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Participatory Design Research as a Practice for Systemic Repair:

Doing Hand-in-Hand Math Research with Families

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Abstract

Success and failure in formal mathematics education has been used to legitimize stratification. We describe participatory design research as a methodology for systemic repair. The analysis describes epistemic authority—exercising the right or the power to know—as a form of agency in processes of mathematical problem solving and learning. We asked: What will aid families in advocating for their children's math learning, particularly when they expressed concern about their ability to do so? Participatory design research provided a collaborative and iterative method to work with people who shape math learning: parents, children, teachers, community organizers, researchers, curriculum developers, and mathematicians. Data from four years of participant observation involved the design, facilitation, and dissemination of workshops and take-home materials and family case studies. As participating families claimed epistemic authority, institutional barriers became more visible. This tension maps where participatory design methodology can evolve to address systemic change.

We open our paper with a vignette that illustrates epistemic authority in our work:

> Usually parents are really scared of math and then the parents should know that every single day there is math in our life… just going from point to point, that's math already… it all adds up.
>
> –Blesilda Ávila[1], from videotaped interview

In this brief statement, Blesilda Ávila, a mother of three, encapsulated the story of a transformation in her thinking about math, motivated by a concern with how families—specifically parents[2]—typically experience it. Blesilda's statement was an encouragement to other parents that she formulated while tackling her own math fears. To be more precise, Blesilda implied there is a relationship that is not working—something broken and in need of repair. When she said, "Usually parents are really scared of math" she was invoking parents who return to math in schools while supporting their children's learning only to encounter fears that diminish their participation and can promote "we're not math people" kinds of identities. Those math-based fears—of being shamed or labeled incompetent or found helpless—challenge parents' core commitments to their children's long-term well-being. In this way, those fears reveal a rift that repeatedly forms between experiences of formal mathematics education and parents' aspirations to help their children. Mathematical practice becomes a social, cultural, and historical problem in need of repair. Blesilda transformed her perspective and her practice by creating opportunities to reclaim mathematics as a form of knowledge and practice available to anyone: "…then the parents should know that every single day, there is math in our life. . . .it all adds up." Blesilda's words make the point: there is a barrier, and it is surmountable, possibly

reparable. Her statement opens a channel by reframing daily life as an abundant space to reclaim agency in mathematical practice and, in turn, support children's learning.

We met Blesilda because she was active in an after school organization where we were seeking design consortium partners to co-develop materials to support parents' advocacy in schools on behalf of their children. At the start of our collaboration Blesilda's three children attended three schools: pre-school, second grade, and seventh grade. They attended educational programs after school and on weekends Blesilda worked as a nurse. She had immigrated to the U.S. from the Philippines and lived in a public housing community near downtown San Francisco where she was raising her children. The family regularly participated at a local church ministry committed to serving the inner-city community. Blesilda was already an advocate for her community when we met, and our collaboration widened that scope to include math, a domain where, initially she was hesitant.

Blesilda was also in a parent-organized school safety group who walked the halls and perimeter of the middle school and worked to maintain a safe environment. The parents wore yellow windbreakers that identified them as on-duty. Blesilda explained that she built strong relationships with fellow parents and school staff as she walked. She relied on those relationships while working with us, continuously responding to challenges with participatory advocacy. The parents who joined the design consortium were like Blesilda; they exercised agency within their children's schools through many forms of participation. But mathematics in school posed a different kind of challenge: Like the rest of the collaborative design consortium with whom we worked, Blesilda agreed to partner with us because her personal commitments and questions were well aligned with ours and with others who were joining us. Like other parents who joined the team, at the start, she acknowledged her anxiety about math and what she might be able to

contribute. As we sought partners in design, we repeatedly encountered a rift between people who were actively wielding agency with regard to their children's educational experiences yet were stymied by math in schools.

The Ávilas, and other families in the project, taught us that with time, attention and intention, mathematics entered the family discourse in conscious and in unplanned ways. We saw Blesilda experience a change in agency and authority about math. When she started, she told us she did not see much math in the family's interactions. This was common among families across any spectrum, including nearly every family that participated in the project, and is evidenced in literature on everyday math (Lave, 1988; Saxe, 1988). Even when families told us they saw a lot of math in their lives, their examples were usually limited to arithmetic. Towards the project's finish, Blesilda viewed math as highly relevant to many aspects of life, stating you could "just stop and see it" in situations.

We describe Blesilda's transformed orientation to mathematics as an evolution of epistemic authority—as exercising the right or the power to know. She and other parents consistently described their own fears about math and their sense that they were not generally engaged in mathematical practices. They saw us, the researchers as well as their children's teachers, as having mathematical authority: We could name things mathematical and make math visible. In other words, we were initially perceived as "knowing" math while, by their own estimations, they were not. This was another indication of a huge rift. The math rift, as reflected in Blesilda's story, is indicative of the ways in which many families "juggling both 'non-dominant' and 'dominant' cultural capital" (Carter, 2003, p.137) are positioned with respect to mathematics and schooling. The politics of the rift—power relations between people with and without epistemic authority—were in play because we wanted to design together. At the start,

lines were fairly rigidly drawn along the lines of epistemic authority, distinguishing committed but mathematically-timid parents from researchers and educators. This participatory design research explores these dynamics and describes ways in which the restoration of epistemic authority became a form of agency.

Foci of Design

We set out on a participatory design research journey with families, teachers, scholars, students, community organizers, curriculum designers, and a mathematician to confront math fears and tap into people's math resources, making them visible. The first step in restoring families' epistemic authority and producing forms of transformative agency was making people's everyday math visible. Following this, we engaged in designing new ways for families to create new avenues for dealing with their children's schools. With participatory design research as our method we involved ourselves in mathematics as both disciplinary and cultural practice. Our initial design premise was that we could displace parents' fears of math by naming our everyday math practices and letting them start building new confidences. The project resulted in three major foci of design: family workshops, take-home materials, and a series of family portraits of math agency.

This paper is a tour through a version of Participatory Design Research (PDR) that revealed some of the accomplishments of the method and some of the tensions and challenges encountered as we tried to support families' advocacy on behalf of their kids. The process made systemic issues we needed to contend with visible and showed us opportunities for repair. Our analysis of PDR reveals the method's role in supporting parents to develop power in legitimizing their authority in everyday mathematics practice—a sorely needed systemic repair. The project provides ample evidence of practical and flexible collaborative design work that PDR can

support while revealing tensions to address, such as the need to be vigilant about repairing problems instead of replicating them.

Who Designs and Why

The participatory design research project explored was called PRIMES: parents rediscovering and interacting with mathematics and engaging students[3]. The project allowed us to think with families about their daily problem solving, identify math practices prevalent in everyday tasks, and highlight links with middle school math learning standards. At its core, it was a project about parent advocacy and participation rights. We asked: What will aid parents in effectively advocating for their children's math learning, particularly when they have expressed concerns about their ability to do so? Ultimately, the entire project team engaged in ethnographic research and design activities. The design work became the focal point of shared, reciprocal activity and was the site for developing materials and resources that would help parents build knowledge and confidence about their familial math engagements and help to sustain engagement in their children's middle school math. The project developed nine family workshops, a television special on family math, and a resource guide for parents about navigating school math in middle school years. The project also produced articles about family math, design-based research, and methods (Goldman, 2006; Goldman & Booker, 2009).

The project began with a process for establishing the collaborative decision making of the consortium of researchers, parents, teachers, and community workers to determine the design and research work. The participants, comprised of parents and educators from three Bay Area cities, were there to come to know each other, learn about experiences with math, and move their various personal and project goals forward. The work was based in mutual exploration and experimentation—what we called "hand in hand" (Goldman & Booker, 2009). The approach was

ethnographic, participatory, and located at the nexus of ethnography and design-based research (Bang, Medin, Washinawatok, & Chapman, 2010; Barab, Thomas, Dodge, Squire, & Newell, 2004; Brown, 1992; Engeström, 2011; Gutiérrez, 2008).

For almost four years, the consortium met quarterly on weekday evenings. Families attended the meetings together, with our youngest attendee at two years old. Most children who participated were between the ages of 10 and 13 years old. Together we developed materials and activities, collected research artifacts on ourselves and our experiences, and conducted data analyses. In return for consortium participation, we offered modest stipends. Eventually, the meetings included social time (including some light supper and personal updates), discussions or tryouts of workshop activities or materials (e.g., topic for a workshop or activities that might address a design idea that was floated), and time with research data (looking at a videotape of workshops or planning an upcoming event).

Our systemic focus indicated there would be breakdowns, as with any long-functioning hegemony. Methodologically, PDR helped us hold our focus on systemic repairs, staving off hegemonic pressures to seek and repair deficits *in people*. This was especially important because at the start of their participation in the project, parents consistently expressed fears about their own math deficiencies (e.g., “I’m not a math person”; “I struggled with math in school, and I’m worried about being able to help my child with math.”).

Under what circumstances would people who are not math teachers or researchers decide to devote a significant number of their evenings and weekends to math that was not a requirement of their job or a passionate personal interest? In his rigorous critique of design research, Yrjö Engeström (2011) asserted, “Scholars do not usually ask, who does the design & why” (p. 600)? His critique highlighted ways that a potential strength of design research—to

create conditions for social agency to thrive—has typically been lost to the assumption that the method can be distilled to its implementation and refinement cycles:

> While there are many different versions of design research, it seems fair to conclude that the following weaknesses are quite pervasive. First, the unit of analysis is left vague. Secondly, the process of design research is depicted in a linear fashion, starting with researchers determining the principles and goals and leading to completion or perfection. This view ignores the agency of practitioners, students, and users. It seems blind to the crucial difference between finished mass products and open-ended social innovations. (p. 602)

With the intent to keep researchers from dominating the responsibility for goal setting and focus, we invited parents and other team members to help define specific goals, research aims, and educational resources needed. We relied on PDR to discipline us to consistently attend to agency among participants. Specifically, we examined systems of activity—(a) everyday math practices, (b) hand-in-hand design of workshops and supportive media materials for families, and (c) advocacy efforts on behalf of children in schools—for intersections and contradictions as we persistently redefined our activities together.

To the researchers, math was a daily human practice of problem posing and problem solving, and those practices mapped well with middle school math concepts. In order to look analytically at our use of the PDR method, our unit of analysis is a set of workshops that were the objects of our first design efforts. The analysis examines when and how discords and rifts were revealed and how participatory design methods molded our attempts to address them. We share cases from our initial and redesigned workshops that were led alternately by teachers and parents on the design team. The cases are representative of the cycles of evolution that

accompanied the participatory design of artifacts throughout the project. We close with discussions of how PDR guided our collaborative practices and our sense of methodological challenges and opportunities going forward.

Repair as a Mode of Agency

Agency and power were central aspects of advocacy for access to mathematics learning. Bandura (2001) discussed the extension of social cognitive theory to address collective agency, stating, “People’s shared belief in their collective power to produce desired results is a key ingredient of collective agency” (p. 14). It could be said that our systemic repair attended to “shared belief” about math practices. Relatedly, Holland Lachicotte, Skinner, and Cain (1998), addressed agency as a form of authorship that reveals epistemic authority as a kind of agentic repair:

> The world must be answered—authorship is not a choice—but the form of the answer is not predetermined. It may be nearly automatic, as in strictly authoritative discourses and authoritarian practices. . . . In either case authorship is a matter of orchestration: of arranging the identifiable social discourses/practices that are one’s resources. . . in order to craft a response in a time and space defined by others’ standpoints in activity. (p. 272)

Families and researchers aligned in our disciplinary concerns with mathematics. The children were concerned with doing well in school, which served as a proxy for their learning. Parents were concerned with how to support their kids’ effective academic engagement during a period of increasing complexity in the disciplinary work. Middle school mathematics curricula moved well beyond arithmetic and early number sense into the foundations for algebra and geometry: functions, proportional reasoning, probability, and statistics. We—researchers and

activity designers—were concerned with ways to effectively sustain people's connection with mathematical ways of knowing, seeing, and doing, and understanding how math in school and math in daily life could be better connected. We acted as agents for these concerns through participatory design research. The researchers set out to help establish or restore people's epistemological authority in mathematics. Parents were setting out to ensure their kids would have many future choices, seeing math as a vehicle for doing that.

We began with the idea that there was a math rift that served as a potential site for repair. The rift, as we initially understood it, was an uneven split between people's everyday math-related practices and the style of mathematical problem solving found in schools. It was uneven because schools were the sites for declaring who held epistemic authority, which was enacted by determining what qualified as math and discerning who was good at it (e.g. through grades and class placements). When inviting people to the project, we consistently encountered their fears about their own inadequacy in the subject and for their children's potential or real struggles. We found that people did not want to attempt math publicly. Something was broken here. A persistent standard has been cultivated where some folks are "math people" and others are not.

For us, this was an opportunity to engage in repair, a practice of caring for and restoring what is valued and integral to people's lives. In his essay "Rethinking Repair", Steven Jackson (2014) addressed repair of sociotechnical systems as occurring in the space between "an almost-always-falling apart world" and "a world in constant process of fixing and reinvention" (p. 222):

> The fulcrum of these two worlds is *repair*: the subtle acts of care by which order and meaning in complex sociotechnical systems are maintained and transformed, human value is preserved and extended, and the complicated work of fitting to the varied circumstances of organizations, systems, and lives is accomplished.

> Repair in this connotation has a literal and material dimension, filled with immediate questions: Who fixes the devices and systems we "seamlessly" use? Who maintains the infrastructures within and against which our lives unfold? But it also speaks directly to "the social," if we still choose to cut the world in this way: how are *human* orders broken and restored (and again, who does this work)? (p. 222)

This returns us to our earlier theme of who designs and for what purposes. Jackson (2014) argued convincingly for attention to "the forms of innovation, difference, and creativity embedded in repair" (p. 228). For us, participatory design research was a form of repair to address a rift in epistemic authority around mathematical ways of knowing. The method offered ways to try out new interpretations and responses to repair needs. Those who participated in design identified what was in need of repair. How repair efforts would proceed, in turn, was dependent upon the group's defined purpose.

Understanding the Function of Workshops in Our PDR Process

In the first year of the project, we explored how already existent family practices might contribute positively. The goal was to identify practices that were so familiar, relevant, consequential, or even comfortable for people that they might be uncovered, explored, and easily connected to school math. Initially, the researchers acted as the math authorities, identifying contexts where everyday math practices were likely to emerge and presenting rough prototypes as springboards for developing potential workshops. Examples included household budgeting, home improvement work, and playing games.

Workshops defined the group's activity for several years and became sites for the group's learning and insight. The design and practice of workshops—and the tensions that emerged—

revealed the phenomenon we describe as a math rift, processes for establishing epistemic authority, and the kinds of flexibility that our relationships grew to sustain. In this way, the workshops help us address broader methodological questions and opportunities to theorize about participatory design research when it is framed as a context for repair that can nourish forms of agency.

We started with two workshop prototypes: *Nutrition* and *Build a Planter Box*. We thought the nutrition workshop would be widely appealing because families could take up the topic while shopping, cooking, packing lunches, and negotiating what food they ate. The mathematics emerged in the task and included proportions and percentages. The planter box workshop was a hands-on activity during which families produced a planter box to take home while measuring for optimization of materials and considering two and three-dimensional shapes. Two middle school math teachers in the group volunteered to host and facilitate the first workshops at their schools. Parents told us they did not yet want to lead.

First Workshop Pilot: The Soon-to-be Shelved Nutrition Workshop

Pam Allen, a middle school math teacher, hosted a weekday evening nutrition workshop. She invited parents and kids to attend together, encouraging students to bring their families. The design team had talked about ways to make parents comfortable, particularly when asked to problem-solve in front of their children and others. We also wanted to shift away from the teacher being the sole authority, and we thought the familiarity of the content would support that. Pam opted to hold the event in the multi-purpose room and she felt ready to facilitate in a gentle way.

Two challenges developed almost immediately. The families ceded the event entirely to Pam. Second, Pam did not have the supports she needed to hand the activities back to the

families. The result was a very quiet, attentive experience, similar to a teacher giving instruction to students in a classroom. When it was time for families to problem-solve together—to create a healthy lunch that would be the sum of multiple, balanced, nutritional elements—parents mostly put the tasks in their children's hands and supported them as you might imagine them supporting homework tasks. This was a blaring sign of the math rift: authority rested with the teacher and the math became a practice exercise for the kids.

The atmosphere resembled a classroom and homework session. It was quiet. The healthy lunch activities did not inspire developing a shared approach to problem solving. No one seemed particularly satisfied. While parents expressed appreciation for the opportunity, we didn't observe or hear reports of any "aha!" moments.

That workshop, and the kind of math problem solving accomplished, felt a lot like school, and as such, it reproduced the systemic rift we were seeking to repair. We did not know if it was the work on proportion or percentages, the site of the workshop, the facilitation, or some combination of those factors. Parents on the team suggested our hands-on workshops might be more effective because they were more open-ended. The researchers and math teachers thought that facilitation might need to be led by a parent or community leader to disrupt systemic patterns that kept authority with the professional teachers. The design team members collectively debated ways to support facilitators and create a more open, active, and inquisitive experience. We began to think about facilitator's resources in addition to the workshops' content and how they could be organized for reorganizing the status quo. We simultaneously analyzed data we collected. We developed methods for understanding how our prototypes fared. We observed and videotaped all activities and interactions, collected artifacts of people's work, and informally interviewed participants about their ideas. The research team conducted preliminary interaction and discourse

analyses (Goodwin, 1990; Rampton, 2006), then brought selected videos to the consortium meetings to gather ideas about what the various stakeholders saw. We video recorded those sessions and took notes.

The viewing and feedback changed the directions of the activity designs and evolving research. After analysis of the tensions revealed in the first workshop, our reflection led to three new signals for workshop participants. We featured a hands-on math activity that was more physical and embodied: It was an open-ended woodworking project where families had authority over their own solutions, which repositioned the teacher as a fellow learner. Finally, we moved the workshop outside, and held it on Saturday morning, out of the familiar cycle of the school day.

A Second Field Trial: The Promising Hands-on Build a Planter Box Workshop

On a sunny Saturday afternoon at the middle school where she taught, Judy Capello hosted a group of families for a workshop in her classroom. One parent on our team, Yolanda Martinez, worked with Judy as the front office manager at her daughter's middle school. She partnered with Judy to recruit parents for the weekend workshop. Judy began by welcoming everyone and explaining the activity. For a warm up exercise, each person shared a personal experience with math—good or bad. This warm up went really well and addressed some of the anxieties in the room that were prevalent but typically unspoken. Stories included things like a home improvement project: challenges arose when shifting from measuring and purchasing laminate flooring to installing it; when staggering the pattern of planks to create a nice look, the family had to avoid running out of material (and going over budget). The planter box workshop offered some distinct opportunities because the central activity of the workshop involved designing and building. The open-ended and hands-on-construction changed the dynamics of

interaction. Kids and parents talked to each other about their ideas for form and function: what kinds of plants would they put in their box? Where would it fit in the house or yard? Were the measurements for the pattern going to give them the right parts for a complete box? After planning, families went out into the courtyard, using their plans to build a box. Moving outside, measuring, sawing wooden boards, and fabricating boxes turned into a very social activity. People got ideas by noticing what other families were trying. There were surprises. For instance, most people—particularly those who had not worked with wood before—had not accounted for losing about a quarter inch of board to the saw blade. While working they talked about what was happening in their lives. There was a subtle sense that parents wanted to exhibit competence, and competence looked a certain way—a way that was being validated at school.

When they had finished building their boxes, everyone returned to Judy's classroom to "uncover" the math and discover the related curricular versions of it. Here, the conversation was livelier than it had been at Pam's workshop, but families still oriented toward Judy as the math expert and let her prompt their discussion. While the workshop activity had looked more like what we had hoped, the mathematics, already accomplished competently in action, shifted out of the parents' hands during discussion.

Examining the two pilot rounds of facilitating and experiencing workshops was revealing. At the next design consortium meeting and video analysis session, we agreed that when teachers facilitated, they were struggling to make room for cultural and personal ways of knowing. They wanted to validate what parents were doing yet had to be mindful to not perpetuate the sense that only math teachers held authority over what counted as math.

One important way to meet this challenge was to rely on the powerful rules of engagement we had established where parents were the leaders and experts in setting new

directions for these materials for each context. Though parents had been reluctant to facilitate, Blesilda became the first parent on the team to decide to try facilitation. Our evolving model, similar to the community-organizing model described by Ishimaru (2014), dismantled mechanisms of a deficit model and created the conditions for parents to exert agency as leaders in our team. Seeking deficits in people implies desirable assets reside in others. Our approach subverted the have-and-have-not question to a concerted recognition of a mathematically-able community with distributed and situated resources.

Blesilda's move to being a facilitator led to new design questions about how easily someone who hadn't been a teacher could pick up and adapt a workshop. It required up-front organizing and gathering of resources and a good deal of flexibility when facilitating the closing discussion about the kinds of math people had accomplished. It was time to take up these issues.

Third Trial: Make a Polyclay Picture Frame

Blesilda quickly arranged for a room at her son's school and worked to recruit parents. People attended even though they told us they were scared of math, relating how Blesilda assured them they would have a good experience. One woman told us, "I prayed to God that I would get through this." These anxieties led Blesilda to choose the Polyclay workshop where parents created colorful picture frames with circular, decorative designs of polymer clay and saw ways that craft and math intersect. Like the planter box workshop, this activity was open-ended and made room for parents' epistemic authority to be validated. Yet, the workshop resources and artifacts of our design work needed to accomplish a burst of mathematical agency in parents during a short workshop. Blesilda taking the lead, not only in organizing but in facilitating the experience, helped address several layers of repair. The result was greater than the sum of its parts. It was not a simple shift from a teacher-leader-parent-participant model to a parent-leader

model. It is an illustration of how an intent to repair became a mode of agency when a model of individual learning began to give way to a model for collective learning.

Blesilda set the tone, gently addressing fears with encouragement and confidence. Parents expressed gratitude to participate in a workshop that did not expose them as not knowing school math (the anxieties and gratitude for not being shamed were frequent occurrences at future workshops hosted in New York, Florida, and Michigan). As the workshop proceeded, parents shared that they felt the activity gave them confidence, that they were doing well, and they realized no one was giving them a test. The difference born of supportive social relationships in the community caught the design team's collective attention. The workshop seemed to be effectively targeting the kind of repair we hoped for until we reached the closing discussion time. All of the parents including Blesilda turned to the researchers in the room to summarize the math of radius and circumference accomplished during the making of the polyclay frames with "circle" and "bulls-eye" designs. When they oriented to us, one of the researchers posed a question to try to re-invigorate a wider field of epistemic authority. But we recognized we would need to address this ingrained tendency to defer to perceived authority in future design iterations.

Following this workshop, the team committed to providing supports that parent facilitators could choose to incorporate when hosting workshops for other parents including parent-oriented facilitator guides and videos that introduced the starting activity and later closed up the workshop with an easy to follow discussion, visuals, and discussion points about the workshop math and how it related to school math. Within the team, it was a turning point in parents' orientation to their own epistemic authority. They began to bring personal examples of math practice and advocacy efforts to the table. This led to projects that came after the

workshops: a Parent Action Guide to help parents navigate math at their children's schools and a television special featuring family portraits of everyday math practices.

Our Learning Through Workshop Design and Facilitation

Design learning aside, we highlight how the workshops organized us to develop a more specific understanding about the math rift. The rift became visible when we recruited workshop participants, facilitated workshops, and participated in the activities. It punctuated the moments where families were engaged happily in using math in problem solving activities. Most striking was the consistent sentiment that the revised workshops were unusual for everyone attending. It was atypical in math, and in school in general, for parents to engage in the thinking, problem posing, and problem solving with their children and their children's teachers, with an equal stake in the work. This suggests that our team had designed a repair for the math rift by establishing a math learning environment that disrupted persistent hegemony and supported a kind of democratized epistemic authority.

Together we looked for ways to ensure that the workshops were designed so that participation produced openings rather than constrictions. The invitations, workshops, and facilitators' guides had to be carefully attuned to the actions set in motion by the rift. In addition to effectively showing links between daily problem solving and middle school math, we also needed to be responsible with the hopeful combination of bravery, commitment, and skepticism that occurs when people willingly step into a realm where there is a real possibility (and often a history) of experiencing shame, pain, or the need for self-preservation. These were signs of the rift that served to diminish people's epistemic authority. As such, it was an opportunity for visibility and repair, one that carefully considered the histories of school math encounters of people who were going to participate in or facilitate workshops.

Portraits: Open-ended Results from an Evolving PDR Process

As the workshops rolled out, the design team began turning attention to immersive studies of families' math practices. Three families who were members of the design consortium agreed to have us visit their homes and join them during family activities. Three additional families who came through the consortium's networks also agreed to participate. There were two goals for the case studies: (1) conduct knowledge-building research on family math opportunities and what they might mean for math success; and (2) learn how parents exercised participation and advocacy for their children with schools. All families included at least one child in middle school, though five of the six also had at least one other child in elementary or high school.

For these three families who were members of the design consortium, we drew on the videotapes from consortium meetings and field notes that provided information about many aspects of their lives: their work at schools and in their communities, their livelihoods, what they had shared about home and family, their goals for their children, and the places where they either recognized math practice in their lives or disputed its presence. During our working hours together, they had also cultivated an eye for math in everyday activities, just as we had. We agreed to observe and film together, and kept our cameras running for the duration of daily interactions, which led to more spontaneous problem solving, or discussions of it. The combination of the planned observations and unanticipated activities made up the data set for these families. The families invited us from one activity to the next—making dinner, catching the bus to the grocery store or to their children's schools, visiting an amusement park, preparing for and attending a school talent show, and so forth. Typically, we interacted with the whole family at once, but at times we also spoke with the children or parents separately.

During the initial interviews with the newly recruited families, we asked about the kinds of activities they participated in as a family, their work, hobbies and interests of each family member and about any projects they had planned for the relatively near future. We probed for a wide range of activities, not limiting the interviews to what might appear “mathy.” We did this so we would not miss potential opportunities that were not necessarily considered mathematical by newer participants who were not sensitized to do so. In the first two-hour interview with a family, we branched out, asking family members to describe a typical day in their lives and to tell us about their hobbies, goals, and activities. Interviews were videotaped and transcribed and coded for explicitly stated or potential opportunities for mathematical problem solving. Once the research team identified activities for observation that were math-relevant, follow-ups were scheduled. We returned to accompany families during activities like setting a budget for the prom and shopping for a dress and accessories on a budget; attending a professional baseball game, calculating player stats, and predicting likely outcomes; figuring best bus routes for getting to and from the children’s schools; or stocking, selling, and keeping inventory and books for a home business. We filmed and gathered field notes during these interactions with families, and collected 10-20 hours of videotape for each family. Coding the video and field notes data clarified a wide range of mathematical practices and the circumstances that supported them as occasions for the family to problem solve together (Goldman & Booker, 2009). We also coded when parents discussed the school and life goals they had for their children (see Pea & Martin, 2010), discussions about how they participated in the schools, and ways they supported their children’s learning. We watched the videos together, amplifying the dataset; parents reflected on the ways they and their children talked about intentions and interactions and what they knew of their consequences and outcomes. These sessions brought new ideas into the research and

focused analyses on leads from family members. Through this process, we developed portraits of each family and their orientations to school and to math learning (Lawrence-Lightfoot & Hoffman, 1977).

Working together over a period of years in the development of workshops led to the development of resources rooted directly in the lives of partnering families. Collectively, we had become a group of people who saw and named math perpetually. This was as true for researchers as it was for families. We had become "primed" to distinguish math-related aspects in a wide variety of situations. We had also, increasingly, begun working with families in their homes and learning about the wide range of ways they were interacting with their children's teachers, administrators, and school activities. Families on the team began to show us what it looked like to carry that priming into the wider activities of their lives. By the end of the project, parents and their children had taken over directing us to the math that was relevant and important to them (for several examples, see Goldman & Booker, 2009). This change was also reflected in the research team's shift in role from authority to witness. Briefly, we check in with Blesilda's family once more to gain a sense of what it looked like once PDR had nurtured our relationships with each other and strengthened our awareness of our ways of knowing and doing math.

Blesilda Ávila's family: advocating math awareness wherever possible. The Ávilas came to all consortium meetings, helped create strategies for involving parents in math, co-designed project materials, and often acted as user-testers of prototypes. Blesilda drove the 35 miles each direction with children in tow. She expressed her commitment to what the project was doing on every occasion.

About three years into the project, we visited the Ávila's home for a day of activities they had planned. We saw Blesilda model optimized decision-making. During a trip to a local

amusement park, the family negotiated a schedule for the day that would get everyone to their chosen rides and shows and the same was true of purchases**.** When it was time to have a family photo of the park visit the family collectively optimized for best value on the spot from the many photo packages, balancing best value for meeting Mom's budget and the children's enjoyment. Blesilda made her reasoning available to her kids by talking through the considerations of the decision.

Fast-paced optimization was a skill that helped the family. Blesilda and the children consistently made sure they had the information they needed to make best value decisions. At home in the morning, Ben and Vijay processed some thinking with numbers about the value in renting or purchasing video games in very similar ways to how we saw Blesilda figuring how to maximize budgeted dollars at the adventure park. All told, the details helped the family stay in budget, and enjoy their activities while arithmetic, estimation, mental math, and weighing factors helped determine best value. That the whole family played roles in the problem solving is just the tip of the iceberg. The key takeaway is that daily life easily accommodated commitments to family connections, community commitments *and* math engagement.

Blesilda also illustrates how far a parent could take her math knowledge and practice at school. Where Blesilda saw an academically-relevant opportunity, she connected others to it. She nurtured her social relationships with fellow parents at the school, administrators, and teachers. She combined that with cultivating new patterns of overt, authoritative mathematical practice. She drew on those relationships to get space for a math-oriented workshop at the school, during the school day, while pulling together a group of nervous parents to participate.

However, Blesilda's workshop for parents on campus was as far as any parent, teacher, or researcher in the study got with the school, and we saw this pattern with other parents that

participated in the project (see Goldman & Booker, 2009 for other accounts). Distance from the academic and intellectual activity in school math classrooms stubbornly persisted, another rift—outside of our project's purview—in need of repair.

Through collective efforts to restore epistemic authority—by making daily math practices visible—the design team engaged in a process of systemic repair. We describe the repair effort as systemic because we observed a persistently emerging rift among parents we met throughout the United States as we worked through the design process. Their experiences with math in schools—experiences ostensibly designed to effectively support mathematical competence—left many of the parents we encountered feeling largely incompetent in mathematics or simply disconnected from mathematical practice (for a more detailed discussion of this phenomenon, see Goldman & Booker, 2009). Yet, the will to repair emerged from parents' desire to ensure expanded possible futures for the children.

Summary of Implications for Theory and Methods

> All there is to thinking is seeing something noticeable which makes you see something you weren't noticing which makes you see something that isn't even visible.
>
> –N. McLean, *A River Runs Through It*

Participatory design research disciplined the team to attend to agency among participants. That made it methodologically appropriate for our task. All of us, without exception, were part of a learning environment that was being developed and negotiated through the process of participatory design. However, we did not begin the process as participants in a singular, shared community of practice. Our histories and practices had to be attended to, revealed, challenged, and co-analyzed until a shared community of practice could emerge—one that that could encompass our more stable roles (e.g., researcher, parent, teacher) while supporting and

demanding that we refine our practices in relation to those roles (e.g., witness, facilitation). That was a beginning. By engaging in practices of “making visible” and defining repair systemically, we could establish participatory design as a necessity for addressing the phenomenon of concern. Together, we could cultivate forms of transformative agency and the possibility for disrupting hegemony while accepting that persistent tensions and likelihood of reproduction should be treated as given.

What resulted was a collective effort to identify repairs in how epistemic authority is constructed and persistently affirmed and denied. The principles that follow distill how PDR disciplined our team to attend to agency among participants and signs of repair-oriented shifts, like the researchers shift from authority to witness. Attending to these shifts also revealed theoretical implications for learning that depend upon how we co-construct individual and collective interpretations of learning. That is, does our project demarcate who has a legitimate claim to epistemic authority? Or, alternatively, does it make epistemic authority visible as a collective and dynamic process of engaging in the world? What we experienced through participatory design research was an immersive experience of the foundations of situated learning and sociocultural theory (Holland et al., 1998; Gutiérrez, 2008; Lave & Wenger, 1991). Collectively we attempted to make the intangible visible, risked taking on new vantage points, and discovered new forms of agency. These experiences, and the shifts in epistemic authority that resulted are ways to participate in learning.

We began by framing participatory design research as a method particularly suited to address needs for systemic repair. PDR afforded us opportunities to collectively claim and re-establish epistemic authority that had become concentrated in systemic structures driving formal mathematics education. We addressed three related components of repair work that the method

supported: visibility, agency, and power. We return to these central components here and consider four principles that deal with strengths and challenges related to participatory design research, theoretically and methodologically: (1) sustained open dialogue about what counts as the phenomenon of interest; (2) simultaneous positioning of each of us as learner and authority in ways of knowing; (3) cycles of collaborative data analysis and design that extend the dataset and (re)direct the work; (4) removal of individual and cultural deficit as an explanation for systemic phenomena.

Principle 1: Sustained Open Dialogue

One of the critical functions of PDR in our project was to hold open space for the emergence of multiple interpretations of *what* was in need of repair. The method helped accomplish this by "making visible" layers of systemic experience that render math a school subject more so than a human practice. Recall, for instance, the interview protocol that expressly focused on families' experiences with problem solving rather than *mathematical* problem solving. We developed that protocol together after multiple experiences of inadvertently reproducing the math rift in our early practices together. Our sense was that this easily reproducible discord was powerfully limiting learning, communication, and action in moments when people greatly desired to intervene. Bang, Medin, Washinawatok, & Chapman (2010) described a hypothesized discord when partnering to develop culturally-based science curricula:

> In part we have learned that a central feature of the discord students experience is the lack of connections across the multiple contexts in which students learn science. This lack of coordination manifests itself across a range of levels, including, but not limited to: content knowledge, practices, values, and relevance to family, community, and society at large. We continue to work with and refine

> our understandings of what this discord means and what it looks like in teaching and learning practices, and how addressing it pedagogically opens new opportunities to develop effective teaching and learning strategies that build on the variety of resources for learning Native children bring to the classroom. (p. 586)

We engaged in related work in the realm of mathematics with families, particularly the ongoing nature of coming to understand the discords at work. That ongoing process also produces a challenge that becomes visible where funded design work collides with systemic expectations for scalable solutions. As with Bang et al. (2010) and Engeström (2011), our PDR experience leads us to conclude that "open-ended social innovations" are crucial to systemic repair and that scaling method rather than product is a challenge for which PDR is well matched.

Is visibility, as a mechanism, enough to effectively achieve systemic repair? In our experience, the answer is it is necessary but not sufficient. It is difficult, at best, to exercise agency on what goes unnoticed, and people in different positions notice different things. The types of agency that emerged during our project appeared as we looked together and noticed what we had not yet seen. Our connections with the math rift became visible and forms of agency followed, evident in our designs, design practices, and implementation. Our PDR experience showed promising ways to address one aspect of the rift while usually revealing another (e.g., the design trajectory from the teacher-facilitated nutrition workshop to parent-facilitated and open-ended, hands-on workshops). As with plumbing, once you start, you may find a much more complex repair beneath the walls. Everyone on the team could recognize the opening up of engagement and access to math-related activity at home, in their community lives, and even at work. But engagement and access to the daily intellectual activity of math

classrooms remained closed. This is not surprising, but it informs areas of attention for the future of PDR projects that intend to address power.

Principle 2: Learner/Authority Positioning

PDR did help us attend to distributions of power inscribed in *our* relationships and relative positions in our shared quest for effective math learning. In our example, restoring epistemic authority was the target of repair, brought on by a systemic concentration of mathematical authority in school structures. Authority was also concentrated among the researchers who conceived the initial project and recruited the initial participants and among the math teachers who carried their credentials in their title. Likewise, parents on our team were simultaneously hesitant about their math skills and how they might be able to contribute to design work on the subject and expert in what parents of middle schoolers where facing and in what community organizing required. We all had so very much to learn from one another, and we had a lot to learn about collaborative design. We absolutely needed methodological support to re-calibrate our positions as learners and people with epistemic authority. PDR helped us organize participatory action through open-ended, collaborative design practices and in turn helped us restore epistemic authority within our team. Much of this occurred as we designed materials to help others do the same. This is as much a methodological point as it is a theoretically important one. Processes for restoring epistemic authority produce learning as, at least in part, a process of repair that touches all participants in a community of practice by making demands on all participants to shift their practice in service of collectively defined goals. Learning, itself, is conceptualized as susceptible to systemic dysfunction and accessible for repair. In these ways, power was in play in our project. PDR helped us become visible to each other as both learners and authorities.

Principle 3: Collaborative Data Analysis

A central part of our use of participatory design methods was a collaborative cycle of data analysis. As we gathered data—recordings of our design-team meetings, field notes from our prototyped workshops, interviews with families—we brought that data to the meetings and reviewed it together. In this way, we learned what collaborators on the design team made of the dataset, and we generated data about our own collaborative process. This is a key advantage of PDR. In essence we generated data about what we were designing to share (e.g., workshops, Parent Action Guide, etc.) while also generating data about our methodological process and how it was functioning as another site of learning. Community collaborations require dedicated attention, lest we continue to reproduce the very circumstances we set out to address. The dataset produced with PDR methods efficiently and effectively informs this joint process.

Principle 4: Muting Individual and Cultural Deficit

The tendency to repair deficits in people is one way that the rift in epistemic authority gets reconstructed. Through PDR, we sustained our attention on systemic repair and noticed our potential for reproducing aspects of the math rift. At the same time, we challenged persistent deficit-based discourses that produce math people and non-math people. Ultimately, our quest was really embedded in some deeper goals: love for our children and our respective communities, respect for and humility regarding people's daily practices, and the importance of open-ended models for participation. The character of family and community activities among people on the design team mapped well to these open-ended models. Deficit-based framings of the problem only served to diminish participation. School math curricula and classrooms already presented closed practices—problems for which there were already solutions, progressions through problem solving that were settled, and established authority through the credentialing

mechanism of schools. We needed openings to increase participation. To us, this kind of friction and discord made PRIMES a strong candidate for a PDR approach that could mute deficit and amplify people's agency.

In sum, participatory design research methods supported us to make power part of the conversation, first through "power to legitimize" and then through "power to practice". It made classroom boundaries *and* how we could enact our encounters with those boundaries more visible. Simultaneously, PDR allowed for several key contributions to the work. With PDR, long-term, big, humanizing goals could be pursued with the aid of research. The method allowed for shorter-term focus on specific practices and their effectiveness. It also allowed for flexibility in what would be designed and how it could be adapted by different people with varying conditions and contexts. Importantly, PDR made tensions and systemic rifts visible, available for multiple interpretations, naming, and action. We saw this most poignantly in the barriers to participation for parents in school math and the parents' evolution of agency and epistemic authority.

The most persistent challenges appeared with the pressures associated with bringing products of design, such as workshops, to scale—*rather than methods*—and the slow road of incremental changes that, at present, appear to leave bigger systemic problems intact. Renewed or newly discovered epistemic authority was powerful for developing agency. Yet we must acknowledge the tension in working to establish the belief that Bandura (2001) indicated was necessary for collective agency. In this case, as epistemic authority became increasingly available to parents and families who participated, institutional barriers became even more visible and seemingly intractable. PDR must take these tensions seriously if the method is to play a significant role in addressing systemic change rather than reproducing it further down the line.

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1 All last names in the paper are pseudonyms. Blesilda, one of the mothers we worked with in the participatory design research project, spoke these words in Year 3 of the project.
2 While we use the term “parent” in this paper, we anticipate that caregivers and allies fulfill similar roles in the lives of children. As it happens, in our study, parents and teachers were the primary adult participants.
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