community play and learn from each other in a fail-safe environment where all are encouraged to share in a knowledge exchange. In the process of making, the focus is not necessarily on designing an end product. The point is to discover as much as you can through the process - to learn how things work by playing around with ideas, to think and learn about things by DOING, and to make something creative in the process. In this context, failure (or not getting something right the first time you try it) becomes an important part of the learning process. Fostering a safe space for experimentation, exploration and play is a key aspect of idea generation, allows makers to take chances, and supports the process of trial and error that leads to innovative thinking and discovery.

Co-learning

The role of the facilitator is to lead the training modules and guide the students toward project completion. Facilitators should "create the conditions for invention rather than provide ready-made knowledge" (Papert, 1993). Children should be given the opportunity to investigate through creating and designing using real life products, tools, and applications. The facilitator should set targets and only guide the children towards the correct path. While students need to be constantly reminded to integrate learning across contexts, facilitators should allow students to learn by doing and seek to foster a collaborative atmosphere where students can pool their resources, share their skills, and share in the tasks of teaching and learning. In this context, learning becomes a negotiation and collaboration between participants, where different perspectives are valued and respected.

Community

Situated learning theory defines learning as a socio-cultural activity that is central to human identity, as individuals experience identity development through participation in communities of practice (Wenger, 1999). The characteristics, traditions, and values of a community are embodied in practices, which shape cultural understanding and social structures within the group. Hence, as members perfect community practices, they are concurrently "learning to be." As students practice their roles as makers in the context of a community Makerspace, they will develop a maker identity and self-efficacy toward the process. Community participation engages a variety of strategies that encourage explanation and deeper understanding (Martin, 2004).

Unit Elements

Modules

✱	**Electricity/Energy Transfer Module:** What is electricity? How do we use it? What makes something conductive or insulating? This introductory module teaches students about static electricity, electric charge, and conductivity. Students will express and build on prior knowledge by constructing a KWL Chart, and follow a recipe to make conductive and insulating Playdoh. Week two will focus on Energy Transfer and Circuits. Students will learn about a complete circuit, and construct complete circuits using conductive paint, and constructing squishy circuits (from the homemade Playdoh).	**E1** **A**
✱	**Creativity Training:** Children will play with tools and ideas while taking on mini-tinkering challenges. This module includes a demo of the littleBits open source electronics. Students will be shown a littleBits starter project and introduced them to the littleBits project site for inspiration. Then, they will be given time and space to play around to make something of their own. Later, they will go through a MaKey MaKey Tutorial and be introduced to a "musical fruit" project. They will spend time deconstructing and reinventing the project using the MaKey MaKey.	**W, H**
✱	**Using Tools in the Lab:** Facilitators will discuss lab safety, how to use tools in the lab, the importance of wearing safety glasses, rules for using scissors, box cutters, sharp objects, screwdrivers, hammers, glue gun, and injury procedures. Children will discuss why safety, trust, respect, and responsibility are important in the Makerspace.	**E1** **A**
✱	**Organizing Ideas:** Students will use concept mapping to organize the ideas they want to present about their projects. They will identify the they have learned about through the process of making their projects, the procedures taken, then use a storyboarding concept to order their steps with post-it notes on a large poster board and select pictures that correspond to each step. They will use the storyboard to create an electronic document.	**R** **A**
✱	**Choreographic Composition Tools:** Students will use composition tools to make their ideas come to life, create movement phrases from sentences, stories, and ideas, and shape them by varying elements of body, space, and time. The module will focus on the following tools: Narrative, Accumulation, Inversion & Retrograde, Rotation, Mirroring & Symmetry, Dynamic Quality, and Brainstorming through Improvisation.	**E1** **A, M**
✱	**Creative vs. Scientific Thinking:** Students will be prompted to creatively answer a question or solve a problem about energy flow through circuits using multiple methods. "How does energy flow through a circuit?" They will explore a scientific explanation, draw out a complete circuit, and create an explanation using movement, dance, and people. They will create movement phrases about Energy Transfer (using the Energy Stick). We will discuss analogies between dance and science problem solving strategies.	**E1** **M, T**

Group Share/Brainstorming

During group share meetings, each team will share their progress and/or setbacks with the entire group. Students from each of the other groups will help that team to brainstorm, remix their ideas, and/or suggest ways to improve or "plus" their project and give helpful feedback, tips, assistance when they think that a project could benefit from what they have to offer. Giving others working on other projects feedback and helping make their projects the best they can be creates a positive, creative, dynamic spirit is an essential component of our maker space.

Brainstorming Activity: During Group Share on the first days of the camp, the children will participate in a brainstorming activity to help them learn to generate ideas. Facilitators will challenge the group to see how many different project ideas they can come up with in 5 minutes (as an entire group). The goals should be to generate 20 or more ideas. The activity will be introduced as a game with a prize for each group (some kind of special material to work with) if they produce more than twenty ideas. All ideas will be written on post-it notes. Children will work together to rank the ideas from easy to hard and discuss possible ways in which to implement their ideas.	**M**
Share Card: Students will fill out a share card each day that explains: "What we did," "What we learned," and "What we're going to do next." During the daily group share time, each team will share the progress they've made, the challenges they are facing, the questions they have and need answered in order to continue. The other groups listen and provide critical feedback, resources, and suggestions.	**R, E2**
Idea Remix: On Tuesdays and Thursdays, the Group Share activity will be an idea remix in which each group is given two ideas randomly selected from the initial brainstorming session and asked to them combine them given a randomly selected constraint (i.e. must include magnets, must be silver, can use no paper products). Students will sharpen their creative thinking skills and might even provide some useful ideas for their projects.	**M**
Peer Critique: Students will be introduced to the process of peer critique. Each student will receive a handout with the rules of peer critique (1. Start out by stating something positive. What is good about the project? 2. Talk about how it can be improved. 3. Be specific. 4. Talk about the work, not about people.) These rules will be discussed and enforced and students use them to give feedback to other teams.	**R, E2**

Make Time (WHERTO) (A, **M, T)**
To develop mastery, students must not only acquire component skills, but practice integrating them, and know when to apply what they have learned. Modules give students an opportunity to develop understanding of component knowledge and skills. The practice of making provides an opportunity to choose which skills may be relevant to their projects and to apply what they have learned immediately and directly. *Make Time* will provide creative time and space for children to build prototypes, explore questions, fail and retry, bounce ideas off one another and build something together and allow for ongoing assessment. Projects will be defined so that students have the opportunity to succeed through a route of their own choosing. Students must decide what the final solution will be, what constraints will be met, and the path to get there. They will need to plan to have certain pieces of the project completed along the way. If a solution doesn't work the first time, students must analyze the failure and assess what happened, why it happened, and consider what to do differently. They must also document the process, taking pictures of each step, and taking notes about the important choices that you made, the materials you used, what worked and what didn't.

MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
Day 1	Day 2	Day 3	Day 4	Day 5
Static Electricity & Conductivity	**Conductive & Insulating Playdoh**	**Creativity Training with littleBits**	**Using Tools in the Lab**	**Creativity Training Toy Hacking/Upcycling**
Making Ideas Come to Life	**Making Ideas Come to Life 2**	**Dance Composition Tools**	**Brainstorming through Improv**	**Dance Composition Tools 2**
Day 6	Day 7	Day 8	Day 9	Day 10
Creativity Training with MaKey MaKey	**Energy Transfer (Drawing Circuits)**	**Energy Transfer (Squishy Circuits)**	**Energy Transfer (MaKey Makey)**	**Energy Transfer (Makey Makey)**
Creating Dances about Energy	**The Energy Stick**	**Creative vs. Scientific Energy Transfer**	**Creating Dances about Energy**	**Creating Dances about Energy**
Day 11	Day 12	Day 13	Day 14	Day 15
Organizing Ideas (Think like a scientist)	**Review of Concepts**	**Help with Documenting the Process**	**OPEN**	**OPEN**
Incorporating Dance into Make Projects	**Incorporating Dance into Make Projects**	**Incorporating Dance into Make Projects**	**Finalize Web Documents**	**OPEN** **6:00 Final Presentations**

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STEAM Makerspace Lesson Plan

Lesson Background

Lesson Designer/Instructor: Dionne N. Champion
Date: May 25, 2013
Test Audience: DancExcel students, ages 9-12

Title of Lesson: Creativity Training Module

Goals:

The primary goal of this lesson is to hook novice makers on the idea of building with electronic components. Students will become familiar with key components of a circuit and build a creative project that includes a simple, functional electronic circuit using littleBits, a kid-friendly, open source collection of electronic modules that snap together with magnets. Through the process of "playing" with circuits, participants should begin to develop innovation self-efficacy (Gerber, 2011), become excited about the possibilities of what they can build, and come to see themselves as Makers. This lesson should provide the foundation for young makers to develop their more extensive group projects and to come to believe that STEAM is not for someone else – it's for them.

Rationale:

This lesson comes early in the trajectory of the program. It is designed to build confidence through immediate positive feedback in order to motivate and sustain students' interests in building with electronics. Providing an authentic, real-world task will help to establish value for students, and the flexible nature of the task offers opportunities for early success.

Learners are naturally motivated by the belief that they can achieve a goal. Working with the littleBits offers affordances that increase the possibility of successful outcomes and thus goal achievement. The ten color-coded modules, each with one simple and unique function (i.e. led light, blinker, dimmer, buzzer), snap together magnetically to create larger circuits; the magnets prevent children from connecting components incorrectly, and allow them to create, combine, and change components without wiring, soldering, or programming. Students should not only develop positive outcome expectancies through their engagement with the litteBits modules, but also develop the efficacy expectancies that are necessary for motivated behavior (Ambrose, 2011). This is essential because students' motivation determines, directs, and sustains what they do to learn, and positive feedback from innovative actions builds the confidence that leads to innovative behavior (Gerber, 2011).

Relationship to the Standards:

This lesson connects to Dimension 3 of the National STEM Standards: the Nature of Engineering –

- Children will be creative and innovative in their thought processes and actions.
- Children will use a logical process for inquiry, solving problems, critical thinking, and innovation.

CREATIVITY TRAINING MODULE **LESSON 1**

Introduction

In this lesson students will be introduced to the idea of making with electronic components. They will be prompted with a design challenge, introduced to the electronic components that will help them begin to think about designing with electronics, and allowed to tinker in order to discovery multiple solution possibilities.

Learning Objectives

By the end of the module, students should:

- See themselves as capable of creating a project with a functional electronics component
- Be able to identify some components of a circuit
- Be able to share and ready to consider multiple project ideas

Key Messages

- An electric circuit needs a power source.
- Energy flows from one component to the next, beginning with the power source.
- You are only limited by your ideas.
- Test early, test often.

Time Needed – 45 minutes
Prep Time – 15 minutes

Materials

- littleBits open source hardware/littleBits Starter Kit
- Arts and Craft Supplies: construction paper, cardboard, glue, scissors, popsicle sticks, tape, foam paper, pencils, paint, paintbrushes, computer (with Internet)
- Recycled materials: Water bottles, styrofoam

Prep

Set up building materials in the workspace. Make sure that all materials that will be needed are readily available to students. Set up any sample projects that you may have. Cue video of sample projects (youtube, litteBits.com).

Procedure

Steps	Expected Student Response	Teacher Response
1. Prompt with a design challenge: "Create a project lights up, makes a sound, or uses electricity in a cool way" Have students share ideas for solutions.	Students will give generic responses and may demonstrate false confidence. Students may be unsure of what to say or do.	Ask questions for clarification of their thoughts and ideas. Get them to be as specific as possible.
2. Show examples of projects done with littleBits (by kids who are in their age range)	"Cool!" "I want to try that!" "How did they do that?" "Wow"	
3. Let students try to create a circuit and figure out what each module does.	Students may fumble a little to get the components to work together, but it shouldn't take long for them to figure out.	Observe and let them play.
4. Present solutions and discuss	Children will generate naïve theories about conductivity, and how each component works. They my say things that already know, or things that they figured out from playing around the circuit components.	Pull out key ideas, clarify.
5. Learn to make a simple project	Students follow step by step instructions given by the instructor.	Keep students on task.
6. Generate 10 new project ideas	Students should be able to come up with 2-3 ideas easily; it may be a little challenging to come up with 5-6 ideas; it may be a struggle to come up with 9-10.	Offer prompts to help with brainstorming.
7. Students create their own simple projects	Students should work on a specific idea. They may stumble a little through the process of designing and building their idea and may change their minds a few times before settling on a final idea.	Observe them and let them play.
8. Students summarize learning (Share Card)	Students will share what they did, what they learned, and what they still want to know.	Ask questions for clarification of their thoughts and ideas. Get them to be as specific as possible.
9. Repeat the design challenge… discuss ideas for solutions	Students should have more ideas, their ideas should integrate circuits in a meaningful way.	Ask questions for clarification of their thoughts and ideas. Get them to be as specific as possible.

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Gerber, E. (2011). Innovation Self-Efficacy: Fostering Beliefs in Our Ability Through and By Design.

http://www.nysstemeducation.org/STEM_Docs/2012K-12STEM_in_USA.pdf

* Data will be collected on:

- The differences between students' initial and final responses to the project prompt. Do their responses reflect more of an understanding of how to integrate circuits into the project? Do they demonstrate more confidence in their ability to imagine creative project possibilities?

- The facilitator's interactions with students. Does the instructor allow adequate time and space for children to envision and develop their ideas? Does the instructor offer guidance without leading students with too much information? Do students have enough guidance to act? Are they developing understanding?

Lesson Observation Log

Title of Lesson: Creativity Training with littleBits

Goals of the Lesson:

By the end of the module, students should:

- See themselves as capable of creating a project with a functional electronics component
- Be able to identify some components of a circuit
- Be able to share and ready to consider multiple project ideas

Observation Objectives:

Our team will collect data on:

- The differences between students' initial and final responses to the project prompt. Do their responses reflect more of an understanding of how to integrate circuits into the project? Do they demonstrate more confidence in their ability to imagine creative project possibilities?

Outside observers are asked to collect data on:

- The facilitator's interactions with students. Does the instructor allow adequate time and space for children to envision and develop their ideas? Does the instructor offer guidance without leading students with too much information? Do students have enough guidance to act? Are they developing understanding?

* The lesson was conducted with two groups of students. Each group was made up of three students.

- **Group A: Current 4th-6th graders, ages 9-11**
- **Group B: Current 7th-9th graders, age 13-14**

Observations from both groups were consolidated into one data log below:

Time	Observation	Significance
0.30	When asked if they could create a project that lit up or made a sound, younger students responded by expressing confidence that they could build projects that made sounds. However, the examples they gave involved things in which they used their bodies to create the sounds (i.e. hand-clapping, tapping a pencil, or rubbing hands together) There was a long pause with the older students. Instructor did not intervene, just let them sit quietly and think. Finally after about 1 minute, one of the students asked a question.	Did not connect making a project that moved or had a function with needed electric power.
1:30	**Student 1:** "Can it be something that glows in the dark?" Instructor responds, "It can be anything you want." Instructor's response leads to discussion among the teens. **Student 2:** "This is exciting because you can make anything you want." **Student 3:** But it scares me because I'm thinking inside the box still." **Student 2:** "The electricity part is hard. I'm not good at science. I need a basic understanding of wiring." **Student 3:** "I need some batteries and a light bulb" **Student 1:** "I need a firefly." **Student 2:** "I want to make something that's like a DJ something… a turntable that glows in the dark and makes music." **Student 3:** "I want to make a music box that lights up… I figured out how it makes noise with the rubber bands… if you put the rubber bands in a certain way…" **Student 1:** "I want to make a lamp that lights up when you rub your feet on the floor." (They are generating ideas, but their ideas don't seem to be very well grounded in feelings of competence.)	Their responses demonstrate imagination but not necessarily efficacy.
2:05	Group A watches videos to see examples of projects they can make using electric circuits. **Student 1:** **"**Oh, wow! That's cool!" **Student 2:** So that's what you mean. I didn't get how to use like the batteries and lights and stuff." **Student 3:** "Wow. That kid is only in the third grade? That's a cool project."	Students begin to get excited and see real concrete project possibilities
4:00	Group B watches the video, students begin coming up with other materials that they want to use. **Student 3:** "Oh yeah, I would like to use some clay."	
7:00	Instructor shows the students how the littleBits modules work by connecting the first bit to the battery and each additional bit in series. **Student 1:** "That makes it go faster and slower…" **Student 2:** "Cool! The light comes on when you plug it in." **Student 3:** "That one is a buzzer!"	Students have an opportunity hypothesize about what's happening and how the system works.
9:10	Instructor introduces littleBits components and demonstrated how a few of the bits worked with one another. Then, students were instructed to play around with the bits and figure out how they worked. They played around with them for about five minutes. They discovered that the bits were magnets, and that they only fit together one way. They began reading the words to figure out what each bit does. They figured out that the pink modules are controllers and the green modules are outputs; that the blue is power. Student 1 is having trouble understanding how energy flowed through the components. She is trying to get the button to work, but is putting it at the end of the series. After about 15 seconds	

	of watching, the instructor intervenes by asking a series of questions: "What do you think is happening? What do you think each component does? Where is the energy coming from? How is it flowing?" She finally figures it out.	Instructor is trying to guide without telling the answer. When the student has to figure out the answer for herself, does this lead to better understanding?
14:15	They were prompted them to figure out what the screwdriver was for. It took them about two minutes to figure out the purpose of the screwdriver (to adjust the color of the lights or the speed of the pulse)	
17:01	Students work together to build something. They begin discussing their ideas. They want to build something with the vibrator but they are trying to figure out what to use and how to attach the vibrator. They decide on a monster. The instructor suggests they put paper inside the cup and cut eyes out then put a light inside so the eyes will light up. They agree it's a good idea and start to work on it.	Instructor offers advice when she assesses that students are at an impasse.
17:26	Instructor asks students to share what they've learned so far. The students explain what they have figured out: "the blue starts everything, the pink pieces are mechanisms to control the power, the green ones are the energy outputs, the lights and sounds."	Responses show a developing understanding of how the circuit component works.
27:35	As students were building, the instructor intervened to ask about how the dimmer switch they were using worked. They couldn't explain. Student 2 said something about it being connected in parallel series but quickly retracted that idea. The students were stumped. The instructor explained using an analogy about water flowing. The children could then explain that the energy flowed from the battery into each component and offered the analogy of a door that open and closes. Student 1: "So it's like a switch" "Oh… I have a dimmer in my house… and it's connected to a switch."	Students' responses reflected more of an understanding after the analogy of flowing water was given
20:17	Students began constructing a boat made of water bottles, tape, styrofoam, and blinking LED lights.	
35:43	Students reflect about their discoveries. They are excited about making their own individual projects. And explain in more detail how they would go about making them.	Students admit they have more confidence levels in their ability to make a project.
42:00	Students were prompted to come up with ten ideas for new projects. They doubted their ability to generate that many ideas, but it took only about 45 seconds for them to come up with the ten. They came up with an additional five before they ran out of ideas. They reflected on their experiences and admitted that they were far more confident about their ability to create an electronics project than they were when they began. Student 1: "I understand more how to use the electronics. At first, I thought I had to be a scientist to use electronics." Student 2: "Designing it got easier once I had the circuitry right there, and being able to see other people's projects and how simple they make it look is kind of inspiring and it gives you other ideas. And you're like why not." Student 3: "I didn't think I could do it before because me and science don't really get along. I think I would just keep trying stuff and it wouldn't work and I would just get frustrating; but now that I see I could use paper and other simple things, I feel like I can do it."	

Summary of Observations

The lesson seemed to meet the learning objectives. Students were able to see themselves as capable of creating a project with a functional electronics component. They were able to identify some of the functions of components of a circuit, and they were able to consider and share multiple project ideas. Students understand and could explain by the end of the lesson that an electric circuit needs a power source; that energy flows from one component to the next, beginning with the power source. Because this was an introductory lesson, its purpose was to hook students and to help them feel a level of efficacy about the idea of making their own electronics project.

While one key message of the lesson was to convey the message that students are only limited by their ideas, one of the key observations in this lesson was that students' imaginative efforts depend a lot on the materials that are readily available. It will be important to have enough materials and useful materials for prototyping with ease. For example, a lot of their ideas were not possible in the context of this lesson because they required glue which took too long to dry for this short session. More batteries and bits are also necessary if this lesson is to be used for a larger group.

Students made connections between known information and new information. Because of the design of this lesson, there is no way to accurately assess students' depth of understanding or ability to apply their new knowledge, but that's not what this lesson is really about. It may be beneficial to find a way to more formally share what has been learned and what students still want to know. Due to time limitations, the share cards proposed in the lesson plan were not used in the actual lesson; however, it is recommended that they should be integrated into the lesson. Perhaps this lesson can be an introduction to the share card and students can learn how to use it.

Another important observation was that students seemed to generate more ideas when working in groups than they did from working alone. They were also able to build on each other's ideas, an important form of scaffolding that led to higher levels of engagement.

Recommendations for Improving Student Learning

- **Materials**: Use materials for easy prototyping
- **Share Card:** Introduce and Implement Share Card into the lesson
- **Groups:** Allow students to make projects and come up with project ideas in small groups