Diving into Practice with Children and Undergraduates: A Cultural Historical Approach to Instantiating Making and Tinkering Activity in a Designed Learning Ecology

Lisa Hope Schwartz, University of Colorado Boulder, lisa.h.schwartz@colorado.edu
Daniela DiGiacomo, University of Colorado Boulder, daniela.digiacomo@colorado.edu
Kris D. Gutierrez, University of Colorado Boulder, kris.gutierrez@colorado.edu

Abstract: "Making and Tinkering" has become popular in informal education circles. The practice links science, technology, engineering and mathematics learning (STEM) to the do-it-yourself "maker" movement, where people of all ages "create and share things in both the digital and physical world" (Resnick & Rosenbaum, 2013). This paper examines a cultural historical approach to Making and Tinkering at two sites of El Pueblo Mágico (EPM), a social design experiment that joins university students, researchers and k-8 youth from predominately non-dominant communities together in joint activity for expansive and consequential learning (Gutierrez & Vossoughi, 2010). In the lineage of design experiments in the learning sciences our work addresses what Resnick and Rosenbaum discuss as the critical importance of designing contexts for tinkerability from a theory-based and iterative design approach that aims to both understand and change practice. With our work we seek to re-mediate normative STEM learning contexts for youth from non-dominant communities.

"Making and Tinkering" has become popular in informal education circles. The practice links science, technology, engineering and mathematics learning (STEM) to the do-it-yourself "maker" movement, where people of all ages "…create and share things, in both the physical world and the digital world" (Resnick & Rosenbaum, 2013, p. 163). This paper examines how undergraduates, children and researchers worked together to instantiate a cultural historical approach to making and tinkering at two instances of *El Pueblo Mágico* (EPM), a social design experiment that joins university students, researchers and k-8 youth from predominately non-dominant communities together in joint activity for expansive and consequential learning (Gutierrez & Vossoughi, 2010).

In the lineage of design experiments in the learning sciences our work addresses what Resnick and Rosenbaum (2013) discuss as the critical importance of "designing contexts for tinkerability (p. 179)", from a theory-based and iterative design approach, that aims to both understand *and* change practice and the context of learning (Gravemeijer & Cobb, 2006). Expanding the design experiment in what Gutierrez and Vossoughi (2010) discuss as a social design experiment, an overarching goal of our research is to address issues of equity by engaging theory in practice to circulate power in joint activity, so that participants work to collaboratively negotiate the process and objectives of their work. We articulate this process as re-mediation (Gutierrez, Hunter & Arzubiaga, 2009), or the redesign of what is normatively the social organization of STEM activity in academic spaces in order to expand and reconfigure the forms of mediation available for youth, in particular girls and youth from non-dominant communities, within STEM learning environments.

Following an emphasis in design research on situating a theoretically articulated approach in practice, in order to recursively generate new theoretical understandings and design principles, we first present our theoretical framework to Making and Tinkering (M & T) at *El Pueblo Mágico* as a hybrid model. Our approach engages commonalities across the Maker Movement as articulated by Resnick &Rosenbaum (2013), tenets of cultural historical theory that are integral to the designed learning ecology that is the context of our work (see Tables 1 and 2), and our research theorizing the "inventos" or inventive, everyday practices of Latino youth and families (Schwartz & Gutierrez, 2013). To examine our theoretical approach in practice at the sites of our research we investigate two interrelated questions**:** 1) How do undergraduates enact and conceptualize cultural historical concepts in M & T activity with children? and 2) How does our approach work to provide opportunities for participants to engage in robust STEM practices that involve children and adults in joint articulation of the objectives of activity? To explore these questions we present examples of what we view as effective appropriation of our theoretical approach as well as how less successful activity is reflective of the normative STEM education practices we are working to re-mediate. We argue that our cultural historical approach to M & T within our designed learning ecology presents a significant example for other researchers and practitioners who are working to create contexts for tinkerability that address issues of equity in STEM education.

A Cultural Historical Approach To Making and Tinkering

Our implementation of M & T at *El Pueblo Mágico* is based on tenets of cultural historical theory historically taken up in the social design experiments developed by Gutierrez (Gutierrez & Vossoughi, 2010). These activity systems involve undergraduates enrolled in university courses on child and adolescent development in joint

activity with children in an after school space. This multi-sited social design experiment is organized around what Gutierrez and Vossoughi (2010) call "equity-oriented and robust learning principles (p. 101) taken up "toward transformative ends through mutual relations of exchange (p. 101)". Of significance, our work seeks to re-mediate the functional system of science education for all students, and in particular for women and students from non-dominant communities. We do this through foregrounding the joint activity, playful inventiveness, and human ingenuity we see as common threads of theory and practice across social design experiments, maker spaces, and the activity of members of non-dominant communities.

An overarching goal of both EPM and M & T articulated by Resnick and Rosenbaum (2013) is to re-mediate normative school practice. Resnick and Rosenbaum explain that rather than a focus on planning that is often pervasive in academic contexts and that adheres to formal rules and recipes for activity, tinkering is messier, more improvisational and more open ended, and is actually more like how science is actually practiced by scientists. What they refer to as "bottom and up" forms of participation align with cultural historical activity theory's (Engestrom, 1987) emphasis on horizontal and vertical development that underlies EPM. In other words, both approaches seek to leverage participation in a range of activities for deepening, broadening and connecting interests, and for forming sustained inquiries through multidimensional movement. The biggest shared criticism of M & T and the EPM design experiment from teachers and novice teachers respectively is that activity seems unorganized and unstructured. We concur with both Resnick and Rosenbaum that this view is misguided because "true tinkerers (p. 167)" know how to move tinkering into focused activity. It is precisely this capacity that we are working to foment in teachers and children at EPM. Rather than teaching lesson planning and top down classroom control, we emphasize "diving into practice" with children and a process of mediated praxis (Gutierrez & Vossoughi, 2010) whereby novice teachers reflect on activity and visualize new possibilities for joint activity with children.

Table 1. A Cultural Historical Approach to M & T at *El Pueblo Mágico*:

El Pueblo /4411 Learning Ecology	**Making and Tinkering**	**Practices in Homes**
Play and the imaginary situation as forming zopeds (Vygotsky, 1978)	Play; Experimental, iterative style of engagement	Play is the main activity videotaped in 14 homes
Stone & Gutierrez (2007) - Joint problem articulation - Serial mediation e.g. continual reassessment and re-directing of object-oriented activity - Just enough assistance Gutierrez & Vossoughi (2010) - mediated praxis	- Continual goal reassessment - Continual exploration of new paths and imagining new possibilities - Immediate feedback	Schwartz & Gutierrez, 2013 - Directives - Assistance for "leveling up" - Tool sharing - Idea sharing - Assisted turn-taking
Expansive learning (Engestrom, 1987) - horizontal / vertical movement - growing together everyday and scientific concepts (Vygotsky, 1978)	- Fluid experimentation: easy to dive in, connect and extend - Process over product - Open exploration - Improvisation/adaptation/iteration	Schwartz & Gutierrez, 2013 *Inventos*: crafting new rules of engagement with digital media to engage tight circumstances
Community of Leaners (Rogoff, 1994) - Distributed expertise among intergenerational ensembles - Learning as taking on new roles and responsibilities in joint activity (Vygotsky, 1978) - Cultural mediation	- Engagement with people and materials	- Distributed expertise, fluidity of roles between expert and novice - Assistance for novice players - Shared / negotiated access to tools within families
(Gutierrez, 1999) - Hybridity and heterogeneity	- Diverse examples, divergent thinking	- Hybrid language practices

Table 1 above outlines our approach to M & T within our designed learning ecology. Table rows are organized to show complementary concepts across the three approaches and activity systems. Column one outlines the main tenets of the cultural historical approach articulated in the university course. Column two, derived from Resnick and Rosenbaum's seminal paper, shows how our approach connects to and draws new emphases from M & T. Column three shows how we pull from our research on digital media and learning in homes (Schwartz & Gutierrez, 2013). Overall, each of these contexts and frameworks highlights play, joint mediated activity with people and things, hybridity, joint problem articulation, distributed expertise and fluid experimentation.

Putting the Design into Practice: Context and Methods of Data Collection and Analysis

In the sections that follow we focus on the work of undergraduates, called *amigos* (friends) at EPM, and children in the two instantiations of our approach to M & T within the social design experiment of *El Pueblo Mágico*. Table 2 and Figure 2 and 3 show information about each context. In both sites of EPM, members of the research team served as designers and facilitators of activity. To differentiate these two contexts we use 1) EPM1 for the Spring 2013 instantiation with undergraduates and predominately Latino children from non-dominant communities in grades 2-5 at Posada elementary school, and 2) EPM2 for the summer 2013 site with undergraduates and middle school students from privileged and non-dominant communities at Smiley Middle School. At this site, Schwartz conceptualized the M & T activity and coordinated the research team. Fundamental to the EPM social design experiment is providing space for reflection and dialogue between the undergraduate and the instructor. In EPM1 the cognitive ethnography (CE) that engages students in dialogic reflection on activity is the key space for mediated praxis. At EPM2 this occurred primarily through interaction, blog posts and course papers. Consequently, our primary data sources are CEs for EPM1 and videotaped data, course papers and blog posts for EPM2.

In order to address our questions regarding how undergraduates enacted and conceptualized M & T we first conducted an overall analysis of CEs for EPM1 and videotaped data for EPM2 (see Figures 1 and 2). For EPM1, a subset of CEs was identified through text searches for M & T and key concepts taught in the course (e.g. mediation). Out of 132 CEs by 26 students, where students averaged 5-6 CEs/EPM visits, 86 (65%) of CEs by 24 (92%) of students discussed M & T, and of this subset, 76 (88%) of CEs by 23 (96%) of students used key theoretical concepts. Subsequently, we selected the work of a subset of students (n=8) that demonstrated a range of effectiveness in putting theory into practice for further analysis. We chose 26 CEs written by five undergraduates from EPM1 and the work of three ensembles at EPM2. For EPM2, initial analysis and coding was a team effort between Schwartz and our undergraduate research opportunities (UROP) team of physics and education students. We assigned a ranking scheme and notation for undergraduates' questioning strategies and indicators of group collaboration. After selecting representative cases we coded data with a focus on 1) types of strategic assistance, 2) distributed expertise and roles emerging in activity, and 3) use of key theoretical concepts for mediated praxis.

Table 2. EPM1 and EPM2, Site, Participants, Key Activities and Data Sources

Sites	Participants	Key Activities / Terms	Data Sources
EPM1 - 5507 child development course - EPM at Posada Elementary School over one semester	- Undergraduates in 5507 (one time a week over 2.5 months) - 5507 instructors - EPM staff (doctoral students) - Children in grades k2-5 (~85) - Researchers / M & T support	Adventure Guides: - Zoom Zoom (cars) - Scribble machines - Squishy circuits - AgentCubes / Sheets - World Maker	- 86 Cognitive Ethnographies (CEs) by 24 students - X CEs by 4 students for close analysis - Video data; field notes
EPM2 - 5508 adolescent development course - EPM at Smiley Middle School / CU Boulder, 6 days over 2 weeks	- Undergraduates in 5508 - Children grades 6 and 7 (18) - Researchers, 5508 instructors, and M & T and EPM2 designers and facilitators - UROP student designers and researchers	- Solar Cars, solar theramin - Produce circuits - LED/squishy circuits - Sewn circuits - Minecraft circuits	- Videotaped data from 6 days of EPM2, ~1.5 hours per day - Utilized closely three 8-18 minute long clips - Field notes - Student papers, blogs

Strategies and Concepts for Learning and Becoming in Practice

Figures 1 and 2 below show the big picture regarding the theoretical concepts and forms of assistance utilized by undergraduates as well as instructors. On closer examination of the work of 8 students in EPM1 and EPM2, our analysis revealed that successful strategies for re-organizing the roles and responsibilities, or what we term distributing expertise in activity and jointly articulating problems, involved strategic questioning, in particular what we designate as "design questions". We found that that successful design questions allowed for children to "dive into practice" and extend their inquiries by focusing children's attention and imagination on particular

aspects of the task, re-voicing children's nascent ideas to the group, and giving options for potential directions for activity that included children's choices and interests. Undergraduates reflected on their activity and the role of play, motivation and engagement primarily through the concepts of mediation (and related forms, e.g. serial mediation, re-mediation), zoped, and community of learners. The examples shared here show how these students also used terms resonant of M & T, such as "dove into" and "trial and error". In both instances of EPM, moving away from a planning and recipe approach and taking up fluid experimentation where children could immediately engage with tinkering and were subsequently supported in reflecting on and extending their practices was acknowledged by participants as a critical re-mediation of accustomed school practice. Activity discussed below demonstrates how the common tensions felt by teachers to have all the answers and to serve as the sole authority were re-mediated by the process of jointly articulating the objectives of activity with children through distributing responsibility for thinking, imagining, teaching and learning to undergraduates and students.

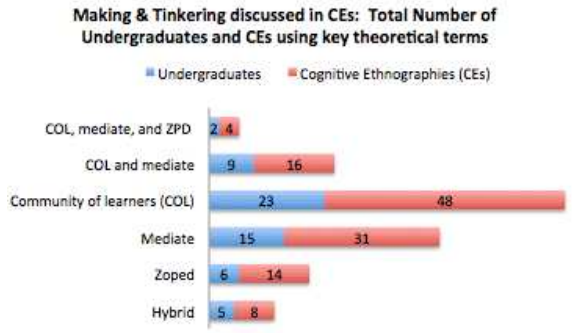

Figure 1. Concepts used by undergraduates regarding M & T at EPM1

Undergraduate assistance: Questioning, direct assistance, modeling, side-by-side, doing nothing, sharing ideas	
1: good	12 instances identified
2: adequate	11
3: poor	9
Peer support: Modeling, turn-taking, sharing ideas, etc.	
1: good	10 instances identified
2: adequate	9
3: poor	5

Figure 2. Ranking of assistance strategies in 32 instances of interaction at EPM2

We present an example from Ann Smith's CE to show how activity created new participation pathways for children. Smith documented her group's creation of "squishy circuits" with playdoh and LED lights. She explained how she turned thinking over to the students, through idea sharing and questions eliciting their thoughts about design. Smith related how this provided the space for 2nd grader Cecilia to take on a new voice and role in activity:

> I asked them if they all remembered how to make the Squishy Circuits and Flor and Cecilia said they did, but Michael told me he had never made them before and asked me how to make it. (OC: This is where I thought that making the other kids the in group the expert instead of me would be a better way of getting the instructions across). Cecilia, who usually doesn't talk much, piped right up and started explaining to Michael how the Playdoh had to be on top of the insulating dough and the Playdoh couldn't touch other Playdoh or it wouldn't work. Then she said that the battery wires had to be touching the Playdoh, but not the insulating dough and that the light had to be plugged into those same Playdoh pieces. (OC *…it was a nice change to hear her talk more than I had ever heard her talk before. Cecilia also acted as the mediator in this process between the instructions and Matthew understanding how to make the circuit.*). Michael looked like he kind of understood what Cecilia had said, but tried to pretend that he understood everything because he dove right into making a mermaid.

This example demonstrates how Smith privileged distributed expertise. Significantly, Cecilia a Latina girl and second grader, who Smith related was usually extremely reticent, became the expert teaching an older boy. She gave Michael what Stone & Gutierrez (2007) call "just enough assistance" for him to dive into making his circuit. Smith recounted "Their interactions also showed Vygotsky's ZPD. Matthew was not able to make his lights turn on until Cecilia turned his light the other way. This simple act of assistance showed me that Cecilia understood how the circuits worked and was able to help Matthew come to that same understanding." Cecilia continued to provide assistance to Michael until he eventually completed a circuit on his own. The interaction shows how consciously distributing expertise to students and allowing them to take on new responsibilities supported fluid experimentation and the creation of zopeds that engaged students' potential development. Importantly, activity in Smith's group supported a young Latina girl, a member of two groups (women and Latinos) underrepresented in many scientific fields in taking on the role of an expert. The following example also demonstrates expanded possibilities for normative gender roles with 3rd grader Maria taking a leading role.

In the next example, Schwartz supported an undergraduate, Suz Miller and 3rd grader Maria, on strategies for joint problem articulation. Maria wanted to create squishy circuits but was resisting group work

and getting started. Schwartz, through privileging joint activity among a wider range of participants, assisted their team with how they might collaborate with a group that was creating a movie. She suggested that Maria might contribute to the movie by helping to fabricate set items the group wanted with squishy circuits materials. In her CE, Miller described the learning opportunities that were opened up by widening the frame of possibility for collaboration:

> …Maria used her experiences with the scribbling machine to communicate its function to the group. No one else had done the tinkering activity so they were all novices making her the expert. The children's roles swapped while filming as Maria had a very minimal understanding of that project. Operating in a diverse group promoted the members zone's of proximal development as they acquired the opportunity to apply knowledge across many activities. Problem solving through group trial and error produced unique solutions as the ensemble members exchanged ideas and learned together. The opportunity to revise activities further enhanced critical thinking and the transfer of knowledge. Our problem solving process resembled a reflective collaborative learning model as the undergrads initiated communication and the children expanded on topics/ ideas.

Despite Maria's initial reluctance to join the new group, Miller related that the merger was extremely successful primarily through the cross-pollination of ideas, and distribution of expertise and roles among participants. Miller's work with the children also utilized what we term design questions to mediate joint problem articulation:

> "Oh, so you think we should lay the propeller flat like this instead of attaching it upright like a wing? What do the rest of you think?" I "What feature of the machine do you think needs to change in order to make it fly?" [OC: using open ended questions I guided the children's thought processes and re-structured my questions when they did not seem to grasp what I originally presented]. "It needs to have four spinning things not two, like a helicopter," Maria suggested. "So you think we need more propellers, and Isaiah thinks the propeller needs to be attached differently. Should we try these theories out and see if they work?" [OC: Maria used her understanding of flying objects to construct an analogy that helped her articulate her hypothesis to the group].

Miller's open ended questions about the design of the "flying boots" for the film assisted children in connecting their thinking to prior experiences and to features of the design needed for their current objectives. She specifically asked children what they thought and modeled taking up others' divergent thinking as resources for activity. Miller also used scientific language and practices to suggest to the students to test out their ideas with continued tinkering. Overall, her strategic questions distributed expertise to the children and expanded their activity. The open-ended but specific function of the questions that Miller used to turn decision making over to the children are what we define as features of "design questions". In her CE, Miller discussed her question-asking strategy with the concept of mediated serial assistance (Stone & Gutierrez, 2007), a process where the facilitator helps to organize interaction so children jointly determine the sub-tasks and direction of activity. She wrote "mediated-serial assistance appeared far more often in my group this week…As we worked through the flying machine issue I promoted critical thinking by posing "open-ended" questions to the group. … as the children responded I acknowledged their ideas, reflected on them, and expanded on the question in new ways".

In each of these examples, a focus on design and the imaginary situation engaged children in fluid experimentation whereby they could jump into activity, but also pull back and reflect on the direction of their goals. By helping children imagine possibility, undergraduates used play to form a zoped that engaged students' potential understandings. Additionally, undergraduates' discourse moves provided immediate feedback that did not restrict children's imagination and helped push them into new perspectives and practices.

Problems with Planning

Within M & T and EPM, play can be hard work, but there is an element of spontaneity and experimentation that enlists participation. In CE1 Ruth Penn wrote her group attempted to begin the adventure guide for Zoom Zoom (car creation). She related that Andres and Jose easily shared ideas and drew complex sketches, but that they quickly lost interest in planning and went to play computer games. She surmised that if they had immediately worked on building the car, they might have stuck with the activity. In CE3 her group was undecided on a project. Penn related how an EPM staff person intervened to lecture them that they had to create a plan before they began "worldmaker". The dialogue shut down the boys' enthusiasm, with Andres's lack of voice indexed by the action of putting a piece of tape over his mouth. This situation, where an EPM staff-person presented an approach contrary to the one espoused in this article, is also indicative of the gaps that often arise between

university and k12 schools, the hurdles for putting theory into practice, and how easily novice teachers will refer to a perceived authority, even if the interaction does not align with theory they are learning in their university courses.

In CE4 Penn wrote that Andres exclaimed, "I can't believe I am having fun!" Her final CEs show a move away from planning and the introduction of new tools to immediately tinker with. In these CEs Penn's discourse evolved into more strategic questioning and idea sharing. In CE5, Penn explained her role in Andres and Miguel's design of an experiment with Mentos candy and soda.

> … the new goal became how to make the soda explode higher, while putting in as many Mentos as possible before it exploded. Once we went inside the library, my assistance turned to become a mediator. I mediated the discussion we had with the experiment. When discussing what we would do for the future, and why the soda exploded, I asked open-ended questions to encourage critical thinking. I didn't want to give them the answer, but at the same time, if I didn't ask them to think about what they would change in the future, I'm not sure if they would have volunteered the information. So, I acted as the lever to get them to answer these important questions (CE6).

The progression of activity in Penn's CEs shows how when children are restricted from tinkering and articulating he goals of activity, they lose interest and motivation, but when Penn allowed for the youth to jump into activity first, she was able to position herself, through questioning and framing the boys inquiry, to serve as the "lever" for expanding their thinking. Unsurprisingly, when Andres was having fun, he was engaged and extended his abilities as he created and reflected on his world building in AgentCubes and his "candy chemistry" experiments.

Hands, Control and Distributed Expertise

Enjoyment and learning also went hand in hand at EPM2. On the last day Schwartz asked children to relate what they had learned and what they enjoyed. Children shared they liked designing and testing their cars, learning about circuits, building and competing with others in popular digital game Minecraft, and working with undergraduate amigos. Many students expressed that what they enjoyed and learned were the same. This section discusses joint activity at EPM2 among middle school aged youth and undergraduates in an adolescent development course. EPM2 focused specifically on M & T activities as exemplar practices for learning theory within the university course and at EPM. Our discussion highlights best practices and problematic exchanges in instantiating our approach to M & T. Table 3 below outlines the activity of the three ensembles we selected for further analysis. In each group children from non-dominant communities immigrant heritage were paired with Anglo youth and undergraduates, one of whom was also Latino. These ensembles present a range of forms of assistance, from primarily top-down, to a mix of directives and guided design questions, to more open-ended assistance.

First we focus on the movement of hands on materials in the different ensembles. For solar car construction there were tensions around the control of materials. In groups two and three the instructors utilized more heavy-handed "next-step" design questions—questions that veered towards known answers and lacked a distribution of agency to the children for deciding the direction of subtasks (Stone & Gutierrez, 2007). The most problematic interaction occurred in group three. It began with Amber constructing the solar car while the three boys looked on:

Instructor Bill:	Why are your hands all over it?
Amber:	I was trying to put the wheel on
Instructor Bill:	Why are *you* trying to put the wheel on?
Amber:	Because they can't do it
Instructor Bill:	(playful tone) What do you mean they're capable 8th graders with working hands.

This exchange re-mediated Amber's top-down approach and the boys took control of the car materials. But, shortly thereafter activity moved back to Amber and Instructor Jim who took the materials to demonstrate when he saw the boys having trouble. Watching the adults work together indexed their authority for Jorge. He exclaimed, "you guys are so smart!". Eventually thinking and acting was turned back over to the youth when Marnie initiated two design questions modeled after Bill's and with his support negotiated a shared placement of the car's motor. Activity in ensemble two was less problematic but also relied on directives and "next-step" design questions. As seen in row two, the children had double the amount of time on turn with the materials as Tamara. Still, Manuel's time with the materials overshadowed Yolanda's turn-taking, even as he oriented more than Yolanda to Tamara's approval. A positive aspect of this group was their use of hybrid language practices.

During the most interactive sequence between the children they utilized Spanish to discuss their shared decision-making.

Table 3. The Activity of Three Ensembles at EPM2

	Group 1	Group 2 (3 people)	Group 3
1. Participants	Undergrad: Marnie 3 boys: Merza, Tarik and Tom	Undergrad: Tamara Manuel and Yolanda	Undergrad: Amber 3 boys: Edgar, Bob, and Joe
2. Materials	Produce Circuits: Multiple sets	Solar Cars: One set	Solar Cars: one set
3. "Hands On": Times on turn with materials, and implying manipulation of materials	Undergraduate, Tarik and Sam: each have their hands on their own materials Merza: observes (related that Merza was able to explain the whole process later)	Undergraduate: 8 Manuel: 14 Yolanda: 4 turns (touched materials 15x) Girl & Undergrad: 4 Boy and girl: 1	Undergraduate: 10 Instructor Jim: 5 Jorge: 8 Bob: 5 Joe: 0 Adult total =15 Children =13 Among Instructors: 1 Undergrad & Boys: 2
4. Primary Undergraduate Discourse Strategies	- Models her own thinking (8) - Questions boys to explain their thinking (18) - Suggests boys view each other's work (10) - Refers to prior experiences (8)	Explicit Directives (7) "Next step" design questions, e.g. ""how will the wheel turn?, "where does this go?" (7)	Explicit Directives (2) Yes / No questions (3) IRE (2) Next step design questions (9) Design questions (3)
5. Role of Course Instructor(s)	Bill: Strategies and ideas for participants thinking, models discourse for Marnie	No instructor present in interaction	Bill: Re-mediates top-down approach, design questions Jim: Models, questions

In group one the movement of people and expertise was much more fluid and open. Merza and Tarik moved constantly, and Marnie followed suit, in order to engage with them. Marnie referred to the children's prior experience, during the summer program, and more broadly in their lives to assist the creation of produce circuits:

Marnie: When it didn't work last time with the play do, what did we do to the light?
Tarik: We switched it.
Marnie: We switched it. Do you wanna try to switch that and see what happens?
Tarik: So… (Mumbles. Sticks LED into playdoh, pauses). This is what we did with the playdoh
when the light didn't work. (Pulls LED out, turns it around, sticks it back in)
Marnie: hmmm (points, touches LED) What could be wrong? I wanna have you trouble shoot it.
Tom: Maybe the bulb burned out?
Marnie: The bulbs burned out? Okay, lets try a different bulb.
Tom: (Puts a new bulb in the circuit, it works).
Tarik: Ah I knew it worked!
Marnie: Awesome you just made another circuit. Congrats! How can you use that to extend it?
Tarik: You can connect another battery

Marnie's discourse encouraged Tarik to trouble shoot. The tone of interaction remained playful despite initial lack of success. When the LED did not light up, Tarik was not blamed, rather it was recognized that the issue may be with the materials and not the user. This interaction literally ignited Tarik's confidence. He took up Marnie's invitation to extend his tinkering, exclaiming "Ooo!" when Marnie obtained more batteries for him to use. Marnie's learning was also supported during this activity. Akin to the situation with Amber, Instructor Bill offered examples of questions to elicit students thinking and agency that Marnie used when the group struggled.

Tinkering With Our Design

At EPM the complex layers of mediation from children, undergraduates, and instructors present us with rich resources to support continued tinkering with our cultural historical approach to M & T. We saw positive outcomes regarding the re-mediation of participation in STEM activities for youth from non-dominant communities when undergraduates allowed for children to dive into activity, and when their strategic questioning and assistance distributed thinking to children. While these may seem like very simple strategies, unfortunately we also saw in our own sites how often this is not the approach adults take with children. Undergraduates who were successful in re-mediating STEM activity invoked theories of serial mediation and

joint problem articulation and related how their strategies worked to distribute expertise to children so that the youth could form zopeds with their peers.

The kind of multidimensional movement and distribution of expertise that we place as the central affordance of our approach to M & T necessitates examining contradictions that arise in activity. While we see in homes that children's *inventos* foment the creation of new rules for distributing participation when materials are scarce, at home and at EPM we see that it is often far too easy for the older person or the male to take the role of authority and owner of the materials and thereby claim the expertise to dictate the objective of activity. Though we discussed here some examples where young girls took the lead in teaching others, there are also more gender normative exchanges, including the predominance of Manuel's hands on the car materials. Continuing to examine and design for broadening normative gender roles and rules is critical to the evolution of our approach. Aligned with this issue is continued thinking on how to design new rules, roles and artifacts for distributing materials and expertise so that joint problem articulation is embedded in interaction.

We find with M & T what might be "good" strategies in one context can easily remove agency from participants in other interactions. Design questions can serve as supports for students thinking and distribute agency to youth through "just enough" assistance (Stone & Gutierrez, 2007) to prompt their continued inquiry. Yet, through slight changes in wording or through tone or gesticulation, questions around design can work in the more lockstep fashion of next step assistance. We plan to continue retrospective analysis of design questions and discourse with more of our video data and CEs. Through the present analysis we see that many of the contradictions that arise with design questions are linked to issues of confidence. Children and undergraduates worry about being right, and need to be supported in taking risks and not giving up authority to those who normatively wield power. However, in this model, adults *do* need to take the role of facilitator who can widen the frame of possibility and model thinking through sharing ideas and ways to approach open-ended problem solving. A continued tension, also related to this role, is the amount of expertise the undergraduates need in order to extend children's thinking, and how much they should be involved in the activity of tinkering to create their own or shared products with children.

In our next iteration of the design experiment we plan to set up mobile M & T materials centers coupled with undergraduate "connectors" who model generative design questions and idea sharing. The centers will provide spaces for children and undergraduates to jump into activity together. Through presenting an array of materials we will organize the space for horizontal and vertical expansion across activities and ways of knowing. Additionally, we have begun an extension study where we visit children's homes to work with families on M &T activities. With this endeavor we seek to continue to engage families' *inventos* as a source for M & T, and to expand participation through actively valuing and enlisting a wide range of practices for STEM learning. To conclude, we offer a fundamental cultural historical concept that informs this social design experiment: "change in the individual involves change in the social situation itself" (Engeström, 2008 in Gutierrez & Vossoughi, 2010, p. 101).

References

Engeström, Y. (1987). Learning by Expanding. Helsinki, Finland: Orienta-konsultit.

Engeström, Y. (2008). From teams to knots: Activity theoretical studies of collaboration and learning at work. New York: Cam- bridge University Press. Engeström,

Gravemeijer, K. & Cobb, P. (2006). Design research from a learning design perspective. In: Van den Akker, J., Gravemeijer, K, McKenney, S. & Nieveen, N. (Eds). (2006). *Educational design research*. London: Routledge, 17-51.

Gutierrez, K., Hunter, J. & Arzubiaga, A. (2009) Re-mediating the University. *Pedagogies: An International Journal* 4 (1-23).

Gutierrez, K. D., & Vossoughi, S. (2009). Lifting Off the Ground to Return Anew: Mediated Praxis, Transformative Learning, and Social Design Experiments. *Journal of Teacher Education*, *61*(1-2), 100–117.

Resnick, M., & Rosenbaum, E. (2013). Designing for Tinkerability. In Honey, M., & Kanter, D. (eds.), *Design, Make, Play: Growing the Next Generation of STEM Innovators*, pp. 163-181. Routledge.

Schwartz, L. & Gutierrez K. (2013, March). Turn-Taking and *Inventos*: Examining The Everyday Lives of Latino Families and Designing Learning Ecologies with Youth and Under-graduates. Paper presented at the Digital Media and Learning Conference, Chicago, IL.

Stone, L.D. & Gutiérrez, K.D. (2007). Problem articulation and the processes of assistance: An activity theoretic view of mediation in game play. *International Journal of Educational Research 46*. 43-56.

Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes (*pp. 79-91). Cambridge: Harvard University Press.