Designing "Contexts for Tinkerability[1]" With Undergraduates and Children Within the El Pueblo Mágico Social Design Experiment

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Abstract: "Making and Tinkering" 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 designing what Resnick and Rosenbaum (2013) call "contexts for tinkerability" within the social design experiment of El Pueblo Mágico (EPM) – a design approach organized around a cultural historical view of learning and development. We argue that this theoretical perspective reorganizes normative approaches to STEM education through a hybrid approach that brings together concepts from cultural historical theory and from Making and Tinkering (M & T) in ways that are important to how theory is enacted in STEM practice.

Keywords: "Making and Tinkering", cultural historical theory, nondominant communities, informal STEM

1 Introduction

"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 drew on the ecology's organizing theoretical framework and worked together to instantiate a cultural historical approach to Making and Tinkering (M & T) at three permutations of *El Pueblo Mágico* (EPM) (see Table 3). This social design experiment joins university students in courses on learning and development, k-8 youth from predominately non-dominant communities and researchers in an after school program oriented toward expansive and consequential learning (Gutiérrez & Vossoughi, 2010).

1 The term "contexts for tinkerability" derives from the work of Resnick and Rosenbaum (2013) that is discussed in this article.

Transforming the design experiment in what Gutiérrez (2008; Gutiérrez & Vossoughi, 2010; Gutiérrez & Jurow, 2014) discusses as a social design experiment, an overarching goal of the research is to address issues of equity and consequential learning. As in traditional design-based research (Gravemeijer & Cobb, 2006), social design experiments take a theory-based and iterative design approach that aims to understand *and* change practice. To achieve our goals we engage theory in practice to re-organize and circulate power in joint activity – in other words the aim is for undergraduates and youth to collaboratively design the process and objectives of their work. Our approach to M & T activity within EPM engages commonalities across the Maker Movement, as articulated by Resnick & Rosenbaum (2013), and 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).

In university courses on child and adolescent development and their isomorphically designed EPM site, we engaged undergraduates with M & T through sociocultural theories that present a highly mediated approach for putting theory into practice. In this article, in order to analyze how undergraduates took up theory in practice with youth at EPM, we examined the development of what we call "design discourse" among participants. Throughout our iterative design and analytical processes, we focused on Stone and Gutiérrez's (2007) concept of joint problem articulation – a process in which a shared understanding of the presented problem and the goal of the activity develops toward shared practice. In this way, joint problem articulation represents a negotiated practice and discourse of design that distributes expertise and agency to the teacher and students. In our research specifically, we examined how this concept worked to support children and undergraduates in the development of joint activity where adults guided participation and created contexts where both children and adults contributed to the design of STEM activity.

2 Research Questions

EPM works to leverage and extend youths' everyday activity for consequential learning through the development of shared practices among participants. In this paper, we articulate this aim as the development of a shared design discourse and a joint articulation of the objectives of STEM learning activity among undergraduates and children from nondominant communities. We posit that this work is accomplished through undergraduates' use of theory in M & T practice. To examine this conjecture, we ask two interrelated questions: 1) What theories and practices mediated undergraduates' and children's development of a design discourse in which they jointly negotiated shared practices?, and 2) In what ways did the concept of joint problem articulation bring together theory and practice? To explore these questions, we present representative examples of what we view as effective appropriation of an expansive theoretical approach to learning (Cole & Griffin, 1983; Gutiérrez, Hunter, & Arzubiaga, 2009). Situated in the EPM social design experiment and its activity theoretical perspective, this approach works to re-mediate the normative, top-down social organization of tool use, relationships, distribution of expertise, and articulation of objectives in STEM activity (Engeström, 1987). In other words, this approach works to distribute responsibility for thinking and acting across teachers and students (Rogoff, 1994).

3 Theoretical Background

A Cultural Historical Approach To Making and Tinkering

Our implementation of M & T at EPM is based on tenets of cultural historical theory taken up in the social design experiments developed by Gutiérrez (2008) (See Table 1).

Table 1. Key cultural historical theoretical constructs

Key Theoretical Term	Definition
Zone of Proximal Development (Vygotsky, 1978)	The concept of the zone of proximal development (ZPD) represents the development of intersubjectivity among participants and tools in activity, through the sharing of expertise and assistance across people and tools, so that tasks are accomplished through joint activity that could not be accomplished by a learner independently. What occurs in the development of the ZPD is a way of stretching the learner's abilities through assistance so that their potential development is engaged and they can act "…a head taller …(Vygoktsky, 1978, p. 102)" than their actual level of development.
Mediation (Vygotsky, 1978)	The concept of mediation posits that the world is not experienced directly but rather through cultural mediation, that is, our understanding is mediated through tools. These tools can be artifacts, people or combinations of the two in interaction.
Community of Learners (Rogoff, 1994)	Rogoff's community of learners (COL) posits that such a community moves away from a solely adult-run or child-run model of interaction. Instead, the concept of the community of learners offers a pedagogical model whereby the teacher retains authority while they work to distribute responsibility for thinking and acting across teachers and learners.
Joint problem articulation / Serial Mediation (Stone & Gutierrez, 2007)	In joint problem articulation, a shared understanding of the presented problem and the goal of the activity develops toward shared practice. Joint problem articulation is discussed in conjunction with the concept of serial mediation. This concept further describes the shared process of problem formation and negotiation of objectives through explaining how responsibility for organizing tasks shifts across participants over time.

Drawing on Rogoff's (1994) "community of learners" (COL) as an organizing feature of the learning context and an emphasis on joint problem articulation, our approach to M & T within the EPM social design experiment re-organizes the division of labor among children and adults in ways that render traditional and polarizing notions of classroom control as constraining. In line with the Next Generation Science

Standards (NGSS)[2], a cultural historical approach to M & T avoids the dichotomizing debates in STEM education in which process and content learning are separate. Within this perspective, then, this paper focuses on the value and work of creating contexts for undergraduates and children to take up scientific habits of mind and processes of shared design central to the acquisition of a particular content area.

This work seeks to re-mediate the functional system of science education for all students (Cole & Griffin, 1983; Gutiérrez, Hunter, & Arzubiaga, 2009), 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 nondominant communities. Table 2 outlines our approach to M & T within our designed learning ecology.

Table 2. Components of A Cultural Historical Approach to M & T at *El Pueblo Mágico*

EPM Social Design Experiment, including El Pueblo Magico and 5507 and 5508 Undergraduate Courses in Child and Adolescent Development	**M & T articulated by Resnick and Rosenbaum (2013)**
• Play and the imaginary situation as forming zones of proximal development (ZPDs) (Vygotsky, 1978) • Children and families' playful inventiveness (Gutiérrez, 2013; Schwartz & Gutiérrez, 2013)	• Play • Experimental, iterative style of engagement
Joint problem articulation (Stone & Gutiérrez, 2007 – Serial mediation e.g. continual reassessment and re-directing of object-oriented activity (Stone & Gutiérrez, 2007) – Just enough assistance Gutiérrez & Vossoughi (2010) – mediated praxis	– Continual goal reassessment – Continual exploration of new paths and imagining new possibilities – Immediate feedback
Expansive learning (Engeström, 1987) – horizontal / vertical movement (Gutiérrez, 2008) – Growing together everyday and scientific concepts (Gutiérrez, 2014; Vygotsky, 1978)	– Fluid experimentation: easy to dive in, connect and extend – Process over product – Open exploration – Improvisation/adaptation/iteration – Sharing resources – Negotiating access
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 (through people, tools, ideas)	– Engagement with people and materials
(Gutiérrez et al., 1999) – Hybridity and heterogeneity	– Diverse examples, divergent thinking

2 The NGSS are the new US k-12 science standards "rich in content and practice, arranged in a coherent manner across disciplines and grades to provide all students an internationally benchmarked science education". Retrieved from http://www.nextgenscience.org, July 25, 2014

Table columns show the two domains we draw from for our approach to M & T; our university courses and Resnick and Rosenbaum's seminal work on M & T. Table rows depict complementary concepts and how our approach connects to and draws new emphases from M & T. Shared across these domains are processes of shared thinking, risk-taking, horizontal movement across activities, and multiple entry points to activity that a cultural historical approach to M & T within EPM upholds as primary components of re-mediating normative STEM activity in academic spaces.

We aim for students to connect to multiple experiences in their lives and to deepen their knowledge about STEM processes as they create new opportunities for understanding within M & T activity (Ito et al, 2013). Importantly, we view successful M & T as a cycle of collaborative, hands-on, reflective, planned and dialogic activity where a variety of strategies and supports are taken up in order for children and adults to jointly articulate the direction of their inquiries. We emphasize what Resnick and Rosenbaum (2013) discuss as "diving into practice" with children and a process of mediated praxis (Gutiérrez & Vossoughi, 2010) whereby novice teachers reflect on practice, and visualize and enact new possibilities for joint activity with children. In these processes, fluid participation structures provide opportunities for the adult to maintain a role that provides guided participation, strategies, and choices for the children to co-determine the presented problem and direction of activity.

We define design discourse as talk among participants that works towards an ethos of shared design and what Resnick and Rosenbaum call "fluid experimentation" that engages both horizontal and vertical movement within STEM activity. From an activity theoretical view, attention to horizontal movement is integral to the designed learning ecology discussed in this article (Engeström, 1987). Horizontal movement refers to movement across a range of practices, activities and discursive domains, and is a critical dimension of learning theorized by Gutiérrez (2008; Gutiérrez & Vossoughi, 2014; Gutiérrez, 2014). Within this focus, children's everyday practices are leveraged toward more expansive forms of learning, in contrast to a singular focus on vertical forms of learning often privileged in school settings[3]. With the examples we share below, we argue that through this widening of possibilities, we support youth who might not initially be interested in certain STEM activities, and garner more effective participation from novice teachers with varying levels of STEM expertise. Through allowing for lateral movement across a range of practices, we have the opportunity to view how students' interests are taken up in STEM activity, and how this broadening of the field of inquiry may support their movement into more focused endeavors, and deeper learning in a particular practice or content area, or the vertical dimension of learning (Engeström, 2003).

3 Vertical forms of learning generally involve movement from novice to expert, development of domain expertise, etc.

4 Methods: Theory into Practice

In this article, we discuss the work of undergraduates, called *amigos* (friends), and youth in three instantiations of our approach to M & T within the EPM social design experiment. This designed learning ecology is comprised of undergraduate classes on child and adolescent development (EDU 5507 and 5508 respectively) coupled with the EPM after school program. Pseudonyms are used for participants. Table 3 shows information about each research context. These sites are part of a longstanding social design experiment designed by Gutiérrez (Gutiérrez, 2008; Gutiérrez & Vossoughi, 2010). Significantly, EPM is a team effort that involves students, researchers and faculty working in partnership to design and facilitate activity.

Table 3. Three instantiations of the EPM social design experiment

EPM	Participants/Context	Activities
EPM1 Spring 2013	– Child Development course (EDU 5507) – 26 EDU 5507 students at EPM (1 day/per week for 1 semester) – EPM staff (doctoral students) – Children grades 2-5 (~85) at EPM – Researchers/M & T facilitators and EDU 5507 Instructors	– Zoom Zoom (cars) – Scribble machines – Squishy circuits (playdoh batteries and LED lights) – AgentCubes/Sheets (children program their own videogames) – World Maker (create world with recycled materials)
EPM2 May 2013	– Adolescent development course (EDU 5508) – 22 EDU 5508 students at EPM (2 days/per week for 3 weeks) – Children grades 6–7 (18) at EPM – M & T and EPM2 designers/facilitators and EDU 5508 instructors (including the researchers and undergraduate research opportunities (UROP) students)	– Solar Cars, – Solar Theremin – Produce circuits (circuits with lemons and potatoes) – LED/squishy circuits – Sewn circuits – Minecraft circuits (circuits created with in popular sandbox video game Minecraft)
EPM3 May 2014	– Adolescent development course (EDU 5508) – 29 EDU 5508 Undergraduates (2 days/per week for 3 weeks) – Children grades 6–8 (28) at EPM – M & T and EPM3 designers/facilitators and EDU 5508 instructors (including the researchers and UROP students)	– Paper circuits (LEDs, copper tape and paper) – Makey Makey (invention kit for creating computer keyboard controls with conductive materials) – Robot Picaxe (programmable robot) – Rube Goldberg (multistep contraption-invention purposely constructed for complexity)

Data Collection and Analysis

As part of an ongoing social design experiment, data collection and analysis occurred in several stages. Table 4 shows the data collected and analyses performed for the three iterations of EPM.

Table 4. Data collected and analyzed at three iterations of EPM

	Data Collected / Analyzed
EPM1	Text analysis of 86 Cognitive Ethnographies (CEs) by 24 students. Close-up analysis of design discourse for 26 CEs by 5 students The CE – a longstanding feature of EPM – engages students in dialogic reflection and mediated praxis (Hutchins, 2003; Gutiérrez & Vossoughi, 2010). It is the key mediating artifact that links EPM to the adolescent and child development courses. The CE is a structured field note about collaborations with children where undergraduates a) document detailed, moment-to-moment learning activity, b) apply theories they are learning to their practice and c) engage in dialogue with instructors about theory and practice. Video data; field notes
EPM2	• Videotaped data from 6 days of EPM2, ~1.5 hours per day • Close-up analysis of three 8–18 minute long video clips of three ensembles; field notes • Student papers, reflective blogs
EPM3	• Text analysis of cognitive Ethnographies (CEs) by 30 students • Design discourse analysis and analysis of joint problem articulation based on criteria that emerged in analysis of EPM1 and 2 • Video taped observations • Artifacts: Game Cards, Challenge Cards, Project Plans

We first conducted an overall analysis of CEs for EPM1 and videotaped data for EPM2 to gain a sense of how undergraduates conceptualized and enacted M & T activity through the lens of the theories taught in the courses. Table 5 outlines how we selected a subset of CEs from EPM1 that referenced M & T and key theoretical constructs. Figure 1 shows the number of key theoretical terms used in these CEs and by undergraduates. We analyzed the use of theoretical terms in CEs to hone in on examples to code further. For EPM2, Table 6 shows how our undergraduate research and instructional team ranked activity in video clips according to a rubric co-created with Schwartz.

Table 5. Number of EPM1 undergraduates referencing M & T and key theories in their CEs

Total CEs that referenced M & T	**"M & T" CEs using key theoretical terms from the CU Courses.**
86 (65%) of CEs by 24 (92%) undergraduates in the EDU 5507 course	76 (88%) of CEs by 23 (96%) undergraduates in the EDU 5507 course

Figure 1. Concepts used by undergraduates in CEs discussing M & T at EPM1. Top bar: students who used the term in their CEs. Bottom bar: CEs that used the term.

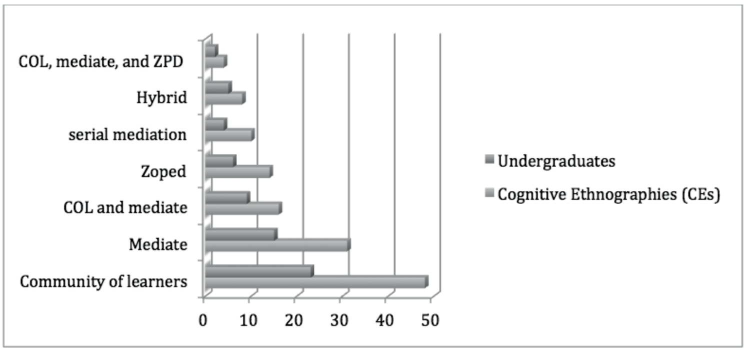


Table 6. Ranking of assistance strategies in 32 instances of interaction at EPM2

Undergraduate Assistance	**Instances**
1 Good: Undergraduate(s) used targeted and open ended questioning, modeled possibilities without taking over the task, worked in concert with students, shared their own ideas and encouraged students to do the same; supported inquiry through idea sharing across participants	12
2 Adequate: Undergraduate(s) used questioning but questions were mainly generic, e.g. "What do you think" and did not necessarily help push students' understanding. Some modeling and side by side work but less interaction among undergraduate(s) and students, or undergraduate gives too much information and sidetracks or limits student inquiry.	11
3 Poor: Undergraduate(s) disengaged or took over task completely, no use of questioning or only "known answer" questions, no sharing of ideas	9
Peer Support	
1 Good: students modeled activity for each other, shared materials and took turns, shared and built off of each others ideas	10
2 Adequate: some sharing of ideas but much less active shared participation	9
3 Poor: did not share ideas or materials, did not let certain students participate	5

In order to address our research questions, the work of a subset of students (n=8) that demonstrated a range of effectiveness in putting theory into practice was selected for further analysis from EPM1 and 2. We chose twenty-six CEs written by five undergraduates from EPM1 whose CEs used key theoretical terms, and the work of three ensembles at EPM2 that were representative of the range of undergraduate assistance. After selecting these cases we coded data to 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. These three areas informed our conceptualization of participants' developing design discourse. We also analyzed data for the development of talk and interaction that both did and did not show shared development of ideas and goals in M & T activity, important criteria for our theorization of design discourse. Of significance, the concept of joint problem articulation (Stone & Gutierrez, 2007), often articulated through a discussion of "serial mediation", while not the most numerically prevalent in students' CEs, emerged in both CE and video-documented data in EPM1 and 2 as generative for supporting the development of a shared design discourse. Of note, this concept has historically served as a key mediating tool in Gutierrez's social design experiments (Gutierrez & Jurow, 2014).

Based on our findings from EPM1 and EPM2 we focused our design of culturally historically grounded M & T activity and analysis of EPM3 specifically on the concept of joint problem articulation. Our aim with the third iteration was to create supports for the development of this theoretically grounded practice within undergraduates' work with children. For EPM3 analysis we selected sections of CEs representative of how students utilized the concept of joint problem articulation, and the artifacts and strategies we introduced in EPM3 to develop a shared design discourse.

5 Findings: Strategies and Concepts for Developing a Discourse of Design

Our analysis focused on how undergraduates and children jointly articulated the objectives of activity through distributing responsibility for thinking, imagining, teaching and learning across members of their ensembles, and through undergraduates' use of cultural historical theory. As seen in Figure 1, 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), zone of proximal development and community of learners (see Table 1). They also used terms resonant of M & T, such as "dove into" and "trial and error" in their work. These concepts are elaborated in the examples shared below.

Our analysis revealed that successful strategies for re-organizing roles and responsibilities, or what we term distributing expertise in a community of learners and jointly articulating problems, involved the development of design discourse through strategic questioning. This questioning involved what we designated as "design questions", or questions that focused on specific aspects of the design of artifacts, and "imagination questions" that queried students to think about possibilities for design that worked to expand upon their interests and playful participation. In the examples shared below we illustrate how the development of design discourse drew upon sociocultural theories and supported children to both initially "dive into practice" and subsequently extend their inquiries.

First, we present two examples from EPM1 that show how undergraduates' design discourse supported new participation pathways for children. Ann 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[4]: 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 Michael 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.

Smith's description shows how the interaction privileged distributed expertise, with Cecilia mediating possibilities for her peer's participation. 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 & Gutiérrez (2007) call "just enough assistance" for him to dive into making his circuit.

Smith recounted "Their interactions also showed Vygotsky's zoped[5]. Michael 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 Michael come to that same understanding." Cecilia provided 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 ZPDs 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 we 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. Through privileging joint activity among a wider range of participants, her team received assistance with how they might collaborate with a group that was creating a movie. Researcher Schwartz 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 moving horizontally across activities and 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.

4 OC in CEs stands for Observer Comments.
5 Here the term zoped refers to the ZPD.

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 also utilized "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?" "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, yet focused questions about the design of the "flying boots" for the film assisted children in connecting their thinking to prior experiences and to concrete 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, expanded their activity and drew them into a discourse of design.

In her CE, Miller discussed her question-asking strategy with the concept of mediated serial assistance (Stone & Gutiérrez, 2007), a process of joint problem articulation, 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". Miller's description captures the emergence of a design discourse where the ideas of all parties are considered and particular features of the artifact are debated.

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 before making additional decisions. Additionally, undergraduates' design discourse provided immediate feedback that did not restrict children's imagination about M & T, but rather helped push them into new perspectives and practices.

5.1 Hands, Control and Distributed Expertise

The examples we share from EPM2 outline the activity of three ensembles representative of interaction that had varying consequences for the development of shared design discourse and problem articulation (See Table 7). In each group, children from non-dominant communities were paired with Anglo youth and undergraduates. In these examples we focus on the movement of participants' hands on materials as they worked on solar cars and circuits, and how this embodied interaction affected the development of a shared design discourse (see also DiGiacomo & Gutierrez, 2014).

Table 7. The activity of three ensembles at EPM2

	Group 1	Group 2	Group 3
1. Participants	Undergrad: Marnie 3 boys: Merza, Tarik and Tom	Undergrad: Tamara 1 boy and 1 girl: 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 Tom: each have their hands on their own materials • Merza observed (he was able to explain the whole process later)	• Undergraduate: 8 • Manuel: 14 • Yolanda: 4 turns (touched materials 15 times) • Undergrad & Girl: 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	• Modeled her own thinking (8) • Questioned boys to elicit their thinking (18) • Suggested boys view each other's work (10) • Referred 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: Offered strategies and ideas for participants thinking, modeled discourse for Marnie	No course instructor present in interaction	• Bill: Re-mediated top-down approach, design questions • Jim: Modeled, questioned

The most problematic interaction occurred with group three. The exchange below depicts how undergraduate Amber envisioned her students' abilities for the design of the solar car, and how the Instructor Bill intervened:

Bill: Why are your hands all over it?

Amber: I was trying to put the wheel on

Bill: Why are *you* trying to put the wheel on?

Amber: Because they can't do it

Bill: (playful tone) What do you mean they're capable 8th graders with working hands.

Bill: (Moves to put children's hands on car. In playful tone). What do you mean they can't do it, they're capable 8th graders with working hands. Hey, do this guys (gestures upwards)

Boys: (Boys hold up hands)

Bill: Lets show Amber that you have working hands. …Jorge has working hands and he can work on it.

Bill's intervention re-mediated Amber's top-down approach and the boys took control of the car materials. Thinking and acting were turned over to the youth when

Amber initiated two design questions modeled after Bill's, and with his support the group negotiated a shared placement of the car's motor.

Activity in group two was less problematic in terms of children's hands-on participation. However the example below illustrates how undergraduate Tamara also utilized directives and oriented her questions in a way that did little to distribute time on materials or expertise to the girl participant.

Yolanda: (Picks up rubber band and holds toward Manuel. He takes it.) No, we're going to put this on there.

Tamara: We're going to use the rubber band for something else.

Yolanda: No (points to rubber band and solar panel) we put that.

Manuel: (Picks up rubber band and axel gear) we need the rubber band for the motor.

Tamara: Yes (points at Manuel, who then dances happily) we do. But… where's the other part of the rubber band need to go?

Despite the youth having double the amount of time on turn with the materials as undergraduate Tamara, Manuel's time with the materials overshadowed Yolanda's. A more positive aspect of this group was their use of hybrid language practices. In the most interactive sequence they utilized Spanish to discuss shared decision-making.

In group one the movement of people and expertise was more fluid. Merza and Tarik moved constantly, and Marnie followed suit. 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 with lemons and potatoes:

Marnie: When it didn't work last time with the play-doh, 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?

Marnie's questions asked Tarik to draw on his prior experience and to troubleshoot in order to design his circuit. The tone of interaction remained playful despite initial lack of success, and Tarik is encouraged to make choices and take risks. When the LED did not light up, it was recognized that the issue might 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.

5.2 Tinkering With Our Design

We saw in EPM1 and 2 that successful design discourse engaged students in thinking both about the technical aspects of their work and the purpose and meaning of their project. For example, in the "flying boots" example discussed above, the technical aspects of the design were negotiated among participants because of their connection to the narrative element of the movie. We also saw that individual children often initially connected more to either the technical or narrative aspects of design. In addition, ensembles that were the most successful tinkerers distributed expertise and decision- making across students and instructors through questioning and discourse that engaged students' interests, abilities and leadership.

For EMP3, due to our observations in EPM1 and 2, we designed mediational tools to explicitly offer participants both "technical" and "narrative" challenges as entry points for an activity, e.g. suggesting features of design such as creating a switch, and offering framing questions such as "what is something you believe in?" (see Table 8). Use of narrative and technical game cards was intended to support participants on specific features of design when they had little or no prior experience with the task. Importantly, cards were also meant to guide students and teachers in developing joint goals through "playing" their individual cards together in a way that captured a range of expertise and interests.

Table 8. Mediational tools for joint problem articulation and design discourse

Tool and Function
Tool: Game Cards Focused attention on particular aspects of design. Suggested and presented elements of design discourse. Supported participants in connecting prior knowledge to new activity. Provided opportunities and constraints for joint problem articulation. Turned responsibility over to undergraduates when they created cards.
Tool: Challenge Game Cards Turned responsibility over to children who created challenges for other groups. Offered groups a chance to "spy" on each other to gain ideas and learn about each other's inquiries. Stretched thinking and challenged students to extend their inquiries.
Tool: "Challenge Plan" Planning Document utilized after groups gained experience with the activities that could be combined for the Rube Goldberg (paper circuits, makey makey, robot picaxe) and a chance to experiment with Rube Goldberg design. Presented a concrete sequence of tasks for combining individual group member's goals into an overall goal for the group's Rube Goldberg. Mediated undergraduates understanding and implementation of joint problem articulation and design discourse.
Tool: Rube Goldberg incorporating three previous activities Built upon participants' experiences and deepened their growing expertise. Modeled a way to connect activities horizontally. Provided an activity with clear design goals but no one right way to achieve them.

An excerpt from Bridget Marsh's CE shares how she and 7^{th} grader Ginger used the game cards to support joint problem articulation in the design of a paper circuit made with card stock, copper tape, LED lights, and coin batteries that focused on the child's self-representation:

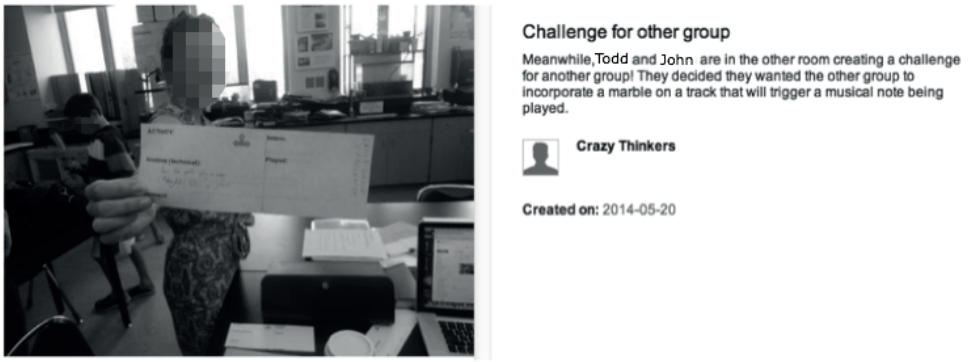
> Ginger didn't have any ideas on how she wanted to make her circuit at first, so we looked at the cards she was given for ideas. Her narrative card was "what you want to be when you grow up" and her technical card was "2 different color LED's", so I encouraged her to come up with a shape that reflected what she wanted to be when she grew up…Ginger said she wanted to be "someone who works with computers" when she grows up, but couldn't think of a shape that could represent this. I helped her brainstorm and we decided on making a lap top computer. (O.C. the idea that in a Community of Learners, "learning is a process of transforming participation in shared sociocultural endeavors" and that the real learning comes from collaboration really resonated with me and I had no problem stepping back into more of an authority role here and helping her come up with suggestions.) Once I explained to her how the circuit boards work, she got really into the activity, and really took control of the process and figured out how the LED's work with the battery on her own, and was really engaged (CE1).

Marsh explained how she used the card to help Ginger, a young Latina, share in the initial design of the circuit, and how this card mediated both her own ability to offer suggestions and Ginger's ability to form a connection with the task. In this example, the narrative aspect of the process facilitated entry for both the undergraduate and middle school student's discussion of the technical elements of circuit design. Subsequently, Ginger, who had no prior experience with the activity, took responsibility for figuring out the circuit design on her own. Significantly, she shared a desire to work with computers as an adult, and here, the circuit building activities helped to support her in connecting this goal to content area learning.

5.3 Shifting Responsibilities in Design

In line with Rogoff's (1994) articulation of learning as shifts in responsibility over time, we also used the game cards to support the movement of framing possibilities for design from the instructors to the undergraduates and to the middle school students. First, we offered game cards that focused in on specific elements of design (see Table 8). Next, we asked undergraduates to design game cards for ensembles of 4–5 undergraduates and middle school students for the culminating Rube Goldberg project that would connect to technical aspects of design, previous M &T activities and students' goals. Middle school students were asked to create "challenge game cards" that required the students to "spy" on other groups and create challenges for them. Challenge cards turned responsibility over to the children for thinking about how to design and structure activity for their peers. (See Figure 2).

Figure 2



Undergraduates' CEs indicated how the challenge cards mediated playful engagement and created ways to push students' abilities and shared decision making in design activity. Sara Marin's CE discussed how the challenge card kept student Lucas interested during less hands-on planning, and how this playful activity served as a meditational tool to address his initial lack of attention. Jim Carter's CE related how, in his words, the ZPD was created *"through the challenge card and the aspect of play it brought to the table"*. He related that after a challenge from another group, his group struggled, but instead of each student working individually on their Rube Goldberg:

…the entire group came together to solve the problem of how we would get our marble to trigger the makey-makey to make music. After a fairly long period of trying different ideas and those failing, Nik came up with the idea to line a track with copper tape that the marble would roll down. This idea led to the rest of the group to add on to this idea and we eventually came up with a system that worked. (CE2)

In this example, joint problem articulation came about through the playful interaction mediated by the challenge card. Students had to come together to accomplish their design, and in the process they deepened their knowledge of how to create circuits.

"Challenge plans" were also used as meditational tools for shifting responsibility to the participants, and as a way to make visible the process of joint problem articulation. We introduced challenge plans for the Rube Goldberg project after participants first experimented with the activity. Sara Marin's CE illustrated the process of joint problem articulation that occurred in planning the design of the Rube Goldberg:

Dom said, "Well, we could turn on a circuit switch." Then Ed jumped in …, "Yea, Lily and I worked on a circuit last time, we couldn't get it to work but I think we could!" I said, "Okay, that is a great idea! Do you all agree that our overall goal should be turning on a switch?" They agreed. Then I said, "Okay so now we have to come up with different sub-goals that are going to get us to our over all goal. That's like what we did last time when Dom worked on a marble track and Lucas connected the tubes, those would all be sub-goals. Do you have any ideas for what you want your sub-goal to be?" (OC: Rogoff explains the COL as a shifting of responsibility between authority and students. I felt that we were constantly shifting responsibility between the students and the UG's through out our planning process.) The students began stating different ideas; Lucas wanted to use tubes, Ed wanted to incorporate the pulley, Lily was interested in using dominoes and Dom wanted to create a marble track. Then we began a discussion on how we could connect all of these ideas. The students offered suggestions and so did we…. asking questions like, "What is going to be the very first thing that happens?" "How will that connect to the next step?" James suggested that we could get the pulley to work by connecting it to the robot and eventually our entire plan was complete. (OC: Here we used mediated joint problem articulation to find a solution to our larger problem, which was to create a plan for the Rube Goldberg.) (CE3)

As seen in the example, individual students created goals based on their interests. This step fed into the development of an overall group goal for their Rube Goldberg. Once a team goal was decided, the team decided on sub-goals for their project through discussing each individual's aim and how it fit with the team objective. An important component of negotiating the team's plan was sharing each members' interests, goals and experiences. As Marin notes, the task of joint problem articulation centered upon how students could connect their objectives. She supported the process through questions that asked about specific features of the students' design. Solutions emerged from participants' design discourse that addressed the technical aspects of connecting each person's work as well as their desired goals.

Overall, the design of activities and meditational tools in EPM3 appeared to successfully implement a more focused framework for the "dance" between diving into activity and creating structured ways of extending students' inquiries and content area knowledge.

6 Discussion: Problems of Practice and Tenets of Design

Our work began with the goal of designing a context for tinkerability within the EPM social design experiment. We aimed to bring together the main sociocultural concepts undergirding the EPM social design experiment with aspects of M & T pedagogy as articulated by Resnick and Rosenbaum, as well as our understandings of children's innovative practices. With this approach we sought to re-mediate normative academic STEM practices in order to address longstanding problems of practice: a) lack of participation in STEM fields for women and members of nondominant communities, b) problematic discursive and pedagogical practices in STEM education, and c) the need for learners to view their everyday practices as linked to academic STEM learning.

Through the three iterations of M & T within our designed learning ecology, we saw that ensembles were successful at jointly articulating the goals of their work and in extending their everyday knowledge when undergraduates used questions that focused children's attention on particular features of design, while also querying children to put forth their own ideas and objectives for specific tasks. We use the term design discourse to refer to the features of such interaction. Other critical features of design discourse supported students in moving horizontally across a range of activities to expand their STEM repertoires, and in developing narratives that framed and oriented their work on multiple dimensions. For example, in EPM3 we used game cards to support undergraduates in asking the kinds of specific design questions that we saw were generative in EPM1 and 2. These cards helped to support both undergraduates and children dive into new STEM practices through leveraging their everyday knowledge and interests.

The EPM social design experiment afforded the opportunity to engage and extend the abilities of undergraduates who come to the program with little background in STEM activity as mediators of children's STEM learning. However, we acknowledge that there are limits to how deep students may be able to dive in, as well as to our assessment of STEM content learning, within the time and space context of our designed learning ecology. What we observed across the instantiations of EPM is how theoretical concepts, in particular that of "joint problem articulation" captured the imagination of undergraduates. This concept supported undergraduates in distributing expertise and agency to members of their intergenerational ensembles as they collaboratively constructed a shared understanding and objectives for their work. We argue that shared problem articulation worked to re-mediate normative classroom structures where the teacher is positioned as the primary knowledge holder "delivering content" and where initiation recitation and elicitation (IRE) scripts that have been shown to alienate children from the scientific inquiry process prevail (Lemke, 1990).

7 Conclusion

We propose that an expansive, cultural historical activity theoretical approach to learning and pedagogy in the creation of contexts for tinkerability paves the way for acquisition of STEM knowledge situated in content and in practice. Our work supports educators in both formal and informal contexts in thinking about how to design for putting theory into practice. It calls attention to the importance of developing both horizontal and vertical forms of expertise and their distribution across participants and practice (Gutiérrez, 2014). We shared examples that depicted a range of success in terms of undergraduates jointly articulating problems, objectives and the direction of activity with students – practices that are central to expansive and equitable forms of learning. The concept of joint problem articulation supported undergraduates in framing their participation with students so that they developed a design discourse that guided activity through questions and through leveraging students' own interests and expertise. As Marin wrote in her final CE:

> The students were learning how to plan out a Rube Goldberg machine and so were the UG's. We were all contributing to a goal and although the UG's held the authority, we never held the power. The power was distributed evenly among all of us. We were a community. (CE3)

We argue that the sharing of power Marin references is critical for supporting all students in STEM learning that is personally meaningful and academically consequential. We plan to continue to analyze participation across the permutations of EPM we discussed in this article, as well as in future design work, in ways that will contribute to the development of robust and equitable learning environments for children and novice teachers.

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