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Co-creating Playful Environments That Support Children's Science and Mathematics Learning as Cultural Activity: Insights from Home-Educating Families

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Abstract
Decades of research support the importance of open-ended, self-directed play in children's cognitive, socio-emotional, and academic development. However, a "demise of play" is influencing science education, although such exploration is critical to building science identity and agency. An ethnographic study of the science, technology, engineering, and mathematics (STEM) learning practices of home-educating families documents the importance of negotiated, co-created, playful learning events. We posit these events emerge from an inherent flexibility within homeschool family systems, and because facilitators and learners have strong emotional ties to one another and value play in learning. Three specific situations highlight flexible and co-creative playful STEM learning activity: (1) an adult and child play and learn together through an intentionally designed "play-lesson"; (2) play emerges from an intentionally designed academic lesson; and, (3) a lesson emerges during play. Although the context is home-education, we believe these examples offer insights for how to support the culturally relevant and natural tendencies of children to engage in play-based STEM learning and how to design, or co-create, science and mathematics play-learning environments.

Keywords: play, STEM learning activity, homeschool, science identity, agency

Introduction

Child development professionals, psychologists, learning scientists and other childhood experts agree that play is an essential component of healthy childhood development (Almon 2003; Rasmussen 2004; Ginsburg and Committee on Psychosocial Aspects of Child and Family Health 2007). In particular, the central importance of creative play in children's cognitive, socio-emotional, and even academic development is well supported by decades of research (Vygotsky 1976; Smilansky 1968; 1990; Smilansky and Shefatya 1990; Bergen 2002).

Despite these well-justified arguments, children's creative play is increasingly endangered, particularly opportunities to engage in open-ended, self-directed play. An overemphasis on shallower and narrower learning in school and busy schedules outside school (after school programs, scouting, extracurricular activities, etc.) are major contributors. Some experts even argue that the "demise of play" represents a crisis in early childhood education (Olfman 2003). We argue that this situation is equally a crisis in science education, where open-ended, self-directed exploration is critical to building a science identity and sense of agency as a competent and engaged science learner.

Although it is easy to point fingers at schools, there is evidence that many parents also are complicit in this trend. In addition to over-scheduling children, some parents regulate the type of play and environments in which their children engage. For example, research conducted in children's museums indicates that many adult visitors accompanying children are concerned if the children are "only playing" and quickly try to redirect their play to more goal-oriented galleries and exhibits (Beaumont 2006; Benton 1979; Snow 1987a; 1987b; 1989). At home, the toys and activities that many parents buy for their children are often highly structured and academic goal-oriented. Although not the case for all home, leisure, or museum play experiences, many of the choices for play activity are highly designed, perhaps even over-designed. Even though designed play experiences may be "informal," they often require direction and/or facilitation by an adult. Such facilitation is important and needed sometimes, but to foster agency and an identity around science, children also need choice and control in their science play. Children need to have opportunities to play in more open-ended, self-directed ways that empower them to transform the spaces and contexts in which they are engaged into arenas for playful science learning. In these contexts and situations, the children *themselves* become co-creators and active agents in the design of an environment in which to engage in playful science learning.

In an ethnographic study of home-educating families' science, technology, engineering, and mathematics (STEM) learning activity, play naturally emerged and was part of the activity, (Bachman 2011). Specifically, negotiated, co-created, playful learning events were an essential aspect of the STEM learning practice observed, whether initially intended as "spontaneous" (i.e., the event emerged by taking advantage of a real life, everyday STEM situation) or more "formal" instruction (i.e., a planned lesson at home), these STEM learning events often included play in some form. Such science learning-play events were especially observed among families who value and engage in learning activity in which children are free to pursue learning according to their interests, needs, and motivations, and in which adults assume roles of the cooperative, co-learner with their children. We posit that these STEM learning-play events emerge because of an inherent flexibility within many homeschool family systems, and the fact that facilitators and learners have strong emotional ties to one another and value play as an essential aspect of learning. Their practice is flexible enough that "formal" learning and play alternates as the focus throughout their activity, such that places and situations not originally intended for play turn into play spaces.

Therefore, we suggest that home-educating families practicing STEM provide an interesting lens through which the role of co-creation and open-ended, self-directed play in science can be understood—particularly families who have chosen to educate at home because of philosophical concerns about the restrictive nature of schooling, including restrictions on play. Parents in these families are fully participating and engaged decision-makers in the learning that their children (and they!) undertake daily. They recognize and articulate the importance of open-ended, self-directed play, both in the learning process itself, but also in the maintenance of a love for learning, a common goal expressed by home-educating families.

This article explores and analyzes the practices observed in an ethnographic study of a self-organized group of home-educating families in the Mid-Willamette Valley of Oregon. The overall purpose of the study was to document and richly describe STEM learning activity as defined and enacted by home-educating families. An additional analysis of findings from the study illuminated the environments and situations in which play and STEM learning activity occurred together and how these were negotiated and co-created by both facilitator and learner. We describe three specific situations that highlight the flexible and co-creative nature of playful STEM learning activity: (1) an adult and child play and learn together through an intentionally designed "play-lesson"; (2) play emerges from an intentionally designed academic lesson; and, (3) a lesson emerges during play. Although these experiences occur in a home-educating context, we believe the examples offer insights about how to support and enable the culturally relevant and natural tendencies of children to design their own games and play objects as they engage in play-based STEM learning.

Theoretical Framework

We analyzed the societal activity of STEM learning using the socio-cultural approaches of Mediated Action and Cultural Historical Activity Theory (Wertsch 1998; Engestrom 2001; Roth, Lee and Hsu 2009). Such analyses identify the social activity, goal-directed actions, individuals and groups involved, and the mediating environment (cultural and physical) surrounding the phenomenon being studied. Thus, we view home-educating families as participating within the larger socio-cultural activity of STEM learning. This lens also conveniently allows us to focus on the role of play in the home-education STEM practice of these families.

Utilizing this theoretical perspective, we define learning as the appropriation of tools including symbol systems such as language, seen through increased participation/change in tool use (Vygotsky 1978; Rogoff 2003). We define play as a purposeful activity, integral to a child's development. Play helps to make visible the learner's zone of proximal development (Vygotsky 1978). As the child gets older, play activity progresses, rules emerge, and child's play activity becomes more regulated. Outwardly, play may bear little resemblance to the development to which it leads, the creation of a new relationship between imagined situations and real ones (Vygotsky 1976), yet play is seen as an essential aspect of healthy social and physical development, as well as the development of creativity and problem-solving abilities. Israeli psychologist Sara Smilansky conducted seminal work in the 1970s and 80s, in which she developed a method of assessing children’s play in pre-school settings. Using these tools, she and other researchers observed 3 to 6-year old children from a variety of socioeconomic settings at play in preschool settings in the U.S. and Israel. They also assessed children’s ability to organize and communicate thoughts and engage in social interaction. In one longitudinal study, children were followed and tested in second grade in literacy and numeracy. Findings indicated that children’s ability to engage in open-ended, self-directed dramatic and sociodramatic play was directly linked to a wealth of skills including: richer vocabulary, higher language comprehension, better problem-solving strategies, more curiosity, more innovation, more imaginativeness, and longer attention spans (Smilansky 1968, 1990; Smilansky and Shefatya 1990). There is also research that suggests children who have open (divergent) play experiences may be more flexible in their problem solving than children with more structured (convergent) play experiences or in non-play groups (Pepler and Ross 1981), and that hands-on play in childhood—for example, taking things apart—seems essential and correlates to engineering and science problem solving abilities in adulthood (Brown 2009, 9-11). From a sociocultural perspective, play is an essential element of learning.

Methods

This qualitative study utilized a composite of Mediated Action (MA) and Cultural-Historical Activity Theory (CHAT) as a framework for design and analysis, and employed ethnographic methodologies to collect the data. These three approaches complement one another, as all enable the researcher to qualitatively understand people-in-cultural-activity; in this case, people engaging in STEM learning activity. Ethnography affords the possibility of capturing unexpected and emergent properties as people interact with each other while engaging in daily activity.

MA and CHAT both use activity as the unit of analysis. By examining activity rather than an individual as with most social science methods, it is possible to gain a deeper understanding of the culture and practice of a community. These approaches view the actors, actions, tools, environment, timing, and motivations or goals for the activity as equally important aspects of the learning.

Consistent with qualitative methods, we recruited a criterion-based, purposeful sample of home-educating family volunteers. Criterion sampling enabled us to choose participants with a particular experience or characteristic, and we used purposeful sampling to select appropriate cases for in-depth observation (Patton 1990). Our criteria were that the participants be families that homeschool (at least one child and one parent) and belong to local home-education networks (mid-Willamette Valley and coastal region). Eight families agreed to participate in the study over the course of six months and all IRB protocols were observed. One of these families was that of the first author, included for reflexivity and to elucidate researcher stance (Lincoln and Guba 1985). Although the first author's family was included in the larger study, their data are not presented in this paper.

Data were collected at the family/participant and at the community level, primarily in the homes of families. Participant observations were made through video recordings and field notes, audio-recorded family interviews, and artifact collection. Initial interviews were audio recorded with open-ended questions designed to capture the families' educational values, style of homeschooling, and interests around STEM. We made video recordings during any STEM-related learning activity that families invited the researcher to observe or that naturally occurred during a researcher visit. We used a small Flip Mino video camera and GorillaPod (tripod) in order to easily move with the participants and capture the natural conversations and actions of the families.

Activity selection criteria were based on families' definitions of science, technology, engineering, or mathematics learning activity. We continuously collected audio recordings during the visit as back-up for conversation during the activity, as well as to supplement interview data, since families often informally offered additional insights about their homeschool practice during visits. The video camera and audio recorder were operated by the researcher, however children were allowed to try the recorders themselves whenever they wished. The camera was either set out of the way to collect the continuous actions of participants, or was used close-up in order to capture the detail of an activity in shorter video segments—for instance, books children were reading, things they were writing, drawing or measuring, or things they were building.

After collecting data on a particular STEM learning activity, we used Mediated Action analysis to code actions, agents, tools and the environment. We conducted a final interview with the families after the initial round of data analysis had been completed. This member checking of the analysis and findings directly involved the participants in the interpretation of the events and their practices around STEM learning (Lassiter 2005). Families' comments were incorporated into the findings. A second round of co-interpretation and member checking was conducted upon completion of the full analysis and write-up of the findings for each family.

Findings

Below, three specific situations within three different families[1] highlight the flexible and co-creative nature of playful STEM learning activity: (1) an adult and child play and learn together through an intentionally designed "play-lesson"; (2) play emerges from an intentionally designed academic lesson; and, (3) a lesson emerges during play.

[1] All names are pseudonyms.

1) Amanda: Keeping a Mathematics Lesson Playful
Amanda and Rick are in their early 40s and have three homeschooled children, Bob (15), Nigel (13), and Molly (5). Amanda is the primary homeschooling parent, remaining home while Rick works full time. She describes their homeschooling style as "secular independent humanists and eclectic homeschoolers."

Amanda considers play as integral to their homeschooling practice; the importance of play extends into their STEM learning activity. Amanda says, "Especially with the younger kids, if you define playtime as doing activities that are enjoyable, then playtime is how we learn." Amanda says about homeschooling, "My focus is that they not (just) memorize stuff, but they learn stuff by taking it in, and experiencing it, and having it be meaningful to them." Amanda wants her children to "value both formal and informal modes of learning."

In this brief excerpt from a full transcript, a toy cash register with a weighing scale and "scanner" provides the focus for an intentionally planned yet playful mathematics lesson about money and the value of objects. Amanda is facilitating Molly's mathematics learning but allowing Molly to have control over how the pretend game of "play store" runs its course. The lesson takes place in their usual workspace around the kitchen table. Molly is calling out "Let's play store! Let's play store!" before they begin. Molly's brother, Nigel, is also present and participates in the game while his lunch is cooking.

Figure 1. Molly "scans" an item on her register in her "store" while munching on a carrot in the family kitchen. Her brother holds the shopping basket.

Amanda begins to shop by placing items from around the house in a basket and play acting the role of a shopper in a grocery store. As she shops she talks to herself out loud about the value of the item and whether she needs it or not. She is modeling for Molly how to think about the value of objects and money when shopping. Molly is waiting for her to come over to the register and is acting as the "manager" or "checker."

> *A: (Amanda approaches the register) Hi, I'm ready to check out. Can you help me?*
> *M: Ruff! (Molly also likes to pretend being a dog)*
> *A: ... Should I pay with money or a credit card today?*
> *M: Money.*
> *A: Alright well, I'm going to need to get a little money here... Here you go, checker. I'm ready, I hope.*
> *(Molly checks out the items by scanning them. Each time she runs something over the scanner a woman's voice responds)*
> *M: Watch this. (She pulls a can across the scanner on the register)*
> *(register: 97 cents)*
> *A: Yeah, that's a good deal. I like this grocery store.*
> *N: How much is this? Can I try this? (Nigel scans a small Kaleidoscope)*
> *(register: 21 cents)*
> *A: Woo hoo! That will make a good gift.*
> *N: How about the crab? (runs it across the scanner)*
> *(register: $3.27)*
> *M: (giggling)*
> *A: Crab is always expensive.*
> *N: But what about the tomato? (scans)*
> *(register: $3.00)*
> *M: Aaiyy (grabbing items back from Nigel)*
> *A: Three dollars for a tomato!*
> *(Nigel scans his iPod)*
> *(register: $1.00)*
> *N: Cool! I'm buying 200 of them!*
> *N: How much do I cost?*
> *(Nigel scans his hand)*
> *(register: "clean up on aisle three")*
> *(laughing)*
> *N: That's not fair! (laughing)*
> *M: Go on, clean up on aisle three! (she pushes Nigel out of the kitchen)*

When they have finished checking out, Amanda helps Molly count some money and separate the quarters from the other coins. Amanda then asks if Molly wants to play one of the games that came with the cash register. Molly says she wants to play the store game again. Then Molly is distracted by Nigel's lunch and asks her mom for ramen noodles. This ends the "lesson" and lunchtime begins.

The activity is fun for all three participants and is highly cooperative. Amanda's goal for Molly during this event is to enjoy learning mathematics, while understanding that mathematics practice is embedded in real life and in play. This play-lesson required advanced planning and preparation, particularly assembling the tools such as the cash register and play money. Amanda is following Molly's lead to play store, role playing with Molly in the pretend game, observing Nigel and Molly as they play with the register and modeling thinking about and using money as Amanda "shops for food." Amanda lets Molly lead the "lesson" by leading the play, but Amanda also suggests "Want to play a game on the cash register?" after they finish the first round. Molly loves mathematics and pretend play, so is intrinsically motivated to do both. Amanda knows from her practice that Molly does not like directed teaching, thus Amanda steers clear of such facilitation and ways of talking (i.e., directing Molly's "play," telling, and sounding like a lecture).

2) Debora: Letting a Chemistry pH Lesson Turn into Messy Free-Play
Debora and Dan are in their mid-30s and are full-time working professionals (Ph.D. in Musicology and Doctor of Osteopathy, respectively) who homeschool their two children, Paige (9) and Jordan (6). They describe themselves as "a liberal, culturally Jewish family that practices a semi-structured, emergent form of homeschooling."

It is important to the family that they spend time together and have freedom to be creative. Debora values playtime, especially for her younger son. "Sometimes playtime might be the beginning of the day. We wake up, they are not quite ready, they wanna play, they go play for an hour and I'll go do something. I have to listen to the mode." One of Debora's overall learning goals is that her children love their family. To that end she recognizes the value of the children playing together. Debora says Jordan usually has free-learning time (playful child-led learning) since he is young, but for Paige a typical day consists of morning school-like work and after that it is often free play time with friends or with Jordan. Debora encourages creative free play in learning, but she also wants to provide academic science opportunities for her children.

This vignette takes place in the family kitchen and on the back porch. They have just been working through a more formal chemistry lesson in a curriculum (the pH unit in *No Hassle Messy Science with a Wow*, a book purchased at the Oregon Museum of Science and Industry (OMSI)), when Jordan remembers what happens when you mix baking soda and vinegar. He gets up to go "make volcanoes" outside. Debora ends the lesson early so Paige can join him. The "lesson" transforms into free science play.

Figure 2. Paige and Jordan mix baking soda and vinegar in a tub on the back porch waiting for a "big explosion"

Jordan and Paige have moved from the kitchen (and formal lesson using the OMSI curriculum) and are setting up a tub of water with the goal of making a baking soda and vinegar volcano. They have added the cabbage water (the pH indicator for the lesson) to the tub.

> *D: Ok, I'm ready.*
> *(Debora takes video with her iPhone) (They pour, it fizzes up)*
> *J: Hey, if you haven't noticed... if you notice that the bubbles made it go away.*
> *D: So this is a reaction when... okay, because the vinegar is the acid right, guys? And baking soda we know is a base right? And so they are opposites, right, you guys?*
> *P and J: Uh huh. (pour again) WHOA!*
> *J: I know. I will get a whole big bottle and fill it up...*
> *P: Oh, I've got an idea.*
> *D: What's your idea?*
> *P: Put this in here (baking soda in plastic water bottle) with vinegar in here than I'll shake it up real well with the cap on and I'll take the cap off and throw it and it will explode.*
> *D: Or a plastic bag.*
> *J: Fill this up with it. Paige let's fill that thing... (they mix larger amounts)*
> *D: So you want a bigger explosion.*
> *All: WHOA!!! (laughing)*
> *J: Hey now you can see the purple, kind of (referring to the cabbage water)*
> *P: A lot better, and pink!*

Debora's initial goals for this STEM learning activity were focused on teaching her children about pH, using a curriculum unit with focused outcomes, but cues from her children, especially Jordan, informed her decision to change the focus. Debora explains why she allowed the lesson focus to change into play: "I am more interested in the gestalt of science. Here there has been an experience. It's made an impact." She recalls that her mother let her do similar experiments. "That's more important to me than the retaining of anything, that they have this real love for what happened and are ready to go into something deeper with it." By allowing free play she also was able to give the children another experience she values, having fun doing something cooperatively that is science-related. Debora and her children are laughing and having fun as they co-create this spontaneous chemistry free play event.

Jordan was encouraged to turn what was initially a more formal lesson into free play because Debora values the creativity, joy, and learning that emerges from free exploration of one's environment, especially for a 6-year old, and their practice is flexible enough to allow this change to happen. With the freedom to explore his own ideas, Jordan becomes more vocal, interactive, and engaged. After taking the activity outside, Jordan was much more involved in the experience, making observations on his own about the bubbles and color changes he was observing. In this context, Jordan was a co-creator and active agent in the design of an environment in which he was empowered to engage in playful science learning.

3) Amy and Neal: Seeing Science Learning within Exploration and Play in Daily Activity on Their Farm

Amy, and her fiancé, Neal are both in their mid-20s. They homeschool Amy's son Jason, age 7 and also have a new baby. They live on Neal's parents' farm where Amy runs an organic community-supported agriculture (CSA) endeavor and Neal a small microbrewery. Amy describes her family as "naturally minded 'unschoolers'." Although Amy never explicitly discussed play during interviews and observations of her family, it is important to note that play is pivotal to the very notion of unschooling[2] and the community of unschoolers with whom she belongs ("Unschooling," 2011). Thus when Amy tells the researcher that she wants learning to be joyful, enjoyable, and to foster a "love of learning," it is reasonable to infer that she is implicitly talking about play during learning. Amy says if her kids grow up and are pursuing what they do in life with passion, then she will know she did the right thing. It is not important to Amy that her children master mathematics or grammar, but that they are not forced to do something that will inhibit them from developing a love of learning. "Whatever is enjoyable to learn about are the things that we do."

Amy and Neal's general educational goals for their children are for them to love learning, to be confident, secure, happy with themselves, and to be respectful of themselves, others, and the planet. "I think that is really in our brain every time we

[2] Unschooling is a style of homeschooling that is notable for its reliance on child interest-led, naturalistic learning. Unschooling was initially described by educator John Holt.

try to plan an activity or let an activity happen." Amy does not have specific or explicit learning goals due to Jason's age. She feels that for them to set goals on a timeline would not be conducive to their more general goal of instilling a love of learning in their son. Amy sees the farm as providing ample opportunity for Jason to engage in STEM learning. For example, Amy says Jason has the opportunity to learn about science from the gardening she does, and to see how things grow or what they need to grow.

The event takes place during a play date between Jason and another friend, Tye. They are in the brewery on the farm, music plays in the background as Amy tends to her baby, and Neal is brewing beer. The boys have been exploring the farm and have stopped inside the brewery to have a soda. This spontaneous science event started when Neal commented on the stove temperature as the boys were standing next to it warming up. One of the most interesting aspects of this event is that it occurs with the context of free play. While in the prior two episodes play arose during STEM learning activity, in this situation there is the reverse: STEM learning activity arises during free-play.

Figure 3. Neal shows Jason the burning pepper in the workshop woodstove

N: Oh, it dropped in temp, you see that? It is now down to 270. So we need to add some wood.
J: Yeah, add more wood. Add more wood!
T: Get a pepper Jason, get a pepper!
J: The pepper!
(Jason brings back a long red pepper, Neal opens the stove door and Jason tosses it in.)
T: (Asks Neal) The pepper is not doing anything. Will you shove it with a piece of wood?
N: Umm.
J: Or the poking stick.

(Neal grabs the poker and stabs the pepper)
J: Put it in front and roast it.
(Neal uses poker to position it)
N: There I'll put it right here on this nail, there we go.
J: Cool! It's roasting like the roasters. Let's keep on watching.
N: Take a look at it in a few minutes, see what it does. You can watch the temperature go up. I think it will shoot up here pretty quick.
(Jason watches the thermometer as Tye becomes distracted. Jason tries to get him to come back to the stove.)
J: Tye! It's gone up in temp
J: It's at 271.
T: 271?
(Jason wants to hold the video camera, he zooms in on the thermometer, then records the baby then goes back to the stove)
J: Hey it's almost to 300! Woo hoo!
(He holds the camera upside down, Tye is laughing)
J: its almost 300. Only two. . . one more until it's at 300.
T: I think it is at 300.
J: No it isn't.
T: It's not even one more, its half, quarter now, now it is at 300. It's finally at 300!
J: Hey, can we see what the pepper has done now?
N: (from across the shop) Where is it at?
J: 300 (Neal is working over in the brewing area).
N: 300? It'll keep going.
J: Come on please!
N: I gotta rinse this real quick.
(A few minutes later Neal is talking with the boys about the wood stove temperature and checking the pepper.)
N: ...It's now at 325?
*("*snap*" from the woodstove)*
T: Oh, wow look at that pepper!
N: (opens the stove) Wow, it turned to carbon....
J: ...carbon dioxide?
N: That's what it's releasing, it's mostly just carbon—that's why it's black.
Researcher: Yeah, it's totally black now.
T: It WAS red.
N: Should we pull it out and eat it? You can eat it Jason!
J: yeaaah (hesitates)... It's a HOT pepper!

In this spontaneous science learning event, the boys are engaged and laughing as they model Neal's actions; reading the thermometer, watching the temperature increase, and being excited to throw a pepper into the fire and see what happens when it roasts. They also have fun with the video camera. Neal accomplishes his goal of adding some science terminology and concepts to the event embedded in their daily life (i.e., a burned pepper is made up of carbon and carbon dioxide is given off by a burning pepper). He also has succeeded in getting the two boys to read a thermometer and watch it change temperature as he adds wood. However, the entire event is child-led; the boys can leave and change to another activity at any time. They stay engaged because they are having fun exploring what happens to the pepper with the increasing temperature (and likely the free use of the video camera).

What is interesting about this vignette is that immediately before and after the episode the boys were engaged in free-play. Jason and Tye were exploring, self-directed learners. They chose to pursue watching the woodstove (it was not required) and it was their idea to burn a pepper. They were more engaged with watching the thermometer when it was *their* pepper in the stove and argued about how to read the thermometer properly. Amy and Neal oversee the time and place of learning and facilitate Jason's learning, but do so by letting him participate in the things the family does on a regular basis. Jason is allowed to wander, explore, play and question the things he observes around the farm and brewery as per his interest. Amy and Neal sometimes create learning opportunities for him, or they take advantage of spontaneous experiences as happened in this case.

Discussion

Each family's culture, philosophies and values towards play and particular STEM learning goals influence the way these play-science learning events unfold in each family. Their learning goals afford more or less structure, which in turn influences parental roles during STEM learning and play. In Amanda's family, she planned and designed the play and mathematics learning, but in such a way that Molly and Nigel could be active co-creators. In Debora's formally designed and planned pH lesson, play developed spontaneously, moved outside and was encouraged by the parent. In Amy and Neal's case, the play and life-learning evolved into science learning (and was never separate from the exploratory play at all).

In each scenario the parents act as cooperative learners/facilitators, flexibly taking cooperative actions to support their children's exploration and discovery. They co-create, learn together, and pursue the activity in support of their children's science and mathematics learning and their family connection. The facilitator and learner have an emotional bond which supports and enables the co-creation of playful learning events.

In addition to their goals and the actions they take, these parents use the environment, specific spaces, and a variety of tools to engage their children in STEM play-learning. These resource-rich and flexible environments (in terms of tools, spaces, and timing) are important. Events unfold without strict time constraints, naturally ending instead when the child is hungry, the vinegar runs out, or the pepper burns up. During the events we observed, resources were spontaneously pulled into play or turned into play objects (e.g., household items, iPods, pepper, baking soda, vinegar, a tub of water).

The children in these families have a significant amount of agency, thus have opportunities (and are encouraged) to actively co-create their own learning experiences. These opportunities occur because these parents value play, love of learning, and choice in how their children pursue learning, as well as the content they learn and the timing of that learning. Because these experiences stem from the families' cultural values, they are culturally and personally relevant, as well as meaningful to the participants. Participant families state that the homeschool context affords the flexibility and freedom for play to arise during their STEM learning activity. All families emphasized how the ability to set their own schedule, take more or less time, move on to other things and come back to something later, as needed, was integral to their practice.

The recent National Research Council (NRC) report, *Learning Science in Informal Environments: People, Places, and Pursuits* (Bell et al. 2009), acknowledges abundant evidence that much of the science that people learn occurs during free-choice learning experiences in out-of-school, everyday settings similar to the ones in which the families in our study engage daily. Our theoretical stance supports the view that STEM learning is the appropriation of scientific and mathematical ideas into one's life and is observed as increased participation in community activity (Rogoff 2003). It is our contention that as the learners described in these vignettes become more comfortable with science and mathematics through playful learning, they likely increasingly identify as people capable of doing science and mathematics. Two of the six strands of science learning described in the NRC report, interest and motivation (i.e., experiencing excitement, interest, and motivation to learn about phenomena in the natural and physical world) and science identity (i.e., thinking about themselves as science learners and developing an identity as someone who knows about, uses, and sometimes contributes to science) are particularly reflected in these vignettes, in great part because these science learning goals align well with the STEM learning activity of these families.

All eight homeschooling families in this study articulated goals of fostering life-long learning, providing STEM learning experiences embedded in daily life, preparing their children for success in college, careers and life, and connecting theoretical scientific and mathematical ideas to their children's daily experiences. Vygotsky (1987) discusses the importance of both everyday and scientific conceptual learning and knowledge for full intellectual development; each type of knowledge supports the understanding of the other. Through their actions, words, and the learning resources they use, these parents demonstrated that they value both everyday and theoretical scientific knowledge. These parents realize that every lesson has both real-life and academic applications, and seem to recognize the importance of learning both theoretical/scientific concepts, as well as experiential/everyday concepts. The focus on learning theoretical/scientific concepts was particularly observed among families with older children since they participated in more discipline-specific learning (e.g. chemistry or geometry), but a focus on learning scientific concepts was also observed in families with younger children as Debora and Amy and Neal's family vignettes show. For these families, play and learning, theoretical/scientific concepts and experiential/everyday concepts are not seen as either/or but as both/and.

Conclusion and Recommendations

So, what does this all mean for understanding how to design spaces and learning opportunities for playful science learning? Often, the design process for learning spaces is top-down, fashioned by *adults for learners*—be that adult a classroom teacher, an interpreter in a nature center, an exhibition designer in a science center, or a parent at home. However, based on this research and current thinking about learning and engagement, this seems counterproductive. One of the characteristics of a good design for playful science learning may be that there are opportunities for learners to create/modify/co-create the learning setting themselves. In other words, a point of engagement might be the learner making the learning opportunity fit his/her needs while facilitators work closely to adapt the experience on the fly to suit the learner; effective design and facilitation by an adult might even be to get out of the way! It may be that flexibility should be designed into a setting to enable learners to make the experience their own or even create their own opportunity from the bottom up—in other words, a true learner-centered experience.

In terms of creating learning opportunities, the families in this study demonstrate what learning science (and mathematics) looks like when the learners "experience excitement, interest, and motivation to learn about phenomena in the natural and physical world" (Bell et al. 2009, strand 1). These children are likely beginning to "think about themselves as science (and mathematics) learners and develop an identity as someone who knows about, uses, and sometimes contributes to science" (Bell et al. 2009, strand 6). Specifically, flexibility in the goals of activity and the learning environment help foster opportunities to co-create or re-design the space, timing, and tools, in response to the learner (i.e., facilitation in the zone of proximal development as made visible by the learner's play). Parents help focus the learners' interests and motivation on science or mathematics learning activity. In this way, the families in this study help their children see themselves as science and mathematics thinkers and doers, hopefully supporting them in developing a science identity and life-long interest in science.

We want to emphasize and support efforts to restore play in the lives of children and adults (Olfman 2003; Brown 2009; Neugebauer 2009), and highlight the need for more research into the daily STEM learning activity that occurs naturally in homes and communities. The practices of home-educating families in this study help us see that learning in general, and STEM learning in particular, can happen anywhere and anytime, be playful and enjoyable, relevant, and something that parents and children can master successfully. However, there is still much to learn about how children and adults pull the information they need from resources and activity around them, co-create their experiences, and tailor learning to individual and collective needs and interests, thus ensuring relevant and meaningful science learning, along with ample opportunity to play and identify with science. Studying the practices of home-educating families is an interesting lens through which to gain further insights into how to support the culturally relevant and natural tendencies of children to design their own games and play objects as they engage in play-based STEM learning.

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