In Search of Confluences:

Locating Productive Overlap in STEM and Heritage Practices

by

Katherine Carr Chapman

Dissertation

Submitted to the Faculty of the

Graduate School of Vanderbilt University

in partial fulfillment of the requirements

for the degree of

DOCTOR OF PHILOSOPHY

in

Learning, Teaching, and Diversity

October 31, 2021

Nashville, Tennessee

Approved:

Melissa Gresalfi, Ph.D.

Heidi Carlone, Ph.D.

Rogers Hall, Ph.D.

Leona Schauble, Ph.D.

Dedicated to Warren Thomas Chapman, September 5, 1944–September 18, 2014

ACKNOWLEDGMENTS

This work is only possible because of help from formal and informal places. Thank you to our incredible research group—Melissa Gresalfi, Fai Wisittanawat, and Amanda Bell. Thank you to co-conspirators and collaborators, especially Lani Horn and Lara Jasien, and the entire Docktails/Dimly Lit crew. Thank you also to Rogers Hall, Rich Lehrer, and Leona Schauble, without whose inspiration and leadership I might have stopped shorter. I'll always have a fireside glass of whiskey at the ready. This project was funded by the National Science Foundation to Melissa Gresalfi (DRL-1420488).

TABLE OF CONTENTS

LIST OF FIGURES

Introduction: Heterogeneity and continuity

In the last half century, research has progressed from justifying the value of out-of-school knowledge to thinking carefully about how this valued knowledge may or may not make contact with work in schools. Propelled by constructivist views of learning as well as critical scholarship, some researchers are pushing for a perspective in the learning sciences, from which

> "learning is viewed as an activity in which heterogeneous meaning-making practices come into contact—explicitly and implicitly, intentionally and emergently—to generate new understandings, extend navigational possibilities, and adapt meaning-making practices to new forms and functions" (Rosebery et al., 2010, p. 324)

From this perspective, experiences with varied meaning-making enterprises are not only expected, they may in fact be advantageous for developing robust, flexible, and generative knowledge.

This suggests that learning in out-of-school spaces is both meaningful and worthwhile in its own right *and* has the potential to support academic learning. Given the well-documented disconnect between out-of-school and in-school knowledge (e.g. Carraher et al., 1985; Saxe, 1988; Nasir, 2000, 2002), however, this productive contact may only be consistent when specifically designed for (Ackerman, 2011).

Connecting heritage practices to academic STEM

Given the ubiquity of informal learning opportunities billed as academic enrichment, the argument for connecting informal sites to academics might seem trivial. Furthermore, in this work I focus on STEM environments, which are both highly valued in school and well-represented out of school. Many informal environments, however—particularly those expecting short-term visits—project a view of STEM that is considered impoverished with respect to current views of disciplinary learning. Instead of engaging students in knowledge building by developing practices (c.f. NGSS) and empowering students with epistemic agency (Miller et al., 2018), many of these spaces reduce STEM disciplines to facts, recontextualized for amusement, yet recognizable enough to satisfy parents looking for recognizable learning experiences. Others have a multifaceted view of the possibilities for learning in object-rich environments (e.g. Paris, 2002), but struggle when pressured to make contact with deeper disciplinary learning (Schauble et al., 2002), particularly when best practices suggest that school groups come primed with their own agendas and the worksheets to accomplish them (Behrendt & Franklin, 2014; Scarce, 1997).

At the same time, the broader learning landscape includes cultural institutions that have robust communities of practice in their own right, and frequently offer students nonformal groups such as volunteer programs, after school clubs, and summer camps. Through these opportunities, students begin to participate in heritage practices such as knitting (Chapman, in press), sailing (Chapman, in preparation), and woodworking—even marching band (Ma & Hall, 2018) and skateboarding (Ma & Hunter, 2014)—that are typically left out of school curricula. By some accounts, these spaces are potentially more promising than standard object-focused museums for bringing students into legitimate epistemic practices (Lave & Wenger, 1991; Schauble, 2002), since they include near-peer mentoring structures and have legitimate community work to accomplish.

Still, heritage institutions are set up to build the epistemic practices of their own communities, not of academic disciplines. Furthermore, while they have their own agendas, when they attempt to integrate with school, these spaces can also become subject to pressures and stereotypes from school-based accountability systems (or parents' understandings of such systems) and suffer from a tendency to put a simplistic STEM gloss on otherwise independent programming. As such, it behooves designers to think about how these spaces might best fit into a heterogeneous learning ecology (Knutson et al., 2011) in a way that recognizes, rather than dismisses, both their individual contributions and the pressures to conform to more impoverished visions of schooling.

Heritage practices and confluence spaces

Many studies that look at how out-of-school spaces can support in-school learning focus on field trips. Some of these studies offer specific design recommendations—for example that cognitive gains can be optimized by lowering the novelty of a new space through orienting students ahead of time (e.g. Falk, 1983). Others observe that students don't always come away with canonical ideas (e.g. Orion, 1993) and offer design recommendations to anticipate and address this. Still others make the case for field trips based on their affective contributions—students tend to enjoy these excursions and remember them years later (for an overview, see DeWitt & Storksdieck, 2008).

Even in this broad body of work, however, the focus is almost exclusively on in-school learning. As I argue in paper two, when two practices are brought together, creating congruence generally means objectifying one or the other practice. Objectifying school disciplines makes sense as a demonstration of the possible uses of disciplinary "end products: concepts, facts, and theories" (Lehrer & Schauble, 2006, p. 159). Still, it does not address the goal of socializing students into knowledge *building*. In the other direction, objectifying heritage practices, especially in more traditional schooling environments, tacitly devalues these communities and further perpetuates the unilateral hegemony of school. In order to support implementation of practice-based reforms while developing heritage practices and capitalizing on the idea that heterogeneity itself is advantageous, I propose designing for spaces where students can negotiate the contributions of different meaning-making practices.

Outline of the three papers

This dissertation begins to develop a program of study focused on designing to bring heritage practices into productive contact with disciplinary practices. It does so in three parts, beginning with the outcome of one intervention and ending with the beginnings of another.

Paper one reflects on the design of a summer camp that was aimed at giving students new experiences with mathematics as reshaped by the interactional routines of a knitting community. Knitting has for generations invited lifelong engagement from women and girls, whereas K–12 STEM and modern STEM workplaces continue to force women out. At the same time, mathematicians and crafters alike have observed that knitting involves mathematics, suggesting that there may be productive overlap between the two practices. Based on the way school mathematics interfered with one student's experience of camp, however, I focus on math not in the abstract, but specifically on what it means in this interaction. I argue that this intervention inadvertently began to help one girl to coordinate her sensemaking resources across in-school and out-of-school practices. I do so by employing Goffman's notions of *framing* (1971) to show how what counts as knitting and what counts as school math is made a subject of negotiation in interaction. Furthermore, I argue that the work these two did to coordinate their activity appears to have broadened the young knitter's ideas about what counts as mathematics. This suggests that her experience in camp may have been more fruitful for future learning than the repeated employment of well-worn routines seen in other participants.

Paper two begins with this idea and explores some of the theoretical literature on disciplinary practice as well as previous attempts to bring in-school and out-of-school practices into conversation. In that theoretical work, I seek both to articulate more broadly what paper one is a case of, and to see what resonance this kind of negotiation has in previous work. I conclude that designing for the negotiation of boundaries is a promising phenomenon of study related to, though identifiably different from, several constructs in the existing literature, including third space, hybridity, and boundary crossing. In order to mark the differences, I suggest the term *confluence spaces* to highlight the meeting of different epistemic practices that allows for the kind of negotiation of boundaries seen in paper one. I conclude by suggesting preliminary ideas about practical designs, in particular arguing that this work is a good target for nonformal spaces.

Paper three thus takes the conclusions of paper two and begins to develop a design-based research project to explore what it would take to intentionally create confluence spaces in nonformal environments. I argue that heritage institutions that have their own communities of practice are well-suited to this work. I also pull design principles from previous literature and turn them into conjectures for building confluence spaces based on the work in chapter three. The paper thus presents a pilot study at another summer camp, this time aimed at promoting the confluence of science and sailing with a particular focus on the kind of negotiation we created by accident in the knitting camp.

Contribution of the dissertation as a whole

This dissertation builds on ethnographic and equity-oriented work to consider how institutions that support learning about heritage practices can most productively interface with K–12 STEM learning. At each juncture, however, it insists that heritage practices be taken seriously and valued for more than just their instrumental or motivational potential. In doing so, it adds specific empirical work to developing theories about the ever-present heterogeneity of meaning-making practices. This insistence is echoed in the repeated call to think broadly about a healthy STEM learning ecology instead of consistently asking every learning opportunity to blindly serve school goals. While this work does not speak directly to minoritized communities even though it benefits enormously from work that comes from these communities, my hope is that decentering taken for granted (school-based) paradigms and broadening our ideas about valued epistemic practices will help to support student agency and open up opportunities for young people to participate in *and* speak back to the institutions we value.

Paper 1: Finding the math

"Wait—it's a math problem, right?": Negotiating school frames in out-of-school places

Reprinted with permission from Springer Nature
DOI : 10.1007/s10649-021-10099-0
UNCORRECTED PROOF

Abstract

Designers in out of school spaces often negotiate the meaning of mathematics as part of the design process, determining what to include in classes and exhibits both implicitly and explicitly. This analysis suggests that instead of keeping these conversations behind the scenes, we should foreground them for participants. In doing so, we may actually be helping to expand their sense of what counts as mathematics as they participate in legitimate communal activity. The focal analysis examines the case of one participant in a knitting summer camp as she encounters the mathematics that the facilitator deemed necessary to move the knitting project forward. Together they negotiate whether their work counts as knitting or as mathematics, and what the consequences for that designation are for how they make sense of the activity. I argue that this kind of encounter has the potential to build bridges between everyday and school mathematics, and thus to broaden participation.

Overview

Designers in out-of-school spaces have long considered how to engage young people with in-school subjects like science and math. Often, the goal is to increase participation, which means navigating between two extremes. Conventional wisdom says to avoid labels—mention "math" or "science" by name, and designers risk alienating the very people they intend to attract. On the other hand, failing to make explicit connections to school subjects risks creating a different rift—designing complex patterns with finite shapes, for example, may be seen as "just play" or at least "not real math" and therefore have little chance of influencing future engagement (Jasien & Gresalfi, 2021; Jasien & Horn, in press).

Where out-of-school researchers have targeted engagement with concepts, practices, or even communities tied to academic fields, scholars in ethnomathematics (e.g. Ascher & Asher, 1986) have pointed out that the mathematics education community needs to expand our notion of what counts as math. In this study I begin with the general premise that expanding definitions of mathematics is a worthy goal, both for researchers—broadening what we look for and value—and for students—broadening their ideas about mathematics through curricular design. However, I argue that engaging students with other kinds of mathematics is not enough, nor is simply describing or discussing non-standard applications of mathematics. Mathematics encountered in out of school spaces often fails to make real contact with school mathematics, and—as my analysis shows—when it does, it is often morphed by participants' ideas about school mathematics in a way that undermines the expanded sensemaking offered by non-traditional contexts.

I argue that a useful tool for designers in thinking about this problem is the notion of framing (Goffman, 1971), which suggests a mechanism for change by locating these definitional issues not in a single authority (such as an edict from the field of ethnomathematics, or an organization like NCTM), nor in an individual, but in social interaction. Viewed from this lens, designs should explicitly target negotiating the definition of mathematics with an eye toward histories of practice as they are indexed and enacted through complex sociotechnical arrangements. In this microethnographic study, I offer a frame analysis of one interaction during a week-long intervention, the purpose of which was to explore the potential for knitting activities to surface K–12 relevant mathematics. From this analysis, I argue that the lens of framing offers a methodological tool for three design-related problems that traditional notions of mathematics learning obscure: what kinds of unintended cultural modes may become relevant for participants in a designed activity; what aspects of a design might index these other modes; and how facilitators and designers might attune to moments during which such conflict might be negotiated.

Mathematics in Crafting

Connections between mathematics and crafting have been noted by everyone from mathematicians (Hebb, 2003), to ethnographers (Venkatesan, 2010), to geometry teachers (Westegaard, 1998; Wickstrom, 2014). In some cases, this research has challenged the idea that "women's work" (including textile crafts) and the "masculine" sphere of intellectual pursuits (particularly mathematics) are mutually exclusive (e.g. Hebb, 2003). This research also challenges cultural assumptions about who is suited for, or even capable of, doing mathematics. Related work suggests that explicitly discussing the overlap between mathematics and craft can influence the general public's perceptions of these disciplines (e.g. Harris, 1988). Still, the effect itself is unclear.

Depending on the analytic perspective, textile crafts are generally seen as "inherently" mathematical, "tacitly" mathematical, or at least "potentially" mathematical. On the one hand, this leaves little doubt that there is—or at least could be—some overlap between the two disciplines; on the other hand, where that overlap is and what it amounts to have profound implications for designing to teach mathematics. If mathematics is merely potential in the crafts themselves, a finished project or approximation of practice (such as paper piecing) might serve as a useful exercise and object of inquiry in a mathematics classroom (as indeed it can, e.g. Jacobson & Lehrer, 2000; Hartmann & Lehrer, 2000; Lehrer, 2010). If mathematics is only tacitly involved in the production of textile crafts, an intervention for a crafter might aim to connect to that tacit knowledge and build a bridge to more explicit, school-valued concepts. If mathematics is inherent in the production of textile crafts, that may serve as proof that crafters are capable of mathematics, or, if it is particularly robust, even suggest that all mathematics students would benefit from practicing textile crafting as another way into the field. In other words, the nature of the mathematics (e.g. whether it is potential, tacit, or inherent) has implications for possible interventions.

Thus, as calls to increase participation in STEM fields take up the goal of broadening perspectives on what counts as mathematical, it is important to clarify what we mean when we ask whether something is "mathematical". This is especially important when talking about non-school practices, and for specifying the theory of change when our goal is to put them to use in schools. Furthermore, it is worth noting whose answer we pay most attention to (and why). Sociologists argue that mathematics is theoretically inherent in various indigenous practices. And yet, classroom interventions aimed at making that work more explicit use standard K–12 descriptions as add-ons (to make sure the students see the math), suggesting that it is merely potential (e.g. Harris, 1997). In this analysis I suggest two interrelated developments: 1) that it is not only learning that female-coded activities are mathematical, but actually participating in those activities—with their attendant norms, routines, and participation structures—that has the potential to broaden participation in mathematics; and 2) that the definition of mathematics is tied to communities of practice that are elaborated and extended in interaction, not merely by declaration. I illustrate one example of this kind of broadened participation in the context of young people learning to knit, not by defining "mathematics" in principle, but by looking at the nature and consequences of definitions as they are performed in social interaction. In this context, the question for participants is one of framing, which is something more like, "Is this math?" and for analysts, "How do we know?"

Background to the current study

This paper represents a piece of a larger study focused on women and girls in craft and in school mathematics. The larger study explores not only the kinds of mathematics involved in the production of textile crafts (c.f. Harris, 1997), but also the experiences of women both in craft and in school mathematics, and the resulting identification processes for women in these fields (Chapman et al., 2018; Chapman & Gresalfi, in preparation). The study was two-pronged, seeking to identify and explicate existing practices, but also to take the insights gathered from experts and design small-scale interventions. Data for this paper are taken from one of those interventions—a one-week "learn to knit" summer camp.

In the first phase of research, we deliberately interviewed crafting experts (usually teachers) who made explicit connection to STEM fields, whether using the Fibonacci sequence to inform colorwork, or creating spreadsheet formulae for adjusting sweater patterns. Among the most common refrains in these interviews was that "if they had taught me mathematics with knitting needles in my hands, I wouldn't have had any trouble". Numerous experts told us that mathematics was explicitly involved in many aspects of textile crafting, but especially in the design stage. Based on this insight, we designed a summer camp around asking young people to design their own patterns involving a simple rectangle. Our research goals with this first camp were to see 1) whether designing made sense to most young people as a way into knitting, and 2) whether (and what kind of) mathematical thinking came up as a result of this practice. Given our stated goal of designing school-relevant interventions, in this phase we were initially looking for engagement with K–12 mathematics concepts, particularly those around rate and ratio.

Because the broader study was premised on the general observation that women and girls persist in crafting even as they continue to leave STEM fields, we also aimed to make the camp as reflective of typical crafting community practices as we could. Our major foci in this regard were similarly taken from expert interviews, but also from our participant observations. Specifically, we aimed to 1) normalize mistakes (and fixing mistakes), 2) give plenty of free choice within the general goals of the camp, 3) offer compelling materials, 4) let whatever we saw as possible avenues for mathematical thinking surface as a product of the students' own design goals, and 5) as much as possible, act as resources for the novice knitters rather than as experts to be emulated. While these norms and structures were explicitly meant to emulate typical crafting communities, we were also conscious that they are orthogonal to many traditional mathematics class practices that involve waiting for instruction, repeating information learned by rote, and receiving an accounting of your performance from a teacher or other authority .

Theoretical Framework

This work takes a sociocultural perspective—derived largely from the work of Vygotsky (1980), but also Lave & Wenger's notions of Communities of Practice (1991)—that knowing is inseparable from the social context in which it is (per)formed. From this perspective, there is no Platonic ideal of mathematics—mathematics itself is a social accomplishment inseparable from both the activities and communities in which it is used and created. Consequently, using established definitions amounts to aligning oneself with an existing community of practice. This is not to say that such a practice is wrong, but only that scholars who choose to take existing definitions as their starting point would do well to specify which community they intend to align themselves with and for what reasons (and at what point in time) . For this analysis, I illustrate the negotiation of such a definition in joint activity, beginning with the analytic idea that a moment of disrepair is an opportunity to see this social accomplishment in action, but also that such negotiations might represent an ideal site for intervention. I start with the idea that asking "Is this math?" is merely a specific form of a more general question, "What is going on here?"

Framing

The concept of framing is commonly credited to Bateson (1972), was developed by Goffman (1974; 1981), and has since been taken up by researchers in multiple fields. In the Learning Sciences, use of the term has varied from thinking about how tasks are presented by a teacher (Engle, 2006), to emphasizing social aspects such as positioning (Greeno, 2009) to thinking more explicitly about how power circulates in frames that are endorsed or rejected by broader social structures (Hand et al., 2012). For the purpose of this analysis, I use Goffman's notion of frames from Frame Analysis and focus on the student's apparent experience of shifting frames in a single interaction.

As Goffman famously said, frames are our way of answering the question "What is it that's going on here?" (1984, p. 8). From a social perspective, the importance of answering this question might seem trivially obvious. To take a common (if dated) example, if we are playing golf, my object is likely to win, and therefore I will do whatever it takes (within the rules of golf, presumably) to maximize my golf performance. If, however, what we are really doing is using a game of golf as a polite ruse for making business connections, then I might instead adjust my performance to let the person I am trying to impress win the match (though still, one assumes, within the rules of golf). Whether I am to be congratulated for winning the match at the end of the day depends entirely on which kind of golf I and my opponents understood ourselves to be engaged in. (The accuracy (and earnestness) of the congratulations itself, in turn, presumes that everyone knows that in Business Golf the most important person should win; another layer is added if players must credibly conceal that they are not playing their best game.) The distinction—between playing golf as a competitive sport, and playing golf as a networking strategy—relies on our ability to collaboratively construct an understanding of our shared enterprise—as well as our orientation toward that enterprise, and the roles and responsibilities of those involved—and to use that shared understanding to make reasonable assumptions about the behaviors and expectations of other people. It is this ongoing collaborative construction that allows for smooth social functioning.

According to Goffman (1974), frames are guides to interpreting social interaction that are "sustained both in the mind and in activity" (Goffman, 1974, p. 247). They include basic assumptions about the nature of the activity, as well as orientations toward certain actions and actors, sometimes in the form of a keying of activity (a kind of angle on the underlying frame, such as joking, rehearsing, or reenacting). Weight is given, therefore, to the social history of the activity (and presumably the individuals' experience or lack thereof with that history), as well as to the entire sociotechnical arrangement, including tools and personnel. And yet two individuals participating in the same social engagement may conceivably retain different frames—or different keyings of the same frame—of ongoing activity. Shifts in the framing of an activity are sometimes seen in a participant's flustering such as when someone suddenly realizes they are not participating in the same keying as another participant. Importantly, people are not passive recipients of existing cultural frames, but instead actively give shape to, and reshape, shared cultural frames in ongoing activity, sometimes even attempting to forge new ones. Furthermore, what kind of frame might be relevant in which circumstance is far from trivial—there are any number of possible frames that can be properly cast onto a given activity. Both of these realities conspire to make us active participants in meaning making through the process of negotiating both the content and the boundaries of our shared frames.

In this paper, I offer a frame analysis of one case of a student in a knitting camp as she is confronted with a problem and struggles to make sense of both the mathematical concepts, and the sociotechnical arrangement in which she finds herself. This process has implications both for her participation in the activity she is engaged in, and for her "maps" (Frake in Cole et al., 1997), which have the potential to influence her engagement beyond this activity. In doing so, I show that the arena of the pedagogical contest is not just the denotations of, relationships between, and possible uses for numbers, shapes, and patterns, but the meaning she makes of "mathematics" in this exchange and the entailments of that meaning for her sensemaking resources.

Data Collection and Analysis

Participants were eleven young people, all female-identified, ages 9–16, who self-selected to participate in a week-long learn-to-knit program called KnitLab offered over the summer at a public library in a mid-sized city in the southeastern United States. The program was led by three researchers (including the author)—two female, one male, all White—who were proficient with basic knitting practices, but did not consider themselves expert knitters.

Over the course of the week, participants were shown basic knitting stitches and invited to create a project of their own design based on a simple rectangle—in most cases either a bag or a pillow. This project offered a constrained problem space that still involved a considerable degree of aesthetic freedom and design choice. By asking participants to first create a swatch—a small sample of knitting that also serves as a learning and practice space—and also to imagine the size they wanted their finished product to be, the design specifically targeted reasoning about rate and ratio. In order to create a rectangle of a particular size, a knitter will first calculate her gauge—a standard unit rate of stitches per inch—based on a swatch, and from there determine the number of stitches necessary to make a piece of fabric of the target size. Researchers rotated throughout the day and addressed any questions from participants as they arose. For the most part, the calculation of gauge was facilitated in one-on-one encounters between participants and researchers, though there were two notable whole-group discussions that largely focused on these ideas.

All five days of the workshop were videotaped, with standing cameras set up to capture interaction and talk among participants. In addition, a subset of focal students—selected with the goal of capturing the range of age and knitting fluency across participants—wore small video cameras on lanyards around their necks. These cameras thus captured a clear record of students' knitting and gesture, along with the conversations they had with facilitators and other young people. All participants completed a basic in-take questionnaire and a mid-week assessment of knitting-based proportional reasoning, and all but one were briefly interviewed on the final day about their impressions of math, knitting, and the potential overlap between the two disciplines.

An earlier analysis (Gresalfi & Chapman, 2017) focused on episodes with school-relevant mathematical reasoning in dialogue. That analysis highlighted how researchers' (and students'?) preconceptions about what might count as mathematical were salient in interaction. The present analysis examines the influence of such preconceptions, focusing on a ten-minute clip from the second day of camp, which captured an episode between a single student and a single researcher who was acting as a teacher/facilitator. During this episode, the student explicitly negotiates a shared understanding of what is going on, and whether it counts as math, thus providing an important focal point for examining this negotiation. After repeated viewings, the clip was transcribed with a focus on dialogue, key gestures, and tool use. I further followed tenets of Interaction Analysis as (Jordan and Henderson, 1995), including regular co-viewing of video and debriefing with individual colleagues and with an Interaction Analysis lab (a loose group of colleagues who routinely share analyses-in-progress) in order to incorporate fresh perspectives. The case study included here represents a phenomenon that was treated as unproblematic in our study design, but on close inspection was highly consequential and thus worthy of closer consideration. After multiple zig zags between the data and relevant theoretical work, I settled on Frame Analysis as providing a useful heuristic, and returned to the clip with a specific eye for moments of flustering, which Goffman describes as appearing at the boundaries when frames are under dispute for one or more involved party.

The Case: Amy

Amy was a nine year old girl who had no prior knitting experience (though she did have experience with crochet), and said she was not confident in her mathematics skills. Throughout the camp, she was pleased to be introduced to new skills and concepts, and fell into the routine of camp easily, asking for help whenever she was stuck, socializing with the other students, working carefully on her knitting project, and even demonstrating her knowledge of crochet to curious peers. When it came time to calculate her gauge, however, she struggled more with the actual calculation than many in the camp, though she was eventually successful. Elsewhere (Gresalfi & Chapman, 2017; Chapman, 2018) we have shown how Amy's case is mediated by her disfluency with the knitting, as well as her relative unfamiliarity with reasoning about rate and proportion (and multiplication facts about fives). Her case demonstrates that knitting can act as a useful scaffold to these K–12 relevant concepts, even when they might otherwise appear out of her reach. Nevertheless, helping her see the utility of her knitting took considerable work on the part of the facilitator. In this analysis I show that the work itself—negotiating what counts as mathematics and the consequences of that negotiation for determining appropriate sensemaking resources—is an important design consideration that has implications beyond this case.

In this episode, Amy had successfully completed several rows of her swatch and was ready to plan out her design. She approached one of the researcher/facilitators and asked for help with what to do next. The episode begins as the researcher asks Amy if she has calculated her gauge, to which Amy responds that she has not. The two of them thus decide to sit down together and work on establishing Amy's gauge, which needs to be completed before they can plan the rest of her design. While this is only day two of camp, considerable effort has gone into making norms and expectations clear to students, in particular around the observed characteristics of knitting communities mentioned above. On the first day in particular, researchers routinely mentioned that mistakes are a normal part of knitting, that everyone makes mistakes, that you get to decide whether a mistake is annoying enough that you want to try to fix it (or get help to fix it), or whether it's ok to just leave it in. Students seem equally comfortable being in charge of their own projects and soliciting help from peers and facilitators when necessary. There is a relaxed, convivial atmosphere. Facilitators alternately work on their own projects and wander around checking to see if anyone needs support.

The frame for all of this activity seems unproblematic—students see their work as "knitting", or perhaps "knit camp". It is worth adding, however, that they are actively constructing this framing in activity and likely with weighted influence given to facilitators, particularly since many of these students are new to knitting. Facilitators recognize their roles in this broader shared project as well, and this is occasionally apparent in phrasing, such as when a student asks a specific "What do I do here?" question and is answered with a universal statement such as "Well, in knitting you really get to decide."

The knitting frame

The "knitting" frame for Amy appears as it does for other students in the camp: She is engaged in her project; while she knits, she is leaned forward, focused on her needles; she takes full authorship of her work, even when she asks one of the facilitators to help her redo a section, or diagnose a problem. In one instance, she raises her voice for a facilitator to help her, explains what she is having trouble with, and yet does not relinquish control of her knitting needles and instead muscles through on her own (after noting that the facilitator is paying close attention). In another, she determines that casting on is too difficult and passes her needles to a facilitator, though she remains vigilant, occasionally offering commentary (when the facilitator stops to count, Amy raises her voice and says, authoritatively "that's not 75 yet"). The episode under analysis begins squarely in this frame as Amy seeks out an adult to help her with the next step in constructing her pattern.

Negotiating frames

As Amy and the facilitator sit down to figure out her gauge, several elements of the sociotechnical arrangement start to shift. Where they have been working more communally, for this task they sit apart from the other students; once Amy is seated, the facilitator gets up to get a ruler, and encourages Amy to get out her notebook; the knitted swatch is on the table between them (rather than in someone's hands); the facilitator's tone, though always somewhat singsong, shifts in tempo and intonation to something more commonly associated with small children, or with explicitly didactic encounters. Nevertheless, the tone is still casual and conversational. There is not yet a clear frame shift, but rather a sense that everyone is still playing along, waiting to see how everything shakes out. Amy remains engaged and lively, gathering resources including tools (a pencil) and her record of previous work (in her notebook) to move the project forward.

> Amy: That's a fun ruler, that's cool
>
> Facilitator: It is cool, see it's so you can get a perfect edge if you're like ... want it to be perfectly square. Alright, so your gauge tells you how many stitches you get in an inch.
>
> A: Yeah. I've already written down that [gesturing at knitting swatch] gauge.
>
> F: Oh ok, and what was it?
>
> A: It's right here [pointing, with her pencil, at her notebook]
>
> F: In four inches you got twenty FOUR stitches?
>
> A: Yeah
>
> F: So that was on this? [picks up knitting swatch]
>
> A: Yeah, that was on that [using pencil to point at knitting swatch] But... [grumbling sound] yeah
>
> As they move through the task, Amy continues to play along, but begins to step back her engagement as the facilitator questions Amy's contributions.
>
> F: Let's see. Let's check that just to make sure [holding up knitting needle] 1, 2, 3, 4, 5, 6
>
> A: But that was yesterday…
>
> F: 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25. Ok, so twenty five stitches
>
> A: [trying to erase in notebook] Aaah , this pencil doesn't have an eraser
>
> F: Oh, yeah, get a better one.
>
> A: [gets a different pencil] Twenty five? [writing in notebook]

F: Yeah. So now let's measure how long.

A: It's...

In addition to shifting the sitting arrangement, and the tools they are using, the facilitator has now shifted away from Amy’s self-pacing and into a more pre-defined script with more broadly universal statements.

F: And we sorta want to measure it higher up because, see how yours goes up kind of in a "V"? Because you added stitches along the way? So to get your gauge we don't wanna measure the bottom because we know that has only 20 stitches? We wanna measure the top, that's where you have 25 stitches. So we put it at the zero [lining up ruler on knitted swatch]. Let's put this white paper underneath so we can see a little better. So here's the zero on that edge, at the edge. And it looks like you have five and a half inches

A: [writing in notebook]

F: mm-hmm [affirmative]. Ok, so now we have to figure out, how many stitches are in one inch, if we know…

As the activity seems to be shifting, Amy persists in being part of the discussion, though she is increasingly hesitant.

A: Well it was six yesterday, 'cause, it was six. Six inches in one inch.

F: Six

A: [correcting herself] SIX six stiches in one inch.

F: Ok... Well, if... let's ignore this one half for a minute [covering the ½ marking in the notebook with a finger]. If it was 25 stitches in five inches ... how many stitches would it be in one inch?

A: Wait, what?

This moment—where Amy suddenly seems to have lost track of the conversation—I argue is an example of Goffman’s notion of flustering, which occurs when the current frame is under dispute. In this case, it appears to signal an abrupt frame shift that has been creeping in since the two of them sat down.

The mathematics frame

After this point of flustering, Amy shifts definitively to something more closely associated with school math. She changes her posture and her tone of voice, sitting back from the table and straighter in her chair, disengaged from everything that is on the table, and focused on the facilitator as she waits for evaluation, almost whispering her next words. Importantly, the frame does not necessarily shift for the facilitator, who continues on with her questioning seemingly unperturbed, driving at a calculation of Amy's gauge.

> F: If it was twenty five stitches? Right here? [finger on notebook; other hand pointing at knitting swatch] And that took up five inches. How many stitches would be in ONE inch? How could you think about that?
>
> A: [quietly] I need to write it down. I can't do it [unintelligible]
>
> F: [removing hand from notebook] Write down whatever you want!
>
> The total frame shift is verified explicitly when Amy asks if she has properly recognized what they are doing together, and thereafter seems to abdicate all sensemaking.
>
> A: Wait, it's a math problem, right?
>
> F: mm-hmm [affirmative]
>
> A: [softly] What, how would I write it then? I don't know how to write that.
>
> What follows is a kind of grab-bag approach that seems to betray guesswork rather than concerted sensemaking (c.f. Schoenfeld, 1988). This suggests that what "math" or at least "math problem" means to Amy is a set of operations disconnected from practical considerations, evaluation of her performance against a standard she either never learned or can't remember (which she alternately admits explicitly or tries to disguise), and a properly passive posture (reminiscent of IRE exchanges (Mehan, 1979)) in which she is to receive instructions before executing as quickly and accurately as possible (Hand et al., 2013; Gresalfi, Martin, Hand, and Greeno, 2008). The facilitator also seems to notice and attempt to push back on at least some of these assumptions.
>
> F: Well, let's think about it. There isn't really one way to write it, actually. So, this whole thing measures five inches, right? [puts her hands back on the knitting and the T-square]
>
> A: Yeah.
>
> F: Ok. So, what if
>
> A: So it would be five times twenty five? or...
>
> F: Well, what would that tell you?
>
> A: No, that would be something else, that would be... [gesticulating with pencil]
>
> F: That would be making it a lot bigger [spreading hands out in air]
>
> A: No I mean divide it. Divide it, right?

F: And what would that tell you?

A: [whispering] We haven't done the fives yet.

Reclaiming a productive frame

Importantly, the facilitator is able to re-establish a more productive frame with another series of sociotechnical rearrangements. To begin with, she puts aside the notebook and returns to the knitting materials, while also verbally signaling a shift with words like "instead of." Amy's posture softens, and she shifts away from trying to write in her notebook and back to manipulating her knitting, as the facilitator uses a knitting needle to help differentiate the stitches while counting.

> F: Ok! That's alright. Let's just think about this. Instead of... let's just think about on this ruler [holding T-square to knitting swatch, pointing]
>
> A: [leans in]
>
> F: If we are only looking for one inch
>
> A: [holds hand over ruler]
>
> F: Those are the centimeters, the inches are up here.
>
> A: Oh
>
> F: Mm-hmm [affirmative].
>
> A: Up here?
>
> F: Mm-hmm [affirmative]. Yep!
>
> A: Let's see... quickly
>
> F: Yep, look down here
>
> A: So, there would be...
>
> F: [picks up knitting needle] Here you can use this knitting needle. One, two, three, four, five stitches in one inch. And now I'm gonna show you a pattern. […] So if it's twenty five stiches in five inches. And you also know it's five stitches in one inch.... How many. Um, how many stitches do you think that you would count
>
> A: Ten!
>
> F: Mm-hmm [affirmative] [writing in notebook] What about in three inches?

A: Fifteen

F: Mm-hmm [affirmative]. What about in four?

A: Twenty

F: Mm-hmm And you... remember first we measured five and there were twenty five? Yep. So you, when you guessed "I would divide". You were right—when you were dividing... if you divide twenty five by five, that helps you see if there was one inch, how many stitches

In contrast with the abrupt descent into math, the next shift appears more gradually. Once the pair are oriented again toward the material infrastructure of knitting (holding the swatch, using knitting needles to point), Amy appears to be engaged in real sensemaking about the knitting problem again, as she reintroduces practical considerations, which seemed to have been off the table in the "math problem" frame.

F: Ok! So now you know your gauge is five stitches in one inch. How big did you say your pillow was?

A: Um, a foot and three and a half inches

F: One foot, three and a half inches. Ok, how many inches is that altogether?

A: [counting to herself] Fifteen and a half!

F: Yep. Ok, so that's fifteen and a half inches. Ok, so... now we have to do some more math. If you know that when you knit five stitches you're gonna go one inch, but you have to go fifteen and a half inches, how are you gonna figure that out?

A: I probably need a longer needle.

The negotiation of framing is thus accomplished not with content, but with an entire sociotechnical arrangement that not only indicates appropriate physical tools but indexes appropriate sensemaking resources as well. Amy goes on to determine how many stitches would be needed to make her target size of fifteen and a half inches with scaffolding from the facilitator, but with less difficulty and no whispering.

Discussion and Limitations

With this analysis, I do not mean to suggest that the reintroduction of the knitting frame magically made the school mathematics concepts clear—there are certainly other elements of this episode that contribute to Amy's eventual success with these particular examples of proportional reasoning. For one, the facilitator helped her use the material of her knitting to circumvent calculating the unit rate (simply counting how many stitches appear along one inch of the ruler), and then helped her use that empirical unit rate to think proportionally about her target size (thus shifting the task from one of decomposition to one of skip counting, or multiplication, with which Amy was likely more familiar). Future designs might capitalize on this kind of alternative method to talk about error propagation and how that might motivate calculational solutions as well as empirical ones. Even so, I argue the negotiation of framing that seemed to offer Amy permission to use the materiality of her knitting in her sensemaking was a significant breakthrough that could be a specific goal of future designs. With her hands on her knitting, considering things like whether her final product would fit on her current knitting needle, Amy moved from the "grab bag of operations" approach to a more contextualized sensemaking. If an experience like this were designed for, we might be able to facilitate (and assess) how Amy's framing of similar activities changed after such a negotiation.

What the heuristic of framing allows us to see is that the contest is not merely over whether Amy likes to do things with words instead of numbers—that is, it is not reducible to the fact that she can't (or doesn't want to) engage with the content introduced in this episode—nor is it reducible to a dyadic social struggle. It is clear from the timing of the frame shift that it is not merely the introduction of numbers that shifted the frame, since there was a fair amount of discussion of numbers and calculation before the dramatic frame shift. Relatedly, it is not merely calling something "math" that causes the shift. For one, Amy clearly recognized what to her was "a math problem" before labeling it as such. Furthermore, later on in the episode, the facilitator tells Amy that they will need to do "some more math", and this declaration does not cause another suspension of sensemaking.

Finally, while the negotiation of frames was accomplished as a coordinated effort between Amy and the facilitator, it involved an entire sociotechnical arrangement, including yarn, needles, a knitted swatch, a notebook, a pencil, a T-square, a table set apart from the group, body posture, and the rhythm of conversation. Furthermore, the negotiation took place within an emerging social group with its own norms and routines (KnitCamp), and recruited norms and routines from an entirely different, arguably absent group (school math). Future designs will need to prepare for the intrusion of other frames rather than assuming that established norms will carry forward unproblematically for all participants.

Conclusion

What we take as the definition of mathematics determines not only what we as analysts look for, but what we as designers aim for, all of which tacitly describes a theory of change. In previous analyses of these data we have noted that learning to knit shares many features of advancing through school mathematics (Gresalfi, Chapman & Wisittanawat, 2016). Relatedly, we have demonstrated that what part of school mathematics becomes relevant for students in the course of knitting is influenced by their previous familiarity with both knitting and school mathematics (Gresalfi & Chapman, 2017; Chapman, 2018). Both of these lenses rely on a stable definition of mathematics tied to one community—K–12 schooling in the U.S. (or perhaps more properly, traditional K–12 mathematics textbooks). Furthermore, they suggest that exposure to knitting as it is commonly practiced has the potential to produce relevant changes in mathematics achievement in school, presumably because problem solving skills in one domain are either general or analogous enough that they will be relevant in another domain, or because simply seeing potentially school-relevant mathematics in a new context will transform a student's relationship to the discipline. What I am claiming with this analysis is that transforming a person's relationship to the discipline is more complex than exposing them to familiar concepts in a new setting.

Definitions of important, culturally powerful disciplines like mathematics are tied to communities of practice, but also negotiated in situ each time they are made relevant. Like frames, more than one may be relevant at any given moment, and though they are shared—distributed across the community—they may be differently relevant for different people at different moments. As Carraher and Schliemann noted, "we cannot assume that children sharing the same physical settings as ourselves will be interpreting problems in the same contexts that we do" (Carraher & Schliemann, 2002). When we unquestioningly use a stable definition of mathematics to determine whether something is mathematical, we are effectively asking whether that frame (usually just a "school mathematics" frame) is potentially relevant at a particular moment. I suggest that it is important to ask not whether such a frame might be relevant, or is relevant for an approved expert (such as a researcher, or a mathematics teacher), but whether it is relevant for participants in interaction. Furthermore, I am suggesting that a different theory of change we might test is that to influence a person's relationship with mathematics, we must influence the boundaries and uses of their "mathematics" frame (or, what to them counts as mathematics).

Informal educators acknowledge this implicitly when they debate whether (or when) to label something as mathematics (A. Rubin, personal communication, October 8, 2019). Avoid it, and we are either saying that explicit recognition of what counts as mathematical is unimportant, or we are relying on some imagined post hoc reflection time wherein we can say to reluctant students "but remember what you did the other day? That was math!" More importantly, this analysis shows us that the word "mathematics"—or even the type of conceptual work we usually associate with it—is far from the main thing that indexes the definition, at least for Amy. Long before she shifts frames, pulling away from the activity and waiting for instructions, she has been engaged in measuring her work and reasoning about relationships between sizes and even numbers. By looking at this episode through the lens of framing, we see that what indexed a "math problem" for Amy was a confluence of physical tools, conversational routines, ideas about precision and authority, and even body positioning. Thus, it is not enough to avoid (or include) what we might consider mathematics concepts, or even the label "math" to invoke a particular frame.

Furthermore, it is not enough to rely on broad community-level engagement patterns to resist a particular frame. The design of KnitLab rested on norms like normalizing mistakes and relying on peers rather than experts to create an authentic "knitting community" atmosphere. Far from accidental, this was explicitly in keeping with our observations of such communities, and in opposition to typical school mathematics classrooms. While this comprehensively governed even the more didactic, K–12-mathematics-focused portions for many of the participants, smaller patterns of engagement brought in a school mathematics frame for Amy, effectively crashing the knitting party in a way the designers had not planned for. Importantly, other students seemed unperturbed by the introduction of reasoning about ratio and proportion into their knitting (c.f. Chapman, 2018), and while we might argue that the design "worked" for them and "failed" for

Amy, what this analysis suggests is that the negotiation of frames may actually be the interaction that has the most potential to transform a student's relationship with mathematics.

Finally, this suggests three important methodological points. Most broadly, designers must be aware of what other frames may intrude on the intended interaction. Informal designers are well aware of this in terms of "putting people off" by mentioning math, but justifications generally amount to not triggering mathematics anxiety. While that may be a relevant component, this analysis shows that there is more to accidentally re-framing of an activity as "school math" than simply making a participant nervous or otherwise avoidant. Second, the lens of framing can attune analysts and ultimately designers to these micro-level indexes. In addition to community-level patterns, designers can consider interaction-level routines, types of physical tools, and other person-level behaviors that may signal one frame over another. Third, looking for moments of flustering as a signal that frames are being contested is a fruitful analytic tool for finding these kinds of frame shifts, and considering what they have been provoked by. It may even be a useful type of intervention response to alert facilitators to, particularly if these are fruitful "teachable moments" as they seem to be.

References

Akkerman, S. F., & Bakker, A. (2011). Boundary crossing and boundary objects. Review of Educational Research, 81(2), 132-169. http://doi.org/10.3102/0034654311404435

Ascher, M., & Ascher, R. (1986). Ethnomathematics. History of Science, 24(2), 125-144. http://doi.org/10.1177/007327538602400202

Bateson, G. (1972). A theory of play and fantasy. In G. Bateson (Ed.), Steps to an ecology of mind: A revolutionary approach to man's understanding of himself (pp. 177–193). Ballantine.

Carraher, D., & Schliemann, A. (2002). Chapter 8: Is everyday mathematics truly relevant to mathematics education? Journal for Research in Mathematics Education. Monograph, 11, 131-153. doi:10.2307/749968

Chapman, K. (November 2018) Negotiating frames in an informal math space. In T.E. Hodges, G. J. Roy, & A. M. Tyminski (Eds.), Proceedings of the 40th Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education (p. 1004). Greenville, SC: University of South Carolina & Clemson University.

Chapman, K. C., Gresalfi, M., & Bell, A. M. (2018). Room for everyone? Identification processes in crafting and math. In Kay, J. and Luckin, R. (Eds.) Rethinking learning in the digital age: Making the learning sciences count, 13th International Conference of the Learning Sciences (ICLS) 2018, Volume 3 (pp. 1701–1702). London, UK: International Society of the Learning Sciences.

Christiansen, I. M. (1997). When negotiation of meaning is also negotiation of task. Educational Studies in Mathematics, 34(1), 1–25. http://doi.org/10.1023/A:1002944413332

Cole, M., Engestrom, Y., & Vasquez, O. (Eds.). (1997). Mind, Culture, and Activity: Seminal papers from the Laboratory of Comparative Human Cognition. Cambridge University Press.

diSessa, A., & Wagner, J. (2005). What coordination has to say about transfer. In Mestre, J. (Ed), Transfer of learning from a modern multidisciplinary perspective (pp 121–154). Information

Age Publishing.
Edwards, R., & Fowler, Z. (2007). Unsettling boundaries in making a space for research. British Educational Research Journal, 33, 107–123. http://doi.org/10.1080/01411920601104565
Erickson, F. (2006). Definition and analysis of data from videotape: Some research procedures and their rationales. In Green, J.L., Camilli, G., & Elmore, P.B. (Eds.), Handbook of complementary methods in education research (pp. 177-192). American Educational Research Association.
Goffman, E. (1974). Frame analysis: An essay on the organization of experience. Harvard University Press.
Goffman, E. (1981). Footing. In Forms of talk (pp. 124–159). University of Pennsylvania Press.
Greeno, J. G., Smith, D. R., & Moore, J. L. (1993). Transfer of situated learning. In D. K. Detterman & R. J. Sternberg (Eds.), Transfer on trial: Intelligence, cognition, and instruction (pp. 99–127). Ablex.
Greeno, J. G. (2009). A theory bite on contextualizing, framing, and positioning: A companion to Son and Goldstone. Cognition and Instruction, 27(3), 269-275. http://doi.org/10.1080/07370000903014386
Gresalfi, M., Barab, S., Siyahhan, S., & Christensen, T. (2009). Virtual worlds, conceptual understanding, and me: Designing for consequential engagement. On the Horizon, 17(1), 21-34.
Gresalfi, M., & Chapman, K. (2017) Recrafting Manipulatives: Toward a critical analysis of gender and mathematical practice. Mathematics Education and Life at Times of Crisis (MES 9 Conference), p 491, Volos, Greece, 2017.
Gresalfi, M., Chapman, K., Wisittanawat, P. (April 2016), "Re-Crafting Mathematics Education: Designing Tangible Manipulatives Rooted in Traditional Female Crafts" Poster presented at the annual conference of the American Educational Research Association as part of the NSF showcase, Washington, D.C.
Gresalfi, M., Martin, T., Hand, V., & Greeno, J.G. (2008). Constructing competence: An analysis of student participation in the activity systems of mathematics classrooms. Educational Studies in Mathematics, 70, 49–70. http://doi.org/10.1007/s10649-008-9141-5
Gutiérrez, K. D., Baquedano-López, P., & Tejeda, C. (1999). Rethinking diversity: Hybridity and hybrid language practices in the third space. Mind, Culture, and Activity, 6(4), 286-303. http://doi.org/10.1080/10749039909524733
Hand, V., Penuel, W. R., & Gutiérrez, K. D. (2012). (Re)framing educational possibility: Attending to power and equity in shaping access to and within learning opportunities. Human Development, 55(5-6), 250-268. http://doi.org/10.1159/000345313
Hammer, D., Elby, A., Scherr. R. E., & Redish, E. F. (2005). Resources, framing, and transfer. In Mestre, J. (Ed), Transfer of learning from a modern multidisciplinary perspective (pp 89–120). Information Age Publishing.
Harris, M. (1988). Common threads: Mathematics and textiles. Mathematics in School, 17(4), 24-28. https://www.jstor.org/stable/30214514
Harris, M. (1997). Common Threads: Women, mathematics, and work. Trentham Books, Ltd.
Hartmann, C., & Lehrer, R. (2000). Quilt design as incubator for geometric ideas and

mathematical habits of mind. In Proceedings of the 22nd annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education, Tucson, AZ.
Hebb, K. (2003). The Mathematics of Quilting: A Quilter's Tacit Knowledge of Symmetry, Tiling and Group Theory. In Meeting Alhambra, ISAMA-BRIDGES Conference Proceedings (pp. 511-520). University of Granada.
Jacobson, C., & Lehrer, R. (2000). Teacher appropriation and student learning of geometry through design. Journal for Research in Mathematics Education, 71-88. http://doi.org/10.2307/749820
Jasien, L., & Gresalfi, M. (2021). The role of participatory identity in learners' hybridization of activity across contexts. Journal of the Learning Sciences. http://doi.org/10.1080/10508406.2021.1940186
Jasien, L. & Horn, I. S. (in press). Fixing the crooked heart: How aesthetic practices support sensemaking in mathematical play. Journal for Research in Mathematics Education.
Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. The Journal of the Learning Sciences, 4(1), 39-103. http://doi.org/10.1207/s15327809jls0401_2
Lave, J., & Wenger, E. (1991). Situated learning: Legitimate peripheral participation. Cambridge University Press.
Lehrer, R. (2012). Developing understanding of geometry and space in the primary grades. In Lehrer, R. & Chazan, D. (Eds.), Designing learning environments for developing understanding of geometry and space (pp. 183-214). Routledge. https://doi.org/10.4324/9780203053461
Lobato, J. (2006). Alternative perspectives on the transfer of learning: History, issues, and challenges for future research. The Journal of the Learning Sciences, 15(4), 431-449. http://doi.org/10.1207/s15327809jls1504_1
Mehan, H. (1979). 'What time is it, Denise?": Asking known information questions in classroom discourse. Theory into Practice, 18(4), 285-294. http://doi.org/10.1080/00405847909542846
Schoenfeld, A. H., Charles, R., & Silver, E. A. (1988), Problem solving in context(s). In Charles, R.I., & Silver, E.A. (Eds.), The teaching and assessing of mathematical problem solving. National Council of Teachers of Mathematics.
Venkatesan, S. (2010). Learning to weave; weaving to learn... what?. Journal of the Royal Anthropological Institute, 16, S158-S175. http://doi.org/10.1111/j.1467-9655.2010.01615.x
Vygotsky, L. S. (1980). Mind in society: The development of higher psychological processes. Harvard University Press.
Westegaard, S. K. (1998). Stitching quilts into coordinate geometry. The Mathematics Teacher, 91(7), 587. http://doi.org/10.5951/MT.91.7.0587
Wickstrom, M. H. (2014). Piecing it together. Teaching Children Mathematics, 21(4), 220-227.

Paper 2: Confluence hunting

Designing for Confluence Spaces

Introduction

The debate over how to incorporate students' out-of-school knowledge into classrooms returns perennially with every theoretical development, and each new concern about Americans' (lack of) STEM knowledge. Currently, the *practice turn* is reviving these cyclical arguments. At the same time, there is renewed public interest in improving STEM literacies such as "the ability to critically evaluate the science or engineering content in a news report, conduct basic troubleshooting of common technologies, and perform basic mathematical operations relevant to daily life" (NRC, 2014, p 34). A recent poll found that only "[t]wo-thirds of Americans (67%) say the scientific method is designed to be iterative, producing findings that are continually tested and updated"—a number that shrinks to 56% for those with only a high school degree (Kennedy & Hefferon, 2019). This persistent view of science as "final form" rather than as an ongoing process (Duschl, 1990)—or of mathematics as infallible (O'Neil, 2016)—has been blamed for everything from disinterest in STEM careers to misinformed political trends and vaccine hesitancy (Achenback, 2015)—a problem that has proven especially intractable and problematic in recent years.

Some researchers suggest focusing on the "nature of science" (NOS) to address the gap between scientists' view of their work and the public perception of science. Meyer and Crawford (2011) even argue that ideas about multicultural education can be brought together with inquiry-based reform efforts by highlighting NOS as a goal for science education. One problem with this approach, however, is that there is little consensus in the field about what the nature of science—or any STEM discipline—actually is. Critical scholars argue that established definitions "reflect a normative canon of knowledge, values, and practices shaped by colonial and settler colonial histories (Martin, 2013; Medin & Bang, 2014; Mutegi, 2011)" the perpetuation of which is damaging to minoritized students (Sengupta-Irving et al., 2020). By contrast, advocates of practice-based reforms claim that giving students experience conducting scientific investigations and reasoning from models gives them a better sense of what science is, where it applies, and how to assess levels of certainty than adding more declarative content to the curriculum (e.g. Miller et al., 2018). Still others emphasize the importance of developing meta-awareness not just of science but of various epistemologies in order to facilitate fluid navigation of different genres of participation (e.g. Moje et al., 2001).

This paper considers what implications the practice turn has for teaching students about the nature of STEM disciplines. In it, I argue that what counts as STEM (and who gets to say) is a question of disciplinary boundaries. If we want students to develop a more robust understanding of these boundaries, a fruitful addition to a functioning STEM learning ecology would be spaces where students can negotiate what does and doesn't count as STEM in ongoing, meaningful activity. I call these *confluence spaces*. Similar to *third spaces* or *hybrid* activities, these are spaces where two different practices come together in service of a single goal. In contrast to those constructs, however, confluence spaces focus on out-of-school practices like knitting and sailing rather than on racial and ethnic communities that are marginalized in the United States.

By centering these intersections, we can help students see out-of-school practices as related and even mutually beneficial to school disciplines without claiming that they are the same. That is, where third spaces and hybrid activities are often touted as boundary-destroying, confluence spaces are intentionally boundary-defining. Further, I advocate for developing these practices alongside school STEM rather than recruiting practices students are already familiar with, so that diverse classrooms of students have shared experiences to draw on when making connections to STEM. I conjecture that this will open space for students to reconsider the boundaries of the disciplines—what counts and what doesn't—for themselves. Allowing students to participate in this kind of negotiation both honors the situational nature of boundaries and maintains the epistemic integrity of non-academic practices.

Background

For decades, scholars have debated whether and how unschooled knowledge relates to school-valued subjects in the K–12 curriculum (e.g. Delpit, 1988; Gill-Perez & Carrascosa, 1990; JRME, 2002; Alim, 2007). In both humanities and STEM fields, researchers have examined what kinds of everyday practices include routines that appear relevant to academics (e.g. basketball (Nasir & Hand, 2008); cards (Schademan, 2011); and tithing (Taylor, 2013), to name a few recent examples). While the activities are varied, this research has generally targeted out-of-school activities that support the engagement of students from marginalized communities. Designs for learning that build on this work generally conjecture that legitimizing those activities in school will support the participation of marginalized students in academic fields. These designs rest on the idea that in addition to building content knowledge, school experiences develop students' ideas about what counts as knowledge, frequently to the exclusion of everyday practices of minoritized communities.

Beyond content, researchers have also looked to the ways out-of-school spaces facilitate persistence and identity development (e.g. Nasir & Hand, 2008; Chapman & Gresalfi, in preparation). In some cases, these studies highlight parallels between out-of-school participation structures and recommendations from K–12 mathematics reform that have already been shown to support broader participation (c.f. Boaler, 1997; Gresalfi et al., 2016). Designs for learning that capitalize on these analyses are often problem-based and student-led, and even incorporate elements of the out-of school activities they are meant to connect to (e.g. Barton & Tan, 2009) or relocate entirely to out-of-school spaces (Gresalfi & Chapman, 2017). In this way, not only the content, but how it is encountered is said to influence what students understand about what counts as disciplinary engagement.

Some scholars have taken ideas of diversity in a different direction, arguing that focusing on knowledge that is tied to marginalized social groups—often dismissively termed "cultural" knowledge (Mignolo, 2009)—itself has an otherizing effect. Instead, they suggest both emphasizing the fluid nature of participation and considering the productive possibilities of heterogeneity more generally. Rosebery et al. (2010) advocate deep consideration of students' everyday meanings, pointing out that "intellectual rigor results from multiple, varied opportunities to think broadly and deeply about a phenomenon or idea from many places (Hall & Greeno, 2008; Nasir et al., 2006)" (pp 326–327). These and other scholars discuss in-school and out-of-school knowledge in terms of Bakhtinian notions of *heteroglossia* (Bakhtin, 1994; Rosebery et al., 2010; van Oers, 2002) or else Gee's concept of *Discourse* (2015), or Gutiérrez and Rogoff's *repertoires of practice* (2003). The latter suggest that instead of catering to supposed traits or learning styles, emphasis should be placed "on helping students develop dexterity in using both familiar and new approaches" (Gutierrez & Rogoff, 2003, p 23) or navigate different genres of participation (Moje et al., 2001).

Underlying this debate are questions about what counts as STEM knowledge and how to account for powered interactions between communities. Current standards emphasize disciplinary practices instead of simple facts and skills (e.g. NRC, 2012). A practice view of knowing—in keeping with ideas of heteroglossia and repertoires of practice—challenges previous ideas about cultural traits, and even about blending in-school and out-of-school activities. From a practice view, calculations done in service of comparing basketball players (Nasir, 2008) or prices in the supermarket (Lave et al., 1984) are not unquestionably the same as school mathematics, nor are many school activities the same as their supposed disciplinary counterparts (e.g. Jiménez-Aleixandre et al., 1999). People—especially students—experience these practices as distinct, meaning attempts to validate out-of-school practice by calling it all "math" are likely to be insufficient.

Practices, not merely interactional routines, are inextricably tied to the communities they belong to and bound up in associated goal structures (Christiansen, 1997). Furthermore, though these related activities are in some sense continuous with academic disciplines, as Sengupta-Irving et al. (2021) claim, their status as a particular practice is situational (Akkerman, 2011) in much the same way community membership is (Philip et al., 2013). This does not mean that borders do not exist, or that they should all be dissolved, however. On the contrary, the disconnect for students between activities that appear perfectly parallel to researchers is well-documented (e.g. Nasir & Hand, 2008; Nunes et al., 1993). Thus, one goal of current research is to highlight the ways that such boundaries are made meaningful in interaction (Chapman, in press). Because of how power circulates, for example, designers encounter challenges both "in treating the everyday and school-based domain knowledge as continuous, and in resisting the subordination of the everyday to school (Moschkovich, 2006; Taylor, 2012; Warren et al., 2001)" (Sengupta-Irving et al., 2021, p 3).

I follow recent scholars who argue that in order to broaden students' perspective on what counts as disciplinary knowing, we ought to involve them not just in differently valued calculations, but in explicitly negotiating the boundaries of the disciplines. Much of this work happens *from within*, inviting the practices of marginalized communities into school, or involving students in youth and family programs that focus on marginalized practices like Native Science (Bang et al., 2012). These research programs generally seek to push back on disciplinary boundaries and expand students' ideas of the disciplines to include typically marginalized practices. They have shown success in helping to reclaim epistemic authority for marginalized communities. Such programs typically focus on a single racialized or ethnic community, however.

Building on Rosebery et al. (2010)'s call to center diversity, I argue that a worthwhile extension of this work would be to explore the idea that experiences with practices and their boundaries codevelop. In this work I suggest that to help students develop a more flexible sense of the boundaries of the disciplines, they should experience those boundaries from multiple vantage points. Importantly, I consider this a deliberate building-on of, as opposed to a replacement for, interventions focused on minority groups. As with the *curb-cut effect* in disability studies (Glover Blackwell, 2017), designing to promote the participation of marginalized groups frequently helps all students. While I believe this is true specifically,[1] in this work I build on the theoretical developments of equity scholars to think about how they might apply to learning spaces more generally.

Based on a practice view of knowing, I argue that the negotiation of boundaries should be done not in debate class but in ongoing activities that aim to "develop dexterity" (Gutierrez & Rogoff, 2003, p 23) in multiple practices. I am calling these encounters *confluence spaces*, and suggest that while they could theoretically arise anywhere, because schooled ideas about STEM subjects have so much cultural power, these negotiations are more likely to be fruitful when designed into out-of-school institutions that have their own knowledge practices and their own motivations for connecting to school subjects.

Empirical motivation: a vignette

As a concrete anchor to this theoretical conversation, I offer a vignette from a recent study about the mathematics of knitting (Gresalfi & Chapman, 2017; Chapman et al., 2018; Chapman, in press), which I will return to occasionally throughout the paper. Importantly, this story does not describe a confluence space, but instead a *missed opportunity* for one.

In that study, we intended to confront the hegemony of schooling by designing for students to encounter mathematics in the context of knitting. The practice of knitting has historically invited more persistent participation from girls and women than has school mathematics. In an attempt to capitalize on that history, we aimed to let knitting be the leading activity, and designed for mathematics to surface organically as the knitting projects progressed. We conjectured that by letting knitting lead, the young girls in our study would experience less resistance to mathematics participation than they might in another context.

In preparation, we interviewed expert knitters and asked them to tell us where they saw mathematics as part of their knitting practice, rather than imposing our own ideas. Multiple accomplished knitters independently told us that in addition to repeatedly counting stitches and reading patterns, a common use of mathematics in knitting was at the beginning of a project when a knitter needs to calculate gauge.

To accurately predict the size of a project, a knitter will choose materials and then knit a sample section, called a swatch. From the swatch, she will determine her gauge—a unit rate, generally stitches per inch. Having determined the unit rate from her material, the knitter will either follow a pattern (which usually involves adjusting the materials to achieve a target gauge specified by the written pattern), or reason proportionally from the calculated unit rate to determine the number of stitches to reach a target size.

This process appeared to be an ideal *authentic* knitting task to build a curriculum around. Our design assumed that this mathematical task would be neatly subsumed into the knitting project for students as it appeared to be for experts. Trouble arose, however, when students either couldn't or simply didn't want to complete the calculations. Knowing that determining rate and

[1] experiences with Native Science would likely also help non-native students, for example

reasoning from ratios would be difficult for some of the students, we had relied on the idea that the knitting goals would provide motivation to learn the mathematics in these cases. Instead, confronted with the question of how many stitches to cast on, one student simply said, “I just added stitches until it looked about the right size”.

If this exchange had happened in a typical math class—the teacher trying to motivate a particular mathematical solution, and the student finding a workaround—this knitter might have been marked as off task (or worse, acting “clever” or even “insubordinate”). Indeed, even in our summer camp, ostensibly committed to privileging the knitting and centering student contributions, the facilitators noticeably balked, because this approach deviated from their expectations.

From a practice perspective, however, it is clear that the young knitter is simply working from within the epistemic culture of knitting, or a knitting *frame* (Chapman, in press), rather than a mathematics one. Where the designers thought that *calculate a target number of stitches based on a unit rate* was a legitimate knitting activity, it is clear from this student’s response that for her the knitting activity is something more general like *figure out how many stitches you need*. Calculating may be one way to get there, and it may be motivated in particular circumstances, but it is only a tool, not a requirement.

This episode demonstrates that what is true for experts is not always true for novices—evidence of the situational nature of the boundaries. More importantly, it highlights an associated activity shift not anticipated by the design. Where *applying* the relevant mathematical concepts and algorithms may be easily subsumed into knitting when the math itself doesn’t cause problems, stopping the knitting to build and reflect on mathematical concepts is a dramatic change, reorienting participants to new tools, structures, and interactional routines (Chapman, in press).

The design for the knitting camp thus missed an opportunity to engage this student. We assumed that mathematical activity would be a seamless part of knitting, whereas what is truly seamless is only applying a borrowed routine—recalling and reusing previously encountered calculational strategies and algorithms. Learning new mathematics in the context of knitting, or negotiating whether mathematical considerations are relevant to the knitting, is a different sort of project, and one that I argue would be more useful for developing trajectories through the learning ecology.[2] Mathematics practice is never truly subsumed into knitting practice; while knitting sometimes uses routines more typically thought of as mathematical, the practices of knitting and mathematics nevertheless remain distinct.

For this reason, I argue that in order for experiences such as encountering math in the context of knitting to be useful, designers shouldn’t try to subsume one practice into the other, but instead to open up what I am calling a *confluence space*—an opportunity to go back and forth between practices and negotiate the boundaries between them. To make this happen, designers

[2] This same thing happens when designers attempt to integrate across the STEM curriculum and end up confronting the boundaries of field science and mathematics. For example Lehrer and Schauble (2021) describe how students who had previously developed ideas about polar coordinates abandoned the reasoning that had motivated their data collection design when confronted with the realities of collecting field data.

need to consider practices as more than interactional routines, and design for mutual[3] service between knowledge communities. In our knitting example, that means that instead of only designing a knitting goal that we hoped mathematics would help students to achieve, we should also have included a mathematical goal that knitting might prove useful for,[4] and better yet, a goal that both communities could meaningfully contribute to.

A good candidate for the latter might be considerations of error propagation—what are the consequences for rounding to five stitches per inch from five and a half? Do I care about those differences if I'm making a pot holder? What about a blanket? What if the blanket is supposed to fit a bed? What if I'm making a sweater? Or a doll sweater? In each of these cases, working out the problem in knitting and in numbers can theoretically help students think about and compare other solutions.[5] Similarly, moving back and forth between practices requires that both are present in the same space *as practices*, which many contemporary scholars endorse theoretically, though few agree on how to operationalize.

A need for explicit negotiation

In response to the missed opportunity in our knitting intervention, I argue for encouraging new trajectories through a learning ecology by designing nonformal environments[6] (OECD, 2008) that explicitly exist at points of convergence and conflict between knowledge communities, whether academic disciplines vs. other knowledge traditions, or even one discipline vs. another. More than that, I argue that at these points of convergence, students should be able to act with agency in negotiating the boundaries of different knowledge practices. At the broadest level, I conjecture that designing for this kind of negotiation requires attention to when practices are present *as practices*, and whether there is truly *mutual support* between the knowledge communities that are brought together.

In this paper I begin developing the theoretical category that I am calling *confluence spaces*. As discussed in the context of our knitting study, I argue that confluence spaces should be organized around projects of both communities, and alternate which is the leading activity rather than consistently privileging one over the other. In order to further operationalize this, I suggest the concept of *mutual support*—that is, designing so that each community's goals are supported, instead of the more typical meeting where one community's knowledge practices are instrumentalized to serve the other's goals. Furthermore, I argue that in order to allow different practices to be present *as practices*, students must be able to act with *epistemic agency* in both

---

[3] What I will sometimes call "bidirectional"

[4] And I mean, useful beyond the standard "providing motivation".

[5] In their study, Lehrer and Schauble similarly suggest choosing tasks that have multiple opportunities for model test and revision, as well as being aware of the kinds of child-invented strategies that may derail the intended curriculum. In this way, confluence spaces may be relevant to more than just out-of-school practices.

[6] A quick note on terminology: I intentionally focus this work on nonformal spaces (OECD, 2008) such as after school clubs and summer camps, and use the term 'nonformal' to indicate a distinction from both formal instructional environments such as school, and informal or free-choice encounters such as family museum visits. Much of the literature does not make a clear distinction between nonformal and informal learning (or even simply "out of school time" (OST)), so when discussing the field more broadly I use the term 'informal', of which nonformal is frequently considered a subset.

knowledge traditions, including negotiating the boundaries between them. While a confluence could arise anywhere,[7] at a broader level I contend that they are more likely in after school clubs and summer camps, because the historical hegemony of schooling makes it harder to encourage other practices within its traditional domain (e.g. Wisittanawat & Gresalfi, 2021; Chapman, in press). For this reason, I focus generally on nonformal environments, though I hope that the theoretical work will prove useful in other applications.

In order to emphasize the negotiation rather than the outcome, I use the term *confluence*. While it can produce an eventual merging, at the point where two rivers come together they are frequently of equal strength and—if they have distinct properties such as silt or mineral content—still distinguishable one from the other. These (theoretical) spaces are qualitatively distinct from, though likely on a continuum with, spaces where practices have fully merged to create something new—analogous to a pidgin or patois vs. a true creole. Additionally, I use the word *space* in the sense of *holding space* for someone—an idea that I borrow from activist circles that involves extending empathy and reserving judgment in order to allow things to surface that might otherwise be repressed or overlooked. By marking this, I recognize that designing to hold space is something of a double-bind because the designer is in many ways part of that broader social structure.

Outline of the paper

The eventual goal of this work is to develop design conjectures for confluence spaces. In this preliminary paper, I aim to articulate theory and supporting analytic tools, though in some cases those analytic tools blend into or at least hint at design. Broadly, I aim to bring together two ideas that I see as interrelated: ontology and power, or what counts as disciplinary knowledge, and who gets to say.

Parts one and two offer theoretical arguments with suggestions for specific analytic lenses. In the first section, I tie practice theory to recent curricular reforms, such as Common Core Mathematics and the Next Generation Science Standards. In the second section, I connect that definition to ideas from equity work about powered interaction between communities and entailments for disciplinary boundaries. In the final section, I focus more explicitly on confluence spaces, exploring both practical and theoretical justifications for their possible utility. I touch on ideas from the Sociology of Science that consider the disciplines as defined by their *epistemic cultures* (Knorr-Cetina, 1991) and highlight the situational nature of boundaries. In each section, I conclude the theoretical discussion with suggestions for operationalization of the concepts, whether analytic or design-focused (sometimes both).

Part one: Two meanings of 'practice'

Current reform efforts frequently focus on the practice turn in education research, emphasizing that students should engage in disciplinary practice rather than memorizing facts by rote. Even so, not all scholars who talk about practices do so in the same way. Here I differentiate two different uses of the word *practice*—one that is based on interactional routines, and one that more fully captures epistemic culture—and argue that only the latter fully

[7] and in theory at least, they do privately for individuals

capitalizes on the promise of this theoretical shift.

Theory: When is a practice really a practice?

Science[8] as presented to young people has long been characterized by lists of disembodied facts (Duschl, 1990). This vision of science learning is reflected in the entire infrastructure that supports "science for kids" from picture books to textbooks, and from science museums to K–12 classrooms, often with an accompanying sense of wonder. Whatever the mature work of scientists may be, the job of children implied by these designs is to amass bits of knowledge related to the most prominent branches of science—the surprising effects of surface tension, or wild statistics about outer space. Following the *practice turn* in educational research, scholars have focused not only on facts (and skills), but on the practices they are embedded in.

Defining *practice* is nontrivial, however, not least because the word gets used in multiple ways. The first way is as something akin to an *interactional routine*. Even the Next Generation Science Standards (NGSS)[9] (NRC, 2012) use the term this way, as The National Research Council aims for actionable specificity, offering a list of scientific practices around which to build curricula.[10] Researchers following the NGSS have taken up one or more of these recommendations as a focus for their work, seeking to develop *argumentation* or *modeling* in their designs with students. Without disparaging this work, it is important to make a clear distinction. It is possible to engage in the argumentation practices of many different communities (e.g. Ehrenfeld & Heyd-Metzuyanim, 2019), meaning argumentation is not itself inherently scientific (or mathematical). Even further specifying the details of how an argument proceeds does not guarantee its being part of a particular disciplinary practice.[11]

While practices can be described in declarative statements, learning to recite a list of routines, or march through a series of steps by rote, reduces them to objects rather than processes (sometimes thought of as an exercise, done as mimicry or rehearsal and not as a true example of the target behavior). At least partly through this kind of reduction, "school science has developed its own logic and discourses that have set it significantly apart from scientific practices as understood by the scientific community" (Tytler et al., 2017, p 657). Many traditional school designs treat interactional routines as though they constitute a practice—entice students to write down a hypothesis, et voilà!—science! As we saw with knitting, however, being prompted to calculate something does not immediately make mathematics present *as a practice*, only as an object pulled from mathematical practice and used (or rejected) for other purposes.

As Ford (2015) argues, an important feature of practices is that they are not reducible to any

---

[8] Throughout the paper I alternate between examples from science and examples from math, but I mean for the argument to extend to other epistemic cultures as well, particularly STEM cultures

[9] Same goes for the Common Core math standards.

[10] (1) asking questions; (2) developing and using models; (3) planning and carrying out investigations; (4) analyzing and interpreting data; (5) using mathematics and computational thinking; (6) constructing explanations; (7) engaging in argument from evidence; and (8) obtaining, evaluating, and communicating information.

[11] Acknowledging that this is a legitimate use of the word, in order to avoid confusion, from here on I will generally refer to these constitutive practices as "interactional routines" and attempt to differentiate them from a more foundational, philosophical view of practice writ large—a definition that can get at the gestalt of a particular disciplinary practice rather than the particulars of its constitutive interactional routines.

particular set or aspect of performances of that practice: “Practices *exhibit* regularity, and it is tempting to account for these in terms of descriptive and prescriptive rules—what to do, how to do it, and when. However, social practices cannot be accounted for by any sets of rules or descriptions of regularities in behavior or interaction” (Ford, 2015, p. 1043). In other words, practices cannot be identified by the scripts they appear to follow, even at greater and greater levels of specificity, because it is possible to follow the script without truly engaging in the practice.[12]

Examples: Continuity across practices—cultural congruence, or “blending”

When practices are reduced to interactional routines, they are both easier to identify and simpler to incorporate into school. In this way, designs frequently look to smooth over differences between in-school and out-of-school routines. This kind of congruence is sometimes referred to as *blending* practices, or *blurring* the boundaries between in-school and out-of-school knowledge (e.g. Nasir et al., 2016), and usually amounts to couching school subjects in terms that are more familiar and appealing to students. This can mean using music as a vehicle for exploring math and science content (e.g. Elmesky, 2011; Brown et al., 2016) or incorporating family recipes into a unit on calories (Barton & Tan, 2009).

Many of these recommendations fall under what Lee & Fradd (1998) called “instructional congruence”:

> "We propose the notion of instructional congruence to indicate the process of mediating the nature of academic content with students' language and cultural experiences to make such content (e.g., math and science) accessible, meaningful, and relevant for diverse students.” (p. 12)

This work—including some[13] from the “funds of knowledge” tradition that began in Latinx communities, and related “culturally congruent” or “culturally relevant” work in African American communities (e.g. Lee 1993, 1995, 2001; also, see Ladson-Billings, 1995, for an overview of this work)—looks to students’ lives outside of school for community knowledge bases that can recontextualize school knowledge. These can even be elaborate constructions, such as an entire unit in which students pose as science journalists (Nicholas, 2017).

While this recontextualization can successfully invite the participation of students from non-dominant communities at the classroom level, at a theoretical level is has several major limitations. First and foremost, the cultural difference model focuses on interactional routines, not on practices as defined above. From a practice view, it is not possible to bring fundamentally different knowledge cultures into *congruence*, it is only possible to approximate this congruence by objectifying one practice or the other. The most common way, as described by Lee & Fradd, is to objectify academic practices (splitting them off and reducing them to “content”) in order to

[12] And conversely, a person could engage in a practice without necessarily conforming to an expected script.

[13] In every scholarly tradition, of course, there is work that transcends these kinds of generalizations. I fully acknowledge that these are broad strokes.

package them in students' out of school practices (or "cultural experiences").[14] Objectifying academic practice does not fulfill the goal of socializing students into school-sanctioned epistemic cultures. Especially when trivially enacted, then, these designs can actually further marginalize the students they are meant to serve, by failing to provide them access to the disciplines, or to the "culture of power" (Delpit, 1988).

The other way to recontextualize different knowledge traditions is to objectify students' out-of-school practices. Doing so gives so-called *cultural* knowledge a subservient role, rather than making it present in the classroom *as practice*. Instrumentalizing out-of-school practices robs the represented communities of their epistemic authority since they are included only as objects for the consideration of another community, not as authors. At the level of broader social processes, this kind of tokenizing of marginalized cultures can actually perpetuate homogenization instead of encouraging diversity (Sengupta-Irving, 2020). Finally, by making classroom-level changes without addressing the culture of schooling (or the disciplines) writ large, even productive disruption that invites disciplinary scrutiny of cultural knowledge can create "too local" a solution (Carlone & Johnson, 2012, p. 16), effecting classroom-level change that doesn't carry over from year to year or even into other classes.

Analysis: Epistemic Agency—keeping the process in practice

It is common to reduce disciplinary practice to specific interactional routines in written research. Sometimes this is done at the theoretical level, when a designer or researcher sees no difference between a practice and its constitutive routines. Just as often, however, the distinction is argued for theoretically but overlooked for analytic expedience—when the presence of an interactional routine is taken to signal the presence of an associated practice.

So how can we be confident, analytically, in what practice is being exhibited? One candidate for helping to make sure practices are not reduced to interactional routines—either in analysis or design—is the idea of *epistemic agency*, as argued for by Miller et al. (2018). Focusing on epistemic agency as a way to assure that students are legitimately involved in practices and not merely mimicking them (Miller et al., 2018) rests on the observation that above all, science is a *knowledge building* process.

Epistemology in its most basic sense is a system of criteria for separating opinion from justified true beliefs, or "how we know what we know"[15] (Knorr-Cetina, 1999, p. 1). In other words, *epistemology* is a claim about the basis for knowledge, which partially defines different knowledge traditions[16]. Agency, on the other hand, is related to the idea of "free-will" and a logical implication of constructivist roots—that is, of traditions that hold that each student builds her own knowledge rather than receiving it from an authority (Scardamalia and Bereiter, 1991). *Epistemic agency* is more than individual, however, and involves the opportunity to meaningfully contribute to collective knowledge building practices.

Without claiming to be exhaustive, Miller et al. suggest "four opportunities for students to be explicitly positioned with agency, perceive themselves as epistemically agentic, and to act with

[14] Again, this is what we saw in the knitting example that began the paper.
[15] Alternately, the "source, scope, and validity of knowledge" (Bang & Media, 2010)
[16] The key distinction here being justified "by what" and "to whom".

that agency" (2018, p. 6). These opportunities help to guard against what they call a "complacent approach" (*ibid)* to taking up the NGSS. They are:

1. Opportunities to solicit and build on student knowledge as a resource for learning
2. Opportunities to build knowledge
3. Opportunities to build a knowledge product that is useful to students
4. Opportunities to change structures that constrain and support action" (*ibid*)

Giving students agentic opportunities to participate in knowledge building guards against complacent enactments of the NGSS by ensuring that classrooms are engaged in knowledge building and not just recitation of "final form" science (Duschl, 2008).

In particular, these opportunities allow students to participate in the "meta-rules of endorsement" (Sfard, 2007, p. 580), which are essential to the epistemic project. Students are given opportunities to judge whether classroom practices are meeting the epistemic criteria of the local knowledge building project, rather than merely following rules that have no immediate relevance. From this perspective, learning science requires domain-relevant content knowledge—because scientific practices are not domain-general skills—but not in isolation. Students need to learn content and participate in practices, which means acting with epistemic agency in building toward disciplinary goals.

Part two: The (re)making of boundaries

If we cannot bring practices into congruence without objectifying one or the other, how can two practices ever be present in the same space? Put another way, how can we bring together different practices on common ground?

Theory: Giving voice to "outside" practices

Two STEM literacy goals are addressed by students' agentic participation in the practice of science: helping them to see scientific facts as products of a rigorous process rather than as immutable truths; and developing their judgment about what does and doesn't count as STEM practice. This second goal is more complex than helping kids to practice science in school, however.

Judgments about what counts as STEM developed in K–12 schools are shaped by the cultural pressures on these institutions. Generally these include authorities such as textbook authors and standardized tests that rely on one vantage point from which to judge whether something counts as disciplinary engagement.[17] In mathematics instruction, Paul Dowling (1998) refers to this as "the mathematical gaze" and describes it as part of the mythos of mathematics. The mathematical gaze privileges the viewpoint of European mathematics[18] and renders it invisible

[17] Our knitting study design deliberately recruited expert knitters in an attempt to circumvent this singular vantage point; in hindsight, it was not enough.

[18] Dowling is chiefly examining English mathematics texts, but argues that this is true in many parts of the

even while it "implicitly retains the prerogative and principles of diagnosis" (Dowling, 1998, p 15). His description is reminiscent of what Mignolo calls "the *epistemic privilege of the First World*" (2009, p 166), or what Castro-Gómez has called "the hubris of the zero point" (quoted in Mignolo, 2009, p 167). In each case, the privileged epistemological viewpoint is rendered rhetorically neutral while simultaneously acting as the arbiter of what counts.

This observation further illustrates why practices don't just blend. Referencing Lave et al. (1984)'s description of the arithmetic of supermarket shoppers, Dowling (1998) writes,

> "We know that the principles which regulate mathematics and those which regulate shopping constitute distinct systems. One may recruit elements of the other: a shopper may use a memory of a multiplication table; a mathematics textbook may incorporate a domestic setting. But precisely what is recruited is regulated by the recruiting rather than the recruited practice. Mathematics is not about shopping because the shopping settings which appear in mathematical texts are not motivated by shopping practices" (Dowling, 1998, p 16).

This mechanism—where the recruiting practice regulates what pieces of another practice are recruited—highlights one of the pitfalls of working inside a culturally powerful institution like K–12 school, where "school" always acts as the recruiting practice.

Scholars have long acknowledged the power of school to swallow up out-of-school practices and the considerable "pedagogical work that allows for the equal footing" (Sengupta-Irving et al., p 3) of practices deemed *other* by this impossible zero point. Many researchers have focused on teachers, documenting the ways that their expectations render the contributions of minoritized students invisible or even nonsensical, even causing students to self-censor (Moje et al., 2004). More recent work explicates the influence of broader cultural narratives in this process, suggesting that it is not enough for teachers to avoid contributing, they must instead actively resist the colonization of minoritized epistemologies (e.g. Bang et al., 2014) or even of everyday practices (Wisittanawat & Gresalfi, 2021; Chapman, in press) by White mainstream ideas about what knowledge is valuable.

Examples: Establishing equal footing by building new practices

In attempting to escape this zero point and expand ideas about what counts as STEM, some designers aim to incorporate marginalized practices into the general headings of the disciplines. These traditions include *hybridity* and *third space* as well as Megan Bang and others' work on *Native Science*. Similar to cultural congruence, the focus in this work is on helping students to see connections between their out-of-school knowledge and school disciplines. In some cases, this means encouraging use of home languages, and in others it is more generally *everyday* meaning-making resources. Importantly, these in-school and out-of-school knowledge practices are not seen as incompatible.

In keeping with the practice view articulated above, scholars in these traditions frequently emphasize the inextricability of content and practices. As such, they explicitly write against

---

world.

some of the earlier cultural difference work, as well as a simplistic reading of *hybridity.* For example, Ma (2016) writes,

> "a critical consideration in the design for hybrid learning settings [is] the relation between processes of learning and the content of learning. These are not separable; disruptions (and changes in general) to how students learn and engage in learning activity have consequences for what students learn in terms of students' identities in relation to learning as well as how disciplinary content is constructed (Boaler & Greeno, 2000; Jackson, 2009). In other words, expansive, hybrid learning settings transform both processes and the content of learning." (p. 365)

While it sometimes goes unstated, implicit in most of these designs is that they are meant to count as disciplinary engagement. Bang and Medin acknowledge this explicitly, noting that they "resist placing Western modern science and Native science in an oppositional dichotomy because it has the effect of inappropriately simplifying both ideas of Western modern science and Native science (Maryboy, Begay, & Nichol, 2006)" (Bang et al., 2010, p 1015). Outcomes of this work are considered successful when participants begin to dissolve this dichotomy, instead "recognizing science as a more inclusive set of practices and orientations that have spaces for native identities" (Bang et al., 2010, p 1019).

Analysis: Mutual support between epistemic communities

If the purpose of confluence spaces is to negotiate the boundaries of two distinct practices in interaction, both practices need to be present as practices rather than letting one dictate which pieces of the other are recruited. Design work such as Ma's walking-scale geometry (Ma, 2016) makes space for non-school resources by moving students to the football field, making typical school routines—e.g. manipulating figures on a piece of paper with the aid of pencils and protractors—impossible. These and similar studies suggest that school should be actively designed against.

Studies that aim to co-develop indigenous mathematics and Western mathematics have suggested giving equal voice to both in the same space, often by balancing the curriculum and by inviting community representatives into the classroom (Webster et al., 2005, Lipka et al., 2007; Quigley, 2013). Some of this work came out of a program called "Math in a Cultural Context" (MCC). The research goal of MCC was explicitly "a way to put together Yupiaq and Western pedagogy and the teaching of Yupiaq culture, language, and values, and, in this case, mathematical knowledge" (Lipka et al., 2007, p. 111). Similar studies have argued that "Cultural practices within the community should contribute to curriculum development and, in return, the curriculum should affirm cultural practices (Keane, 2008)" (summarized in Glasson et al., 2009, p. 138). Building on these designs, I argue that in order for a confluence space to arise, students must experience epistemic agency within both represented practices. This likely means acknowledging and working toward different goals simultaneously.

According to Ford, a "crucial feature of practices, normatively conceived, is that these patterns of interaction must constitute something at issue and at stake in their outcome" (2015, p. 531). This focus on goals can help differentiate disciplinary practice from "doing school" the same way epistemic authority does, but it can also help identify other practices. Whereas in school frequently what is "at stake" is often merely a grade, for science, what is at stake is something more like an increasingly robust explanation of the natural world[19]. In the knitting vignette I suggested that our design might have offered not only a knitting project that could make use of math, but a mathematical goal that the knitting could help with.

Alternating between activities doesn't necessarily mean splitting them off from one another, as we often do in school. Two practices can be present for different participants, or a single participant can alternate between different interpretations of "what is going on" (Goffman, 1974) from one moment to the next. In another analysis of the knitting camp (Chapman, in press), I show how school math temporarily interrupted the knitting project. Responding to this break in activity, one facilitator was able to help a participant make sense of proportional reasoning using her knitting as an "object to think with". This took considerable work, however, as the two first had to negotiate what kind of activity they were participating in. Future designs will be transparent about sharing different goals up front.

Focusing on epistemic agency does, however, mean recognizing both practices as knowledge-building activities. Another design might ask students to consider a single task—such as designing a sailboat—from the perspective of a scientist or an engineer *and also* from the perspective of a sailor or a builder. Importantly, in a design like this, the sailor and builder are seen as having their own knowledge building practices that may contribute to the shared project, rather than as recipients of the wisdom of scientists and engineers. An even more open-ended space might let students develop a task and then imagine together what kinds of perspectives might be brought to bear, and how they might prove differently useful.

Part three: Delineating and destabilizing the disciplines

Practice-based theories have shown success in inviting the participation of marginalized groups, in part by broadening what counts as disciplinary engagement. These researchers have successfully worked to expand ideas about what counts as STEM, but have little to say about what doesn't count. Additionally, most of these programs have involved targeting minoritized groups separately, whereas many classrooms are made up of heterogenous groups of students from different backgrounds. These two observations frame the remainder of this paper, and support the basic argument for enhancing the STEM learning ecology by building confluence spaces. I will address them beginning with the more pragmatic concern and extending to the theoretical.

i. Resorting to cultural differences

The more practical concern—that the reality of many classrooms does not reflect the cultural homogeneity in many hybridity and third space studies—nevertheless comes with theoretical entanglements.

Recall that the motivation for instructional congruence described in part one relied on the *cultural difference model*. Despite the intentions of early proponents, this model has been denounced for its treatment of minoritized cultures. In objectifying out-of-school practices, the

[19] Clearly this is an "idealized" vision of science, but it will suffice for the current argument

cultural difference model relies on a simplistic view of students' home communities that suggests homogeneity among members—an assumption that many researchers have acknowledged as damaging (e.g. Carlone & Johnson, 2012). It also assumes that cultures are static, which overlooks evolving community and cultural practices (Paris & Alim, 2014) and limits our thinking about individuals' agency within oppressive structures.

Projects such as Gutiérrez's Migrant Student Leadership Institute (MSLI) (2008) or Bang et al. (2010)'s community science partnership escape this criticism because they are committed to centering members of marginalized communities, not only as participants but as co-designers. Their work foregrounds rather than instrumentalizes cultural ways of knowing and also facilitates those communities' speaking back to Discourses of power, thus answering calls to consider "*both* structures and lives" (Weiss & Fine, 2012, p. 174). Individual classroom teachers with diverse groups of students, however, frequently do not have the time or the resources to build such robust interventions, particularly when a single class might require numerous different designs.

Wager (2012) has documented that in the face of these challenges, many teachers resort to instrumentalizing one or the other practice[20], while only one teacher in her study was recorded as "identifying embedded mathematical practices" from a student's home culture—the target strategy.[21] Interestingly, several teachers[22] circumvented the issue of heterogeneity by creating cultural experiences within the classroom, so that all students have the same experience to draw on when making connections to mathematics. This last strategy echoes Rosebery et al. (2010)'s experience with third and fourth graders. In their study, despite the goal of drawing on each student's individual background, a shared experience became an important focal point for the class's exploration of thermodynamics. The authors contend that if a fire drill had not sent the class outside without their coats on, something else would have galvanized the conversations that had been germinating. Nevertheless, the shared experience was inarguably a productive one.

Designing confluence spaces as field trips[23] explicitly addresses these practicality concerns. First, field trips can provide a shared experience for a heterogeneous class. While such an experience does not replace a teacher's learning about his individual students, it can offer a shared reference point. Secondly, rather than requiring the teacher to become familiar with a new practice and draw connections to STEM disciplines, building these experiences as field trips puts the bulk of the design back in the control of the community that supports the out of school practice.[24] Centering these experiences outside of school can also help to put the different practices on equal footing, foregrounding mutual support and guarding against unintentional instrumentalization.

[20] 14 out of the 22 teachers in her study

[21] This is the category in Wager's study that corresponds to the argument above for making outside practices present as practices and not as ossified objects recruited into school practice. In Wager's study, even that one example was qualified as "borderline".

[22] 8 out of the 22

[23] or summer camps, or after school clubs

[24] In this case, heritage institutions.

ii. Defining a practice in opposition

In part one I argued that in-school practices such as *math class* do not blend with out-of-school practices like *knitting* or *dominoes*. In part two, however, the MSLI and Native Science projects implicitly brought two different ways of viewing the disciplines under the same heading. The resolution of this apparent conflict provides the final motivation for confluence spaces.

Defining the disciplines—for example, delineating "science" from "not-science"—is itself a disciplinary practice (Gieryn, 1982). Thus, designs for involving students in STEM practice might reasonably include this kind of definitional work. Furthermore, because defining the boundaries of the disciplines is an ongoing process, what counts as part of the disciplinary cannon is not a settled question, but is always potentially in flux. Asserting that certain out-of-school practices count *as* disciplinary practice[25] is part of opposing the ongoing epistemological violence against minoritized groups (Sengupta-Irving et al., 2021). Yet, merely calling everything "math" or "science" can be confusing and even counterproductive, as students experience disconnects between practices.

The argument about practices not blending relied on the two practices in question constituting "distinct systems" (as Dowling (1998) put it). Anna Sfard (2007) (following Rorty) describes this as the incommensurability of different discourses: "Such discourses are incommensurable rather than incompatible, that is, they do not share criteria for deciding whether a given narrative should be endorsed" (p. 575). This is analogous to the knitting example wherein "how many stitches you need" was quite reasonably solved through a kind of embodied estimation. The knitter's strategy doesn't mean that whatever answer someone arrived at by calculation would be wrong, but neither is hers wrong *as a knitting strategy* despite its potential lack of precision from the mathematical perspective.

Sfard further argues that failing to acknowledge when two discourses are incommensurable—or, when the meta-rules of endorsement have changed—can lead to confusion and frustration for students. Such was (potentially) the case when we told students they were engaged in knitting, but balked when one chose not to calculate her gauge.[26] The same would be true if a math teacher stepped in to correct Lave et al. (1984)'s supermarket shoppers—there is something intuitively unfair about imposing the rules of one practice onto the engagement patterns of another.

By extension, simply claiming that "everything is mathematical", while it may feel liberating, is meaningless from a practice perspective—does that mean that the whole world is subject to the success criteria of a middle school math class? Furthermore, appearing to blend practices but still upholding the endorsement criteria of one practice is a common way that students who endorse the secondary practice are marginalized. For example, as Moje et al. (2004) describe, students can learn to self-censor when they recognize that the game of school is more about playing into the teacher's expectations than genuinely offering personal experiences.

Sfard contends that "a true opportunity for learning, is most likely to arise in a direct

---

[25] or are at least worthy of drawing on for sense making

[26] At least, it would have been the case had the knitter been judged harshly for circumventing the math; I have no evidence to suggest that she even noticed our hesitation, though researchers have certainly noted instances where hesitation on the part of the teacher was taken to indicate the student was wrong.

encounter between differing discourses" (2007, p. 606). This suggests that designing for confluence spaces—where incommensurable practices such as knitting and mathematics are brought together—can be highly productive for learners, but only if the disconnect is acknowledge. As opposed to blended spaces, designs for learning at the confluence of different epistemic cultures are likely to be fruitful if they are explicit about which is the leading activity and careful not to conflate the two when passing judgment. This reaffirms the contention from part two that in confluence spaces the two activities should take turns.

iii. Situational membership

Finally, the question remains of how to reconcile the recommendations of confluence spaces with the observations from equity studies. I follow scholars who argue that the disciplines themselves are dependent on the community of people who make up an epistemic culture (Rouse, 2018; Knorr-Cetina, 1999), and thus are themselves situational (Akkerman, 2011).

In the case of epistemic cultures, what holds members to each other is their investment in mutual intelligibility—people "count as agents and knowers only through their place in ongoing patterns of practice" (Rouse, 2018, p 30), and achieve such a place by anticipating the critiques of the community, particularly about the warrants for knowledge claims. Even so, these identities are diverse and overlapping, and the goal-directed practice of the disciplines is subject to change based on ongoing work of their members. As such, students' developing sense of being part of a community[27] is dependent in some part on the continuous negotiation of distinctions—what constitutes this community vs. that one, or my membership vs. yours. Communities, including the disciplines themselves, are "constructions that shift along with relations" (Akkerman, 2011, p. 22).

In our knitting study, as a follow-up to initial expert interviews, we created a survey. Among other things, the survey asked people who self-identified as "crafters"[28] to say whether they saw math as part of their craft, and if so where. To the question "Do you see any connection between your craft(s) and mathematics?", 95% of respondents (2109/2212) said yes. In follow-up questions, as well as in comments on the survey,[29] however, many immediately qualified saying it's not *real* math, or even that "there are a lot of times […] where people use math concepts without realizing it".

Some of the responses even indicated that crafters had changed their perspectives on whether there was math involved depending on their experiences with mathematics both in and out of school. Further, in conversation they occasionally changed their answers depending on whether we were positioned as math researchers or as designers creating educational experiences for young children. Thus, whether a practice counts as math appears to depend not only on a person's history with math and their present circumstances, but also on who's asking.

In this way, the recommendations from third space and confluence spaces are not in

---

[27] i.e. the community of "mathematicians" or "scientists"

[28] and generally, textile crafters

[29] Generally these were posted on social media sites such as ravelry and Facebook, and occasionally written in emails.

opposition, but only at either ends of a spectrum—whether Native Science counts as science, or is a separate cultural pursuit is, from this perspective, a question of scale, not of kind. At the scale of "science" vs. "not science", indigenous practice may be clearly part of the scientific project (and not worth distinguishing from modern Western science, as Bang & Medin (2010) argued), whereas at the level of "geology" vs. "chemistry" vs. "climate science" it may make more sense in its own category.

Analysis: Brokers and boundary objects

In contrast with hybridity and third space, *boundary crossing* affirms the value of out-of-school practices while acknowledging their differences.[30] Boundary crossing theory was developed in work contexts (Engeström, 1987), and does not specifically advance equity goals.[31] It is less utilized in K–12 STEM, but has been adapted to think about how schools come into contact with working scientists, either when scientists visit schools, or when students are training for STEM careers. These studies tend to emphasize the distinction between the communities while at the same time facilitating "the strategic alignment of contextual elements within a learning environment, such that they connect with elements in other activity systems" (Walker & Nocon, 2007, p 182).

Design recommendations from boundary crossing include promoting the work of *brokers* and *boundary objects*—people and things (both material and conceptual) that have a role in both communities and are able to highlight the boundaries, negotiate across them, and translate between incommensurable discourses. Ongoing interactions at boundaries can serve to develop meta-awareness of the communities as they are (i.e. nature of science a la Rudolph, 2000; Meyer & Crawford, 2011), or else to inform mutual adaptation.[32] By marking the differences between practices, boundary crossing affords students opportunities to "develop dexterity" (Gutierrez & Rogoff, 2003, p 23), or "the ability to manage and integrate multiple, divergent discourses and practices across social boundaries" (Walker & Nocon, 2007, p 181).

Confluence spaces are therefore boundary-defining instead of boundary-destroying. At first glance, such a position might seem conservative rather than progressive. Because boundaries themselves are situational, however, in addition to adding to the diversity of a STEM learning ecology, confluence spaces contribute to a more robust experience with disciplinary boundaries precisely because those boundaries depend on a person's vantage point.

More importantly, this reconsideration of what counts as disciplinary engagement returns some amount of agency to individual participants. While inertia has significant influence on what behavioral innovations will ultimately be adopted, the mutual dependence of community norms

---

[30] To be clear, in many ways this approach is different from the previous examples only in emphasis. As Gutierrez et al. commented, "This focus on heterogeneity is also congruous with our cultural historical activity theoretical (CHAT) approach in which boundary crossing across multiple systems—their tools, people, and histories—highlights the inherent heterogeneity of human experience." (2009, p. 13)

[31] Pushed to establish the connection, I would argue that many out-of-school practices—particularly those that involve working with the body "as opposed to" the mind—are in fact marginalized, particularly as they have been associated with vocational education and thus with lower classes (e.g. Willis, 1978). Tracing that argument is beyond the scope of this paper, however.

[32] For more details about how boundary crossing applies to confluence spaces, see (Chapman, in preparation).

and individuals leaves open the possibility that individuals can push back on the group. Finally, it suggests that participating in defining the boundaries of the discipline is a worthwhile activity for students to experience.

Conclusion

One thing the recent pandemic has brought into full relief is that many Americans have a limited and fragmentary understanding of the nature of science. The question is not merely one of distrust, however—in the face of a problem where consensus is not yet established and data are continually being updated, a "science is infallible" attitude is just as disorienting as a "science can't be trusted" one. Rather than adding to the laundry list of facts to be covered, however, a practice view suggests that what students need is agentic experiences with science as a knowledge-building practice.

In addition to updating the basic curriculum, new perspectives on learning suggest that it is a process of bringing together heterogeneous meaning-making practices to innovate on existing knowledge and create new possibilities. Yet there is ample evidence that many knowledge practices are not recruited by students into school sensemaking. This suggests that, if there is productive potential in these practices, bridges between them and school-valued knowledge practices should be actively designed for.

Previous attempts to build bridges from out-of-school practices have focused on school goals and often on classrooms, which has several drawbacks. First, earlier designs focused on interactional routines but less on epistemic authority, which tends to instrumentalize out-of-school practices for school gains. Second, school has its own inertia, and tends to swallow up outside practices, displaying them to students as mere shadows of their out-of-school selves. Third, defining the boundaries of the disciplines is not a singular, but an ongoing and situational project. Finally, researchers who have successfully navigated this terrain have frequently focused on marginalized cultural groups, which leaves open questions of how to design to support all students to recognize and reflect on how they recruit out-of-school resources.

I have argued that one way to address this chasm is to design explicitly for confluences—places where academic disciplinary cultures meet out-of-school practices *as* practices, and negotiate the shared territory of incommensurable discourses in activity. Given the constraints of school, I suggest that building confluence spaces is a worthy goal of field trips and summer camps, though theoretically they could arise anywhere two epistemic cultures meet. To guard against trivial enactments, I have suggested three interrelated ways of operationalizing the constructs of a practice ontology and the powered relations between school practice and out-of-school practices—promoting epistemic authority, mutual support between knowledge communities, and explicit work at boundaries such as that done by brokers and boundary objects. Giving students experiences in these spaces has the potential to help them not only extend their own navigational potential, but to broaden what is possible within the greater epistemic cultures they participate in.

Citations

Achenback, J. (2015, February 12). Why science is so hard to believe. The Washington Post. https://www.washingtonpost.com/opinions/why-science-is-so-hard-to-believe/2015/02/12/2ff8f064-b0a0-11e4-886b-c22184f27c35_story.html

Akkerman, S. F. (2011). Learning at boundaries. *International Journal of Educational Research, 50*(1), 21-25. DOI: 10.1016/j.ijer.2011.04.005

Alim, H. S. (2007). Critical hip-hop language pedagogies: Combat, consciousness, and the cultural politics of communication. *Journal of Language, Identity, and Education, 6*(2), 161-176. DOI: 10.1080/15348450701341378

Bakhtin, M. M. (1935). Discourse in the novel. Excerpted in Morris, P. (Ed), *The Bakhtin reader: selected writings of Bakhtin, Medvedev, and Voloshinov*.

Bang M., Medin D., Washinawatok K., & Chapman S. (2010) Innovations in Culturally Based Science Education Through Partnerships and Community. In Khine M., Saleh I. (Eds) *New Science of Learning*. Springer, New York, NY. DOI: 10.1007/978-1-4419-5716-0_28

Bang, M., Warren, B., Rosebery, A. S., & Medin, D. (2012). Desettling expectations in science education. Human Development, 55(5-6), 302-318. DOI: 10.1159/000345322

Barton, A. C., & Tan, E. (2009). Funds of knowledge and discourses and hybrid space. Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 46(1), 50-73. DOI: 10.1002/tea.20269

Boaler, J. (1997). Reclaiming school mathematics: The girls fight back. *Gender and Education, 9*(3), 285-305. DOI: 10.1080/09540259721268

Boaler, J., & Greeno, J. G. (2000). Identity, agency, and knowing in mathematics worlds. In Boaler, J. (Ed), *Multiple perspectives on mathematics teaching and learning*, 1, 171-200.

Brent, D. (2012). Crossing boundaries: Co-op students relearning to write. *College Composition and Communication 60*(4)*,* 558-592. www.jstor.org/stable/23264229

Brown, B. A., Cooks, J., & Cross, K. (2016). Lyricism, Identity, and the Power of Lyricism as the Third Space. *Science Education, 100*(3), 437–458. DOI: 10.1002/sce.21212

Carlone, H., & Johnson, A. (2012). Unpacking 'culture' in cultural studies of science education: Cultural difference versus cultural production. *Ethnography and Education, 7*(2), 151-173. DOI: 10.1080/17457823.2012.693691

Carraher, T. N., Carraher, D. W., & Schliemann, A. D. (1985). Mathematics in the streets and in schools. *British Journal of Developmental Psychology, 3*(1), 21–29. DOI: 10.1111/j.2044-835X.1985.tb00951.x

Chapman, *in press*. "Wait, it's a math problem, right?": Negotiating school frames in out of school spaces. *Educational Studies in Mathematics*. DOI : 10.1007/s10649-021-10099-0

Chapman, K. C., Gresalfi, M., & Bell, A. M. (2018, June). *Room for Everyone? Identification Processes in Crafting and Math*. Poster presented at the International Conference of the Learning Sciences, London, UK.

Christiansen, I. M. (1997). When negotiation of meaning is also negotiation of task. Educational Studies in Mathematics, 34(1), 1–25. http://doi.org/10.1023/A:1002944413332

Delpit, L. (1988). The silenced dialogue: Power and pedagogy in educating other people's children. *Harvard Educational Review, 58*(3), 280-299. DOI:

10.17763/haer.58.3.c43481778r528qw4
Dowling, P. (1998). The Sociology of Mathematics Education: Mathematical Myths, Pedagogic Texts (Vol. 7). Psychology Press. DOI: 10.4324/9780203486870
Duschl, R. A. (1990) Restructuring science education: The importance of theories and their developments. New York: Teachers College Press.
Duschl, R. (2008). Science Education in Three-Part Harmony: Balancing Conceptual, Epistemic, and Social Learning Goals. *Review of Research in Education, 32*(1), 268–291. DOI: 10.3102/0091732X07309371
Ehrenfeld, N., & Heyd-Metzuyanim, E. (2019). Intellective Identities in the Construction of a Hybrid Discourse: the Case of an Ultra-Orthodox Jewish Mathematics Classroom. *International Journal of Science and Mathematics Education, 17*(4), 739-757. DOI: 10.1007/s10763-018-9885-z
Elmesky, R. (2011). Rap as a roadway: Creating creolized forms of science in an era of cultural globalization. *Cultural Studies of Science Education, 6*(1), 49-76. DOI: 10.1007/s11422-009-9239-9
Engeström, Y. (1987). Learning by expanding: An activity-theoretical approach to developmental research. Helsinki, Finland: Orienta-Konsultit. Retrieved. Retrieved 8/12/2021 from http://lchc.ucsd.edu/MCA/Paper/Engestrom/Learning-by-Expanding.pdf
Ford, M. J. (2015). Educational implications of choosing "practice" to describe science in the next generation science standards. *Science Education 99*(6), 1041–1048. DOI: 10.1002/sce.21188
Gee, J. P. (2015). Discourse, small d, big D. *The international encyclopedia of language and social interaction*, 1-5. DOI: 10.1002/9781118611463.wbielsi016
Gieryn, T. F. (1983). Boundary-Work and the Demarcation of Science from Non-Science: Strains and Interests in Professional Ideologies of Scientists. American Sociological Review, 48(6), 781. DOI: 10.2307/2095325
Gil-Perez, D., & Carrascosa, J. (1990). What to do about science "misconceptions". *Science Education, 74*(5), 531-540. DOI: 10.1002/sce.3730740504
Goffman, E. (1974). Frame analysis: An essay on the organization of experience. Harvard University Press.
Glasson, G. E., Mhango, N., Phiri, A., & Lanier, M. (2010). Sustainability science education in Africa: Negotiating indigenous ways of living with nature in the third space. *International Journal of Science Education, 32*(1), 125-141. DOI: 10.1080/09500690902981269
Glover Blackwell, A. (2017). The Curb-Cut Effect. *Stanford Social Innovation Review*, Winter, 2017, 28-33.
Gresalfi, M., & Chapman, K. (2017). Recrafting manipulatives: toward a critical analysis of gender and mathematical practice. *Mathematics Education and Life at Times of Crisis*, 491.
Gresalfi, M., Chapman, K., Wisittanawat, P. (April 2016), "Re-Crafting Mathematics Education: Designing Tangible Manipulatives Rooted in Traditional Female Crafts" Poster presented at the annual conference of the American Educational Research Association as part of the NSF showcase, Washington, D.C.
Gutiérrez, K. D. (2008). Developing a sociocritical literacy in the third space. *Reading Research*

Quarterly, 43(2), 148-164. DOI: 10.1598/RRQ.43.2.3

Gutiérrez, K. D., Hunter, J. D., & Arzubiaga, A. (2009). Re-mediating the University: Learning through Sociocritical Literacies. *Pedagogies: An International Journal, 4*(1), 1–23. DOI: 10.1080/15544800802557037

Gutiérrez, K. D., & Rogoff, B. (2003). Cultural ways of learning: Individual traits or repertoires of practice. *Educational Researcher, 32*(5), 19-25. DOI: 10.3102/0013189X032005019

Hall, R., & Greeno, J. G. (2008). Conceptual learning. In T. Good (Ed.), *21st century education: A reference handbook* (pp. 212–221). Thousand Oaks, CA: Sage.

Jackson, K. J. (2009). The social construction of youth and mathematics: The case of a fifth-grade classroom. In D. B. Martin (Ed.), *Mathematics teaching, learning, and liberation in the lives of Black children* (pp. 175–199). New York, NY: Routledge.

Jiménez-Aleixandre, M. P., Bugallo Rodríguez, A., & Duschl, R. A. (2000). "Doing the lesson" or "doing science": Argument in high school genetics. *Science Education, 84*(6), 757-792. DOI: 10.1002/1098-237X(200011)84:6<757::AID-SCE5>3.0.CO;2-F

Journal for Research in Mathematics Education (2002). Monograph, Vol. 11. National Council of Teachers of Mathematics. https://www-jstor-org/stable/i230389

Keane, M. (2008). Science education and worldview. *Cultural Studies of Science Education, 3*(3), 587–621. DOI: 10.1007/s11422-007-9086-5

Kennedy, B., & Hefferon, M. (2019). What Americans Know About Science. Pew Research Center. https://www.pewresearch.org/science/2019/03/28/what-americans-know-about-science/

Knorr-Cetina, K. D. (1991). Epistemic cultures: Forms of reason in science. *History of Political Economy, 23*(1), 105-122.

Ladson-Billings, G. (1995). Toward a theory of culturally relevant pedagogy. *American Educational Research Journal, 32*(3), 465-491. DOI: 10.3102/00028312032003465

Lave, J., Murtaugh, M., & de la Rocha, O. R. B, (1984) The dialectic of arithmetic in grocery shopping in Rogoff, B. & Lave, J. (Eds), *Everyday cognition: Its development in social context.* Harvard University Press, Cambridge, MA.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge university press.

Lee, O., & Fradd, S. H. (1998). Science for all, including students from non-English-language backgrounds. *Educational Researcher, 27*(4), 12-21. DOI: 10.3102/0013189X027004012

Lee, C. D. (1995). Signifying as a Scaffold for Literary Interpretation. *Journal of Black Psychology, 21*(4), 357–381. DOI: 10.1177/00957984950214005

Lee, C. D. (1995). A culturally based cognitive apprenticeship: Teaching African American high school students skills in literary interpretation. *Reading Research Quarterly, 30*(4), 608–631. DOI: 10.2307/748192

Lee, C. D. (2001). Is October Brown Chinese? A cultural modeling activity system for underachieving students. *American Educational Research Journal, 38*(1), 97 – 141. DOI: 10.3102/00028312038001097

Ma, J. Y. (2016). Designing disruptions for productive hybridity: The case of walking scale geometry. *Journal of the Learning Sciences, 25*(3), 335-371. DOI:

10.1080/10508406.2016.1180297
Ma, J. Y., & Hall, R. (2018). Learning a part together: Ensemble learning and infrastructure in a competitive high school marching band. *Instructional Science, 46*(4), 507-532. DOI: 10.1007/s11251-018-9455-3
Ma, J. Y., & Munter, C. (2014). The spatial production of learning opportunities in skateboard parks. *Mind, Culture, and Activity, 21*(3), 238-258. DOI: 10.1080/10749039.2014.908219
Martin, D. B. (2013). Race, racial projects, and mathematics education. *Journal for Research in Mathematics Education, 44*(1), 316–333. DOI: 10.5951/jresematheduc.44.1.0316
Maryboy, N. C., Begay, D. H., & Nichol, L. (2020). Paradox and transformation. *International Journal of Applied Science and Sustainable Development (IJASSD), 2*(1), 15-24.
Medin, D. L., & Bang, M. (2014). *Who's asking?: Native science, western science, and science education*. Cambridge, MA: Massachusetts Institute of Technology Press.
Meyer, X., & Crawford, B. A. (2011). Teaching science as a cultural way of knowing: Merging authentic inquiry, nature of science, and multicultural strategies. *Cultural Studies of Science Education, 6*(3), 525-547. DOI: 10.1007/s11422-011-9318-6
Mignolo, W. D. (2009). Epistemic disobedience, independent thought and decolonial freedom. *Theory, Culture & Society, 26*(7-8), 159-181. DOI: 10.1177/0263276409349275
Miller, E., Manz, E., Russ, R., Stroupe, D., & Berland, L. (2018). Addressing the epistemic elephant in the room: Epistemic agency and the next generation science standards. *Journal of Research in Science Teaching, 55*(7), 1053-1075. DOI: 10.1002/tea.21459
Moje, E. B., Collazo, T., Carrillo, R., & Marx, R. W. (2001). "Maestro, what is 'quality'?": Language, literacy, and discourse in project-based science. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 38*(4), 469-498. DOI: 10.1002/tea.1014
Moje, E. B., Ciechanowski, K. M., Kramer, K., Ellis, L., Carrillo, R., & Collazo, T. (2004). Working toward third space in content area literacy: An examination of everyday funds of knowledge and discourse. *Reading Research Quarterly, 39*(1), 38-70. DOI: 10.1598/RRQ.39.1.4
Moschkovich, J. (2006). Using two languages when learning mathematics. *Educational Studies in Mathematics, 64*(2), 121–144. DOI: 10.1007/s10649-005-9005-1
Nasir, N. I. S. (2002). Identity, goals, and learning: Mathematics in cultural practice. *Mathematical Thinking and Learning, 4*(2-3), 213-247. DOI: 10.1207/S15327833MTL04023_6
Nasir, N. I. S., & Hand, V. (2008). From the court to the classroom: Opportunities for engagement, learning, and identity in basketball and classroom mathematics. *The Journal of the Learning Sciences, 17*(2), 143-179. DOI: 10.1080/10508400801986108
Nasir, N., Rosebery, A., Warren, A., & Lee, C. D. (2006). Learning as a cultural process: Achieving equity through diversity. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 489–504). Cambridge: Cambridge University Press.
National Research Council. (2009). Learning science in informal environments: People, places, and pursuits. National Academies Press.
National Research Council. (2012). A framework for K-12 science education: Practices,

crosscutting concepts, and core ideas. National Academies Press.
National Research Council. (2014). STEM integration in K-12 education: Status, prospects, and an agenda for research. National Academies Press.
Nicholas, C. R. (2017). SciJourn is magic: construction of a science journalism community of practice. *Cultural Studies of Science Education, 12*(2), 275-298. DOI: 10.1007/s11422-015-9724-2
Nunes, T., Carraher, T. N., Schliemann, A. D., & Carraher, D. W. (1993). *Street mathematics and school mathematics*. Cambridge University Press.
OECD. (2008). Recognition of non-formal and informal learning. Retrieved from http://www.oecd.org/education/skills-beyond-school/recognitionofnon-formalandinformallearning-home.htm.
O'neil, C. (2016). Weapons of math destruction: How big data increases inequality and threatens democracy. Crown.
Paris, D., & Alim, H. S. (2014). What are we seeking to sustain through culturally sustaining pedagogy? A loving critique forward. *Harvard Educational Review, 84*(1), 85-100. DOI: 10.17763/haer.84.1.982l873k2ht16m77
Philip, T. M., Way, W., Garcia, A. D., Schuler-Brown, S., & Navarro, O. (2013). When educators attempt to make "community" a part of classroom learning: The dangers of (mis) appropriating students' communities into schools. *Teaching and Teacher Education, 34*, 174-183. DOI: 10.1016/j.tate.2013.04.011
Quigley, C. F. (2013). With their help: How community members construct a congruent Third Space in an urban kindergarten classroom. *International Journal of Science Education, 35*(5), 837-863. DOI: 10.1080/09500693.2011.582521
Rosebery, A. S., Ogonowski, M., DiSchino, M., & Warren, B. (2010). "The coat traps all your body heat": Heterogeneity as fundamental to learning. *The Journal of the Learning Sciences, 19*(3), 322-357. DOI: 10.1080/10508406.2010.491752
Rouse, J. (2007). Practice theory. *In Philosophy of anthropology and sociology* (pp. 639-681). North-Holland.
Rouse, J. (2018). Engaging Science: How to understand its practices philosophically. Cornell University Press.
Rudolph, J. L. (2000). Reconsidering the 'nature of science' as a curriculum component. *Journal of Curriculum Studies, 32*(3), 403-419. DOI: 10.1080/002202700182628
Scardamalia, M., & Bereiter, C. (1991). Higher levels of agency for children in knowledge building: A challenge for the design of new knowledge media. *The Journal of the Learning Sciences, 1*(1), 37-68. DOI: 10.1207/s15327809jls0101_3
Schademan, A. R. (2011). What does playing cards have to do with science? A resource-rich view of African American young men. *Cultural Studies of Science Education, 6*(2), 361-380. DOI: 10.1007/s11422-010-9275-5
Sengupta-Irving, T., Tunney, J., & Macias, M. (2020). Stories of Garlic, Butter, and Ceviche: Racial-Ideological Micro-Contestation and Microaggressions in Secondary STEM Professional Development. *Cognition and Instruction*, *39*(1), 1-20. DOI: 10.1080/07370008.2020.1812612

Sfard, A. (2007). When the rules of discourse change, but nobody tells you: Making sense of mathematics learning from a commognitive standpoint. *The Journal of the Learning Sciences, 16*(4), 565-613. DOI: 10.1080/10508400701525253

Taylor, E. V. (2012). Supporting children's mathematical understanding: Professional development focused on out-of-school practices. *Journal of Mathematics Teacher Education, 15*(4), 271–291. DOI: 10.1007/s10857-011-9187-7

Taylor, E. V. (2013). The mathematics of tithing: A study of religious giving and mathematical development. *Mind, Culture, and Activity, 20*(2), 132-149. DOI: 10.1080/10749039.2012.691595

Tytler, R., Symington, D., & Clark, J. C. (2017). Community-school collaborations in science: Towards improved outcomes through better understanding of boundary issues. *International Journal of Science and Mathematics Education, 15*(4), 643-661. DOI: 10.1007/s10763-015-9711-9

Van Oers, B. (2002). Educational forms of initiation in mathematical culture. In *Learning Discourse* (pp. 59-85). Springer, Dordrecht.

Wager, A. A. (2012). Incorporating out-of-school mathematics: From cultural context to embedded practice. *Journal of Mathematics Teacher Education, 15*(1), 9-23. DOI 10.1007/s10857-011-9199-3

Walker, D., & Nocon, H. (2007). Boundary-crossing competence: Theoretical considerations and educational design. *Mind, Culture, and Activity, 14*(3), 178-195. DOI: 10.1080/10749030701316318

Warren, B., Ballenger, C., Ogonowski, M., Rosebery, A. S., & Hudicourt-Barnes, J. (2001). Rethinking diversity in learning science: The logic of everyday sense-making. *Journal of Research in Science Teaching, 38*(5), 529–552. DOI: 10.1002/tea.1017

Warren, B., Vossoughi, S., Rosebery, A. S., Bang, M., & Taylor, E. V. (2020). Multiple Ways of Knowing*: Re-Imagining Disciplinary Learning. In *Handbook of the cultural foundations of learning* (pp. 277-294). Routledge.

Weis, L., & Fine, M. (2012). Critical bifocality and circuits of privilege: Expanding critical ethnographic theory and design. *Harvard Educational Review, 82*(2), 173-201. DOI: 10.17763/haer.82.2.v1jx34n441532242

Webster, J., Wiles, P., Civil, M., & Clark, S. (2005). Finding a Good Fit: Using MCC in a "Third Space". *Journal of American Indian Education, 44*(3), 9-30. Retrieved August 13, 2021, from http://www.jstor.org/stable/24398495

Wisittanawat, P., & Gresalfi, M. S. (2021). The "tricky business" of genre blending: Tensions between frames of school mathematics and video game play. *Journal of the Learning Sciences, 30*(2), 240-278. DOI: 10.1080/10508406.2020.1817747

Paper 3: Finding the wind
"I can't believe they'd leave us in this boat": Fostering mutual support between science and sailing

Introduction

Encouraging students to draw connections across subjects is theorized to help students with everything from building more connected and flexible conceptual knowledge to increasing interest and identity in STEM fields (National Research Council, 2014; Banks et al., 2007; González et al., 2001). This suggests that students would benefit not just from learning different knowledge practices, but from exploring the relationships between disciplinary practices and other meaning-making enterprises (Bang & Medin, 2010; Moje et al., 2001; Gutierrez & Rogoff, 2003; Walker & Nocon, 2007; Chapman, in preparation).

Out-of-school practices are not the purview of schools, and attempts to bring them into classrooms both add to the burden of already overworked teachers and risk stripping the represented knowledge communities of their epistemic agency (Wager, 2012; Miller et al, 2018; Mignolo, 2009). Thus, drawing connections may be better suited to out-of-school institutions that support their own communities of practice (Schauble, 2002).

Informal institutions have historically supported short-term, object-focused engagement, such as is typically found in family visits to museums (e.g. Falk & Dierking, 2018; Povis & Crowley, 2015). This kind of engagement lends itself well to encountering facts, but less so to developing disciplinary practices—a focus of current K–12 reforms (National Research Council, 2012; Bain & Ellenbogen, 2002). What kinds of practices may be most fruitfully developed in facilitated encounters such as summer camps, after school clubs, or even field trips, is a subject of ongoing work (e.g. Paris, 2002).

In this paper I focus on a summer camp that spans two out-of-school places—an informal science institution (ISI) and a small sailing center. I use the context of a summer camp to explore repeated examples of boundary crossing, which has demonstrated cross-community learning potential (Akkerman & Bakker, 2011). Theoretically, I investigate how the concept of boundary objects—most commonly used in studies of workplace learning, human-computer interaction, and teacher preparation—might be used to think about building intersections between school subjects (in this case, science) and out of school practices (here, sailing). Additionally, I focus on specific instances that highlight negotiation between practices (Chapman, in preparation).

Negotiation between epistemic practices may be especially productive for educational trajectories, particularly for students who hold highly circumscribed views of disciplinary practice. As I have argued elsewhere, however, "transforming a person's relationship to [a] discipline is more complex than exposing them to familiar concepts in a new setting" (Chapman, 2021)—it involves holding space for negotiating the boundaries of epistemic practices in interaction. In particular, the goal of epistemic negotiation is the recontextualization (van Oers, 1998) of knowledge from one practice into another (and back) in a way that expands the learner's sense of what might count in and as disciplinary knowing (Chapman, in preparation).

In this paper, I argue that the lens of boundary objects, with a specific eye toward how they come into being for students, is useful for designers in non-formal spaces as a way to open space for epistemic negotiation across in-school and out-of-school practices.

Design Based Research as theoretical inquiry

Studying exactly how students recruit various practices to make sense of school subjects is tricky for several reasons, many of which stem from centering schools. One of the most significant is the problem of scope. School classes generally include dozens of students from various backgrounds with diverse sets of interests. Even if connections are constantly made from out-of-school practices to in-school meaning making, it is difficult to maintain enough familiarity with individual students' histories to reliably trace and follow these connections (Wager, 2018).[33] Teachers have sometimes responded to this pressure by creating cultural "events" in their classrooms, so that all of their students have the same experience to draw on (Wager, 2018). A similar function is often served by field trips, especially those to museums and other cultural institutions (DeWitt & Storksdieck, 2008).

Even so, timescale itself can be a problem. Predicting when a meaning-making practice from out-of-school time (OST) will become relevant for students in school is effectively impossible, and following such seemingly haphazard connections requires serendipity or else infeasibly prolonged engagement (possibly both). Furthermore, when they are brought into school, outside practices are often distorted by school pressures (e.g. Wisittanawat & Gresalfi, 2021). For these reasons, studying the mechanisms by which students bring out-of-school knowledge to bear on school tasks is a good candidate for a Design-Based Research (DBR) program (Cobb et al., 2003).

In DBR, researchers typically collaborate with educators to bring about forms of learning that are prohibitively difficult to study in other settings. In some cases the forms of learning being studied do not yet occur anywhere else. In this case, however, I assume along with others (e.g. Bhabha, 1999; Gutiérrez et al., 1999; Warren et al., 2020) that such learning occurs frequently though often out of sight, and that designing in this setting only "accelerates the frequency of trials, allowing many mistakes to be made and registered" (Latour, 1983). On the strength of these many mistakes, DBR aims to produce "humble theory" (Cobb et al, 2003) about the necessary conditions for learning. As part of contributing to local goals, DBR projects are anchored in persistent problems of practice. Surpassing the sometimes quite bounded goals of action research, however, DBR projects are also based in relevant literature and aim to contribute to our broader theoretical understanding of learning mechanisms.

As with many informal institutions, the sailing center in this study frequently focuses their field trips on school subjects in order to support both institutional health and equity goals (Bevan, 2006). Making connections between local practice and school STEM is thus a persistent problem of practice for them. The camp I look at in this study was already focused on both science and sailing before I arrived. As such, it appears to be an ideal place for encouraging the negotiation of meaning-making practices. Furthermore, the science part of camp is much like a typical school science class. I argue, therefore, that this camp can also provide insight to the broader problem of connecting in-school and out-of-school.

At the theoretical level, the camp is conjectured to be an idealized location for tracing

[33] Furthermore, when familiarity is the standard by which teachers recognize students' contributions, the most common occurrence is that White teachers fail to recognize the contributions of BIPOC students (e.g. Moje et al., 2004), compounding the social marginalization of these students with epistemic marginalization.

students' developing meaning-making practices, since it ameliorates the difficulties with scope and timescale outlined above: 1) all students in the "class" will be participating in the same "outside" experiences, and 2) instead of one-time encounters as is typical of museum visits, they will all cross from the school-like setting to the sailing center repeatedly over the course of the one-week camp. Finally, 3) the curriculum of the camp is not subject to accountability standards and thus has more flexibility in finding a meaningful connection between practices than might otherwise be true in school. Thus, in addition to addressing specific goals of the sailing center, studying this potential connecting space can produce humble theory about how students can be supported to build connections across disparate social practices.

Theoretical framework: Boundary crossing

Beyond the two halves of this summer camp, in this work I am broadly interested in the learning that takes place at the confluence of two knowledge communities (Chapman, in preparation). Both ethnographic and design-based studies on boundary crossing have noted several aspects of this type of learning. For this analysis, I draw on three in particular, which I elaborate on in the rest of this theoretical overview.

First, boundaries conceived as borderlands between two sociocultural spaces (rather than merely borders) imply both continuity and discontinuity (Akkerman & Bakker, 2011). Second, boundary objects—objects that function as bridges between two sociocultural spaces

> "both inhabit several intersecting worlds and satisfy the informational requirements of each of them. . . . [They are] both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. They are weakly structured in common use, and become strongly structured in individual site use" (Star & Griesemer, 1989, p. 393).

Finally, encounters at boundaries can provoke reflection on the practices of one's own community (what Akkerman & Bakker (2011) call *identification*), but they can also provoke reflection on the practices of the encountered community as well, including adapting existing practices or building new ones at the boundaries (what Akkerman & Bakker (2011) call *transformation*). Negotiating boundaries in practice, as I am advocating, requires reflection on both sets of practices.

Extension and limitations for design work

My use of boundary crossing as a lens rests on the assumption that the two halves of camp can be treated as two separate communities, despite the overlapping personnel (that is, despite it being just one camp). Even if this assumption is granted, however, this is not a typical case of boundary crossing. In a typical study, there is already a meaningfully shared task that brings two communities together and the challenge is to confront and then ease the discontinuity between separate practices as the two groups work together. In this way, learning is achieved at the level of the separate activity systems (Engestrom, 2009).

In this camp, by contrast, the two communities are brought together out of expedience—some unnamed historical person decided a joint camp between these two educational institutions would be profitable in some way. As such, this study is something of an inversion of typical studies of boundary crossing—a meeting in search of a shared problem, rather than a shared problem that necessitates a meeting. Furthermore, while theoretically I maintain that this intervention has the potential to speak back to the broader communities—thus producing learning in the activity systems of the ISI and the sailing center—for this analysis I follow learning at the camp and individual levels.

The unit of analysis is not the only discrepancy between my use of boundary objects and that more typical of the fields in which it is commonly used. I am also proposing designing to support students in orienting toward particular forms as boundary objects. In the context of human-computer interaction, Christiansen (2005) has argued that boundary objects cannot be designed because the term describes an analytic category, not a material one: "So the question for designers is how to design forms so that they when used allow to generate boundary objects around them in the translation of meanings from one context to the other" (*ibid* p 1). Her argument does not contradict my usage here, however. While I orient toward particular objects as being more promising than others, I am not focused on the objects independent of context, but rather on the broader learning environment that supports students in developing boundary objects between specific communities.[34]

Finally, while I have argued that boundary objects may be key to developing opportunities for the negotiation of epistemic practices in situ, this study stops short of making claims about that conjecture. My focus here is exclusively on the design elements that appear to be necessary to intentionally cultivate the creation of boundary objects where there is not yet a meaningfully shared problem space between two communities.

Learning at boundaries

The construct of boundaries as it appears in the literature on boundary crossing—sociocultural differences that lead to discontinuities in action (Akkerman & Bakker, 2011)—suggests both a distinction and a relationship. For a boundary to exist as defined, two communities of practice must be mutually engaged, usually with a shared goal or task, yet remain distinct from one another. Thus, thinking about learning at boundaries requires attention to the work in this shared zone.

Akkerman and Bakker (2011) distilled four major learning mechanisms from 181 studies: *identification*, *coordination*, *reflection*, and *transformation*. Importantly, all four mechanisms are seen as different kinds of institutional learning, without a particular hierarchy or progression. The fourth mechanism—transformation—is the one that involves reflecting on the practices of both communities, however, so I focus on only that mechanism.

Transformation involves multiple processes, many of which appear to be strictly necessary for transformation to occur. These processes thus provide a foundation for my design. These are 1) *confrontation*, or the process of making some lack or problem explicit, 2) *recognizing a*

[34] While the context of this summer camp is much more limited than their extensive classroom work, I follow Lehrer & Schauble (2000) in thinking of the learning environment as defined by multiple contextual factors including objects, but also tasks, tools, inscriptions and notations, and modes and means of argumentation (e.g. *ibiid*, p 135).

shared problem space, usually in response to the confrontation, 3) *hybridization* or building new structures at the boundaries, 4) *crystallization*, the reification of those new cultural forms, 5) *maintaining uniqueness of the intersecting practices* rather than a complete change in the original activity systems, and 6) *continuous joint work at the boundary*, characterized by consistent awareness of the boundary crossing (Akkerman & Bakker, 2011). Based on these learning mechanisms, building new practices at the boundaries of separate disciplines is likely to be fruitful only with consistent awareness of the distinct practices, including identifying the unique contributions of the different knowledge practices to the shared problem space.

Brokers and boundary objects

In addition to these broad learning mechanisms, in cooperative work that spans multiple communities, there are often specific elements—people and tools—that do a significant amount of work translating between the two groups. Without this work, there is likely to be continued disconnect, rather than the overcoming of discontinuity that permits ongoing collaboration.

When the tasks are sufficiently broad (involving many people, larger distances, or longer timespans), collaboration is often facilitated by what Star and others have called "boundary objects" (Star & Griesemer, 1989). While the term has occasionally been used to refer to any material object that appears in more than one community, its stronger sense is specifically as a tool that disciplines (Stevens & Hall, 1998) the collection and sharing of information across more than one knowledge community. As Trompette and Vinck summarize,

> "These boundary objects are supposed to maximise both the autonomy of these social worlds and communication between them. [The boundary object] can take very diverse forms: the malleable object which can be shaped by each and every one; the library object from which each individual can take what he or she needs; the object which can be […] simplified (abstraction), allowing us to ignore the properties we do not need; and finally, the interface or exchange standard" (Trompette & Vinck, 2009, p. d)

Boundary objects are thus structures, both material and conceptual, that help to organize information for use in different social practices.

Boundary objects in school

The concept of boundary objects has not been employed extensively in K–12 settings. Even so, there are several studies that argue for the relevance of boundary objects to this specific work. Studies looking at cross-site collaborations with schools have noted the importance of both boundary objects and brokers—generally people who can serve a role similar to a boundary object, negotiating or translating between the two communities. Bakker & Akkerman (2014) advocate for using boundary objects to achieve cross-site coordination and collaboration between school and vocational settings. Similarly, Tytler et al. (2017) noted that more productive collaborations between science institutions and K–12 schools included specific teachers who were more familiar with industry and thus could act as brokers, and continually stressed "the importance of having someone within the school who could act as a broker to expedite communication, to work around structures, or to interpret curriculum in line with the scientists' understandings and intentions" (Tytler et al., 2017, p 656).

Tsurusaki et al. (2013) have analyzed how teachers can position aspects of the curriculum to create connections to students' lives. In their analysis, representations served as boundary objects "in that they created a context where the students could draw on their cultural representations to learn, explain, and push their understandings of science and how it related to their lives" (p 25). This previous work suggests that boundary objects in general, and scientific representations in particular, may be useful in coordinating between work at the ISI and at the sailing center.

Setting

Background

This study focuses on a week-long summer camp where students participated across two parallel learning sites. The first is a living museum dedicated to maritime heritage,[35] in which the students learned to rig and sail small boats in pairs. The second is an informal science institution (ISI), in which students investigated some of the principles of weather and physics that might help them in their sailing.

The camp pre-dated the research study, but was built on the assumption that the two halves of the camp would complement and support each other, particularly in terms of interest and motivation. That is, using sailing as a context for science discussions would provide motivation for pursuing formal physics topics such as the Coanda effect and Bernoulli's principle (two descriptions of phenomena related to airfoils), while learning to sail would provide an opportunity for students to use and reflect on their newfound science knowledge. The camp thus promised a view of the co-development of both a sailor's perspective and a more canonical science description of the way a sailboat works.

While in one sense the camp was a single place, in that it involved all the same students and mostly the same instructors for the entire week of camp, in another sense it was an opportunity to follow youth across multiple places. The camp was neatly divided—science in the morning, sailing in the afternoon—and each half took place at a physically distinct location. Over the lunch hour, students and instructors walked roughly a mile from the ISI classroom to the sailing center. Though most of the same instructors remained with the students for the whole day, the sailing instructors provided support in the morning and took leadership roles in the afternoon, and the ISI facilitators did the reverse. Furthermore, despite a generally relaxed atmosphere, the ISI portion of the camp was similar to many school science classes, following a typical "kit science" model (Lehrer & Schauble, 2010),[36] which included demonstrating interesting

---

[35] Throughout the paper, I will often refer to it as a "sailing center", but I suspect that the organization's orientation toward heritage preservation influences their success with camps such as this one. Making such an argument is beyond the scope of this paper, however.

[36] Kit science is "the use of curriculum programs in which students use prepackaged materials to pursue questions formulated by the program designers, usually by following lockstep instructions that come with the program. […] While programs like these are efficient, they arguably communicate to students that doing science is the pursuit of a given question toward a known answer, by means of a recipe that purports to follow some fictive procedure like 'the scientific method' or 'the investigative cycle,' neither of which bears much relationship to the practice of science" (Schauble, personal communication).

phenomena and telling students some of the names and applications of related ideas.

Participants

The camp was offered jointly between the two institutions, drawing interest from two pools of parents (and kids). Some clearly were drawn more to the sailing and some to the science, though others were less obviously aligned. The camp took place three times over one summer, and data were collected in all three camps.[37] Each camp had roughly 19 students, ages 10 and 11, and boys typically outnumbered girls two to one.

Facilitators were high school and college students between the ages of 16 and 22. Three of the four main facilitators (two from the ISI and two from the sailing center) were consistent across the three weeks, while the support (generally the younger counselors) changed more frequently. Again, boys outnumbered girls roughly two to one. The two facilitators supplied by the ISI had some previous experience in summer camps, though none specifically with science education, whereas all the instructors from the sailing center had taught sailing before, and most of them had at least taken courses if not learned to sail at the same center.

Curriculum

Sailing a boat requires coordinating the boat's heading and the position of the sails with the direction of the wind. In order to sail downwind (in the same general direction the wind is blowing), the sails need to catch the wind like a parachute. Sailing upwind, on the other hand, requires the sails to be curved and oriented to the wind so they can act as an airfoil to pull the boat both sideways and forward.[38] Modern sailboats can point as close as 45 degrees off the wind. Conversely, there is about 90 degrees of rotation through which a sailboat cannot move by wind power. This 90 degree segment (or *slice of the pizza*) is referred to in camp as the *no go zone*. A boat that is pointed into the no go zone is no longer being propelled by the wind.

The curriculum for the joint camp included an abbreviated basic sailing course. This involved *chalk talks*—sessions on the docks where instructors drew basic illustrations on a white board and talked through the maneuvers to be practiced. More prominently, it included enactments; students practiced the basic movements in a boat that was on a dolly (on the dock) before getting in the small sailboats and heading out on the lake. The first day was devoted to a capsize drill; the second day to tacking (turning the bow of the boat through the wind) around two buoys[39]; third to gybing (turning the stern through the wind) around two buoys; and the fourth to traveling dead upwind by choosing a route. The fifth day, students planned and executed a longer course across the lake and back.

The science portion included boat-related investigations—such as making tinfoil boats to explore displacement, and demonstrations of the Coanda Effect and Bernoulli's Principle (blowing through a straw at a candle with a cup between, and blowing between two cups suspended by strings). It also included weather investigations such as making and using

---

[37] Though I mention it here for completeness, due to excessive wildfire smoke, the third week was nothing like the first two and is largely excluded from discussion.

[38] with the leeway compensated for by a keel or daggerboard

[39] the buoys were replaced each day by the instructors depending on wind conditions

anemometers, and watching "clouds" form in plastic bottles. Day two also included a deliberate crossover—during the designated science time (before lunch), students traveled to the sailing center and sailed a collection of model boats on a large pond.

Study preparation, methods, and analysis

Data collection

Throughout the study, I was involved as a participant-observer. Over the course of one summer I was present for multiple days of training in addition to the three weeks of camp.[40] In keeping with principles of naturalistic research (e.g. Guba & Lincoln, 1982), data collection evolved both as new questions developed, and as my relationships with the institutions deepened.[41] In addition to the subject of this analysis, these data constitute a baseline for a longer DBR project as well as the beginning of prolonged engagement with the institutions that also includes both service to the community and participatory action research.

In addition to my own memos, data sources included a room-level camera on all group discussions and person-level cameras on two to six students at a given time. Person-level cameras sometimes followed one student through the entire camp, and sometimes moved around between the students. Though the specific episodes described in detail in this analysis each took place in one of the camps, broader observations are made across all three. As I will detail later, I also conducted several interviews with local experts before camp began.

Preliminary questions

This camp was identified as being a strong candidate for creating coordination between two disconnected knowledge practices. Even so, the first research question was whether a connection was already present. The second, related question was what evidence there may be that this camp provides a reasonable proxy for the kinds of boundary crossing that students do between schools and after-school clubs.

While it would be a mistake to generalize too far, it was certainly the case that students appeared to experience the two halves of the camp as broadly disconnected. Despite the consistent personnel and ostensible focus of the camp, the students did not appear to attempt connections across the science and sailing divide except when explicitly prompted. Additionally, the science section functioned much like a typical American school—with students expected to observe (and occasionally perform) pre-planned demonstrations from which they were encouraged to take canonical formulations of certain scientific principles. While the sailing may have provided motivation to come to camp, and to sit (relatively) still during the science portion, I saw no evidence that students considered the science learning particularly relevant to their activities in the boats.

As such, I concluded that there was not an easy and obvious connection across the two halves

---

[40] Though I mention it here for completeness, due to excessive wildfire smoke, the third week was nothing like the first two, and thus is largely excluded from discussion.

[41] at one point I was asked to take over the science portion of camp for the day when one of the facilitators called in sick

of camp, and that the ISI program constituted a reasonable stand-in for school science class. The remainder of this paper thus focuses on the narrower questions of what practices might legitimately create a connection across this camp, and specifically what boundary objects or brokers might be leveraged to promote such a connection, and how might they be supported to emerge.

Conceptual framework: Coordinating perspectives through boundary objects

Boundary crossing studies belong to "third generation activity theory" (Engestrom, 2021) which addresses problems that require coordination across multiple activity systems as the minimal unit of analysis. In the case of this summer camp, since the people and the subject matter are largely the same, teasing apart the different intersecting activity systems at any given moment is challenging. While the ISI and the sailing center are different institutions, I am concerned here with their associated social practices. Whether a student is participating in one or the other is thus not a question of personnel or even physical location. As Carraher and Schliemann point out, "we cannot assume that children sharing the same physical settings as ourselves will be interpreting problems in the same contexts that we do" (Carraher & Schliemann, 2002).

I suggest thinking of these different social practices as instantiated in *perspectives*, and that the goal of this design is to bring those perspectives into *coordination* through the development and support of boundary objects. A boundary object is not singular, but effectively embodies multiple objects that "may resemble each other, overlap, and even seem indistinguishable to an outsider's eye. Their difference depends on the use and interpretation of the object" (Star, 2010, p 602). Furthermore, a boundary object is not necessarily an *object* in the colloquial sense. As Star specifies, "An object is something people […] act toward and with. Its materiality derives from action not from a sense of prefabricated stuff or 'thing'-ness. So, a theory may be a powerful object." (*ibid*, p 603).

Bringing a boundary object into being is thus a matter of coordinating the perspectives that students take on across their participation in multiple knowledge practices, and within goal-directed action. Whatever we put in front of students only becomes a boundary object when they act toward and with it from multiple perspectives in pursuit of a goal. This framework emphasizes horizontal coordination—in this case, of the sailor's perspective with the scientist's. It is this increasing coordination—not reconciling the two perspectives, but bringing them both to bear on the same question—that constitutes the learning goal. I use the word 'coordination' here deliberately, because I am not thinking of perspectives as things that individuals *have*. Instead, an epistemological perspective is a way of looking at a problem space that is embodied by members of that knowledge community (Stevens & Hall, 1990). Individuals (students, in this case) can participate in a knowledge community by taking on its perspective, even for a short time. The more they participate in that perspective, the more they may be considered as members of that community.

The two perspectives, literally, figuratively, and locally

In broad strokes, based largely on historical forms, what I refer to as the *sailor's perspective* is (metaphorically (Lakoff & Johnson, 2008)) based in *what it is like to be in a sailboat*. Of course, what it is like is different for different people on different days. What the shared perspective includes is that it is grounded in the immediate experience of being at sail, generally close to the water, with only a partial view of either the boat or the surrounding area. Whether just tooling around or trying to get some place specific, a sailor is at the mercy of the wind and water, making frequent adjustments based on changing conditions. Sailors tend to be keenly aware of small variations in weather conditions, noticing changes in color on the surface of the water that indicate a changing wind pattern, or changes in tension on the rudder or the running rigging. Thus, the sailor's perspective is one that privileges adapting to local variation, vague but patterned idiosyncrasies (sometimes as extreme as superstition or animism), and moment-to-moment embodied decision making.

This hyperlocal perspective—privileging the proprioceptive, momentary, and idiosyncratic—I contrast here with the *scientist's perspective*.[42] While the individual's pursuit of knowledge in science is arguably just as local and idiosyncratic, the goals of the community are broader. Instead of understanding how to move *this* boat, science aims to describe how *a* boat—though not any particular boat—moves. Scientists study variation, though frequently with an eye toward controlling or at least accounting for it. Community norms privilege generalizable patterns and warranted claims that can be verified or challenged by other scientists, and thus the practice of science includes things like recording, displaying, sharing, and critiquing data with the goal of developing increasingly warranted claims about generalizable phenomena (c.f. NGSS, 2013).

While I have chosen to use the common word 'perspectives', these community-level epistemological orientations are not the same as literal perspectives in the sense of lines of sight. Confusingly, however, they are often associated with visual frames of reference. Even rhetorically, science is often expressed as possessing a *view from above*, while I have just argued that a sailor's epistemological orientation is based in the physical reality of a fragmentary, limited sightline. Despite these rhetorical and metaphorical anchors, participants in both communities take on different visual perspectives (literally, rhetorically, or metaphorically). Scientists may put themselves mentally into the phenomenon of study in order to expand their conceptual understanding (e.g. Ochs et al., 1996). Sailors may imagine themselves at—or literally move to—different parts of a boat. Thus the literal perspective does not entail the epistemological perspective, though they frequently move together.

Adding to this complexity is the reality that sailors are obviously able to generalize. Despite a focus on the preferences and proclivities of individual boats, the more experience a sailor has, the more likely they are to be able to sail a new, unfamiliar boat. I am not suggesting, therefore, that generalization itself separates the scientist's perspective from the sailor's. As I will describe in the next section, even beginning sailors are introduced to inscriptions that appear designed to highlight general principles of how boats move. Instead, the sailor's perspective recruits

---

[42] Here I mean the "rationalistic" perspective, though I recognize this is not the only epistemological orientation represented in the sciences (Guba & Lincoln, 1982), and that it may in fact center the modern western (often white) gaze to the exclusion of marginalized communities (c.f. Bang & Medin, 2010). As my goal is to make contact with current K–12 schooling practices, this vision of science seems apt, as it accords with standards including the NGSS. Even so, I have chosen to target coordination with parts of current K–12 practice that I hope will remain relevant following continued curricular reform.

generalities in service of moving a particular boat, whereas the scientist's recruits specific boats[43] in service of defining generalities.

Finally, despite what the broader community takes to be constitutive of a given social practice, a local analysis such as this one necessarily focuses on more immediate instantiations. In this camp, the local norms around science do indeed involve filtering out idiosyncrasies to arrive at a general (or canonical) conclusion, though in other ways they do not resemble the norms of expert or even idealized K–12 practice. Similarly, at least partly due to the students' beginner status, the local norms of sailing are even more extreme in their idiosyncrasies than might be true over a longer period. In this analysis, however, I focus on the elements of local practice that align with the broader perspectives just described.

Anchoring specific conjectures for camp

Conceptual residue in expert practice

Equitable negotiation of the boundaries of knowledge practices requires equal attention to both practices (Chapman, in preparation). Because the physics gaze (Dowling, 1998) was well-represented in the existing curriculum, before camp started I made an initial attempt to inject the sailor's perspective onto the science section. Elsewhere I have argued that

> "it is important to ask not whether such a [perspective] might be relevant, or is relevant for an approved expert (such as a researcher, or a […] teacher), but whether it is relevant for participants in interaction." (Chapman, 2021, p 13)

I do not, therefore, mean to simply substitute an expert sailor's perspective for an expert physics teacher's. Rather, I use the sailor's perspective as a rough guide to what *might* become relevant for students as they learn to sail, though final word will be from the students themselves.

I began by investigating whether the presumed overlap of the existing demonstrations—various physics principles about airflow—would be likely to make contact with students' developing sailing practice. To do so, I conducted a series of interviews with experienced sailors[44]—both instructors at the sailing center and other local sailors. For the most part, the sailors I interviewed were capable of offering basic descriptions of how sails work—in particular, the difference between being on a run (heading downwind, in which the sail acts like a parachute) and being close hauled (heading 45 degrees off the wind, which makes use of the airfoil effect)—but did not report or display thinking explicitly about those details while actually operating a sailboat.

Based on this observation, I concluded that students were unlikely to see the physics demonstrations as immediately relevant to learning to sail. Even so, all sailors were familiar with a basic sailing diagram called a wind clock (see figure 1). In contrast with the airfoil

---

[43] and then strategically eliminates their specifics

[44] These included informal discussions and in situ think aloud protocols. In the latter, I used multiple video cameras on board a sailboat, and asked the sailors to explain to me both how the sails work and what they think about as they are adjusting the sails.

explanations in the curriculum, sailors *did* make reference to the points of sail while operating a boat. Based on these interviews, then, the element of the camp curriculum that appeared to leave the most conceptual residue in expert practice was this particular inscription. Thus, I conjectured that the wind clock itself might provide more immediate relevance to beginning sailors.

The wind clock

While it was unclear from interviews whether this ubiquitous diagram served as much more than a mnemonic for experts, it was clearly a community-wide shared representation, and thus developing fluency with the representation itself fit the goal of supporting the sailing goals alongside the science goals. Furthermore, given that it remained salient for experts, it seems reasonable to assume that fluency with this diagram serves the broader goals of learning to sail, though the specific mechanisms of how that might happen are left for another investigation.

From the other direction, since the wind clock can bring different sailors into the "same" view of a boat—as opposed to the reality of being *on* a boat with other people—I conjectured that it might also serve to make the phenomenon of sailing available for collective scrutiny in a way that the act of sailing does not. As such, the diagram itself was a strong candidate for acting as an "immutable mobile" (Latour, 1986), making the practice of sailing available to the scientific practices of public observation, generalization, and critique (NRC, 2014).[45]

While learning to interpret representations is not coextensive with scientific practice, it is a component at least as important as memorizing and applying settled science (e.g. Greeno & Hall, 1997). The wind clock thus represented a piece of representational infrastructure from the sailing community that provided a potential fit with the aforementioned scientist's perspective, and thus the criteria of supporting the development of scientific practice.

Model boats: Embodying the wind clock

In addition to this representational infrastructure, a related piece of physical infrastructure at the sailing center was a set of model boats and a dedicated pond on which to sail them. The sailing center is located on a large city park that includes a circular, manmade pond for sailing model boats. They also maintain a fleet of boats that sail like the full sized boats, except that they are steered exclusively by the position of the sails (see figure 2). Once the sails are set, the boat will adjust its course until it is at the ideal orientation toward the wind for the given sail position. The sailing center typically introduces the model boats by giving students a wind clock for them to follow, though as far as I have observed little other guidance is given, nor do the facilitators monitor for much other than whether the students appear to enjoy themselves.

Two possible boundary objects

Both the wind clock and the model boats were legitimate elements of practice at the sailing center that also facilitated a third-person view of a boat. As such, I conjectured that they were strong candidates to act as boundary objects in that the objects themselves invited both participation in and reflection on the process of sailing in a way that other parts of the beginning

[45] Again, I am not asserting that using a third-person perspective exemplifies scientific practice, only that it may be conducive to promoting it through things like verifying and challenging generalizations.

sailing curriculum did not. Students could draw connections to their first-person experiences in boats, and also step back to consider more general processes and make their ideas about how to move the boats available to public accountability.

I now analyze the tasks set by the facilitators surrounding these two pieces of durable infrastructure, including the extent to which they were able to act as boundary objects, and the elements of the surrounding interactions that were more or less successful in supporting boundary work.

Results

The canonical wind clock

Students in camp had an especially difficult time with the concept of the *no go zone*.[46] Informal conversations with local sailing instructors confirmed that this is a persistent problem of practice. In theory, the wind clock (figure 1) is meant to help students develop an understanding of how the orientation of the boat and the position of the sails interact with the direction of the wind to produce forward motion. In practice, however, it appears to function as a simple illustration of different possible sail positions, not a complex coordination of movement.

Students were introduced to this traditional inscription on day two. Despite the conjecture that the wind clock might function as a boundary object, students routinely treated it as inert. They were quickly able to repeat the basic information it portrayed when called on, and could reliably say that the no go zone is when you are facing into the wind and that you can't travel in that direction. Nevertheless, when in the boats, youth failed to enact this knowledge (a more experienced sailor would adjust their course to get on a better point of sail). Furthermore, they invoked the no go zone verbally as an all-purpose complaint—several students were recorded yelling out to instructors "I'm in the no go zone!" when they appeared frustrated that they weren't going fast enough, regardless of the direction of the wind or the boat. Ironically, then, despite the wind clock being a piece of representational infrastructure from the sailing community, students responded to it from what was previously described as the scientist's perspective—that is, as representative of a generalizable principle, but not necessarily of any particular instance of sailing.

Over the course of camp, the facilitators and I made several attempts to revisit the wind clock in an effort to reassert the importance of coordination—both between the boat and the wind, and between the representation and their embodied experiences in boats. This included turning it into a game: a counselor pointed to indicate wind direction and gave students a short count in which to move their bodies so that they were not in the no go zone; once frozen, any student pointed toward the counselor's "wind" was in the no go zone and had to sit down until the game restarted. Despite several such interventions, the wind clock appeared to remain inert.

---

[46] As a reminder, the no go zone (or "no sail zone") is an orientation toward the wind at which it is impossible for a boat to sail. This is commonly illustrated with a wind clock—a circle divided into sectors over which are listed the points of sail, often with illustrations (see figure 1).

Model boats

Framing the task

On day two of camp, students were introduced to the model boats during the science time (before lunch). After demonstrations of the Coanda Effect and Bernoulli's Principle, students were told they would have a chance to sail model boats on the model boat pond. In the original curriculum, the goal of this activity was to have students articulate how the phenomena they had been observing in demonstrations applied to sailboats. During week two, however, the activity was reframed in an attempt to get students to orient toward the models as boundary objects.

In the spirit of scientific investigations the lead sailing instructor, Matthew[47], introduced the activity as a kind of experiment. At the ISI, students were first asked to think about how a boat might sail upwind, and where the sails would have to be positioned to accomplish this. During this discussion, the students were encouraged to describe their ideas or draw them on the classroom whiteboard for public scrutiny. In doing so, Matthew and the students together drew representations that resembled those of a wind clock (stylized drawings of a boat from above with the position of the sail indicated by a single line).

After each student conjecture, facilitators (chiefly Matthew and myself) suggested that they should "try out" their conjectures on the boats, and often mentioned writing these ideas in their notebooks for later reference. This was an attempt to reframe the models as sources of information for the shared problem of determining proper sail position. It also positioned the sailing activity as making legitimate contributions to the problem, since any theoretically meaningful deduction still needed to work in practice.

At the pond, Matthew again framed the activity with series of questions: "If I want it to sail from over here to over here, how far [out] should my sail be then?" Students were encouraged to share conjectures about how the boats would sail, make careful observations, and adjust (both the boats and their conjectures) as they continued to play with the boats. Thus the task, as Matthew intended it, was to use information from the science demonstrations as well as trial and error with the models themselves to draw general conclusions about the coordination of relative wind direction and ideal sail position.

Different student approaches

The discussion at the ISI included several student ideas that were physically impossible in the boats (positioning the sails "backwards", for example), suggesting that their thinking in this context privileged attempts to generalize from broader phenomena rather than considerations of how they might physically maneuver the boats. As such, they appeared to be thinking about boats as an abstraction, not about any specific boat, consistent with the scientist's perspective described earlier.

Once the students had their hands on the model boats, however, they seemed to ignore the discussion of principles, instead opting for seemingly random trial and error, suggesting a sailor's perspective and a continued disconnect between the two practices. As they began to play with the models, for the most part students did not appear to use the sail adjustments even as they

[47] All names are pseudonyms

tried to direct their boats. Many tried local adjustments like shoving the boats in the direction they wanted them to go (instead of lightly letting them loose as they had been instructed). Predictably, this had the effect of moving the boats in the intended direction for one or two feet, at which point the boats turned until they were maximizing the effects of their sail position. In this context, then, the pull of the physical object obscured the intended science practice.

One student, Wally, was particularly forthcoming as he played with the model boats and offers some illuminating detail.[48] He initially treated the movement of the boat as idiosyncratic, saying things like, "our boat is magic—it just turns to the side all the time". This treatment is consistent with the sailor's perspective described above, privileging idiosyncratic—even animist—observations about "his" boat, and making repeated attempts to influence its behavior with little thought or attention to what or why he might change. He only began to develop a more systematic investigation once an emergent social goal appeared. After about ten minutes of interacting with the models, one of the students declared himself to be a pirate and the rest decided collectively to either chase or run away from his boat. This created a more specific impetus for wanting the boat to go in a particular direction, and Wally began to make clearer, more systematic attempts to influence the behavior of his boat.

While the activity ended shortly thereafter, I argue that it shows the potential of this activity to open up a legitimate shared problem space, as both the principles discussed at the ISI and other science practices like designing an investigation (NGSS, 2013) might have helped him once the goal of controlling the boat was more salient. Importantly, before the goal of controlling the boats became more immediate, Wally did not appear to treat the boat as a potential source of information (instead, it was "magic"), whereas once he had a specific reason to maneuver the boats he appeared to reorient toward the boat as something to be influenced, and potentially as a source of data.

Analysis and revisions

This episode suggests several theoretical points as well as some simple revisions to the design. First, the specific trajectory of Wally's investigations is a reminder that students at this age may still follow the progression of object play more typical of younger children—namely, from "what can this object do?" to "what can I do with it?" (Hutt, 1966).[49] If this parallel to young children's object play holds, it implies an important development for creating boundary objects. Before a physical object can become a boundary object—something that satisfies the informational requirements of more than one community—its "thing"-ness (Star, 2010, p 603) must be more firmly established. Curricular design should thus leave more time for students to move from treating the boats as self-contained objects to treating them as potential sources of data and only later as sources of different kinds of data for different communities.

Second, several aspects of the built environment could be easily updated to better support a view of the model boat activity as generating data. For one, based on the behavior of the boats,

---

[48] I described Wally's case in greater detail in a previous analysis (Chapman et al., 2019). Wally was singled out because, while he played with the models in a manner very similar to the other kids, he narrated as he went more than most.

[49] or what Ito et al. (2009) have called "messing around" to "geeking out"

many of the students (and instructors) conjectured that the wind direction was not consistent across the entire pond. There was no way to observe the wind in the middle of the pond other than by the movement of the boats, however. With no way to verify or critique this secondary conjecture, it was left as a reason nothing much could be done to steer the boats more intentionally. That is, with no way to investigate scientifically, students' attitudes were more consistent with a sailor's willingness to leave things unexamined or chalk them up to superstition.

Third, except for their pocket-sized notebooks, there was no way of keeping track of observations, nor for sharing observations between groups. Since the practice of using notebooks was not well developed, their presence was insufficient to create real boundary work. And again, while the model boats were conjectured to serve a role similar to that of the wind clock, in that they offered an *outside* view of the boats, the more difficult part of establishing them as a boundary object turned out to be treating them as a sources of data—their "thing"-ness as toys (or even pirates) was much more compelling.

With these observations, a redesign is not difficult to imagine. Other objects and interactional routines could be included to support more concerted investigation (and hopefully a science orientation) such as a portable white board or other way to record and share observations. This could encourage the sailor's tendency to feel things out and rely on personal or idiosyncratic deductions to make contact with more systematic methods of observation (as well as their initial conjectures). Otherwise, establishing a routine of making and sharing observations ahead of time might also address this goal (if, say, a science class with such a well-developed practice were to visit on a field trip).

New conjectures based on this analysis

This analysis suggests several things about designing to promote boundary objects. First, before a physical object can act as a boundary object—one that satisfies "the informational requirements" of two intersecting social worlds (Star & Greisemer, 1989, p 393)—students may first need to explore its features and capabilities as a *thing* (in this case, a toy boat). In this phase, students are effectively answering the question "What can this do?" (Hutt, 1966). Once the specific features of an object are more established, it may be easier to support students to orient toward it as an object in the sense of something that participates in goal-directed activity. In this phase, students are answering the question "What can I do with it?" (*Ibid*).

Next, boundary objects are not merely physical objects wrapped in social practice, but sources or organizers of information. Establishing a boundary object thus may require yet two more stages—that is, it may be useful to support students to orient toward a potential boundary object as a source of one kind of information before supporting them to see it in multiple ways. And finally, some objects may be more easily read as sources of information than others.

1. Before a physical object can become an object of goal-directed activity, it must be reasonably well established as a kind of object (e.g. as a thing qua thing).
2. It may be necessary to support students to orient toward the object as a source or organizer of a single kind of information (i.e. as participating in one community) before helping them to see it from more than one perspective.

3. If the thing qua thing is immediately compelling or familiar as an object separate from its information potential, students may need more support in orienting toward it as a source or organizer of information.

An augmented wind clock: Video as boundary object

The final episode I highlight here includes the workings of a potential boundary object that was not part of the original curricular design, but that in many ways acted as a technologically enhanced version of the wind clock.[50] In this analysis, I build on the conjectures from the model boat pond and argue that an augmented video record was able to act as a boundary object for at least one student.

On day four, during the science half of camp, I showed students a video of one of the boats that was taken from the top of the mast and overlaid with GPS-enabled information about their speed and direction (see Figure 3). The video focused on two girls—Amelia and Noel. The top-down video was itself a record of their embodied experiences that also conveniently resembled the wind clock (in the sense that both were top-down views of a single boat, c.f. Figures 1 and 3). As such, I conjectured that it might be able to function more dynamically where the wind clock itself had appeared epistemologically inert.

In an attempt to establish the video as a boundary object, I asked several questions that might provoke coordination between embodied experiences and data available from the video, several of which were ignored. I also repeatedly drew students' attention to aspects of the video that might offer information, including the GPS displays, but also the position of the sail. After viewing a portion of the video, I asked the group if they could determine where the wind was coming from and articulate what they were using as evidence. For the next twenty minutes, all students were engaged in a lively evidence-based debate about the question, *Where is the wind coming from and how do you know?*

Establishing the video as a source of information

At the group level, discussion started with making observations about the video as object—pointing out the data displays, and explaining what they showed. After establishing what the data displays were, several students made observations based on them—pointing out that 3mph was the slowest. Several also made inferences that compared the data displays at different times—"When they were going to the south, they were going slower".

From there students progressed to making inferences about what could be seen in the video that might bear on the question (e.g. claiming that the wind was not coming from the south, because when the boat was facing south it was still moving). This progression parallels my emergent conjecture from the model boat pond that an object must first be firmly established as one kind of object before it can begin to function as more than one (i.e. as both an object qua object and a source of information; or as a boundary object). At the same time, the video was more easily established as a source of information than were the model boats. Students clearly oriented to the video as a source of data, and specifically of public data that related to the driving question.

---

[50] Portions of this analysis have previously appeared in a published conference paper (Chapman, 2020)

Furthermore, in discussing the video, students demonstrated a more sophisticated oordination of their observations and principled understanding than was generally evident on the lake. Though they made occasional references to specific boats (usually when they were themselves caught on camera) the discussion broadly fit with the scientist's perspective—describing the data they saw in generalized terms—and the majority of the students confined their comments to information that was available in the video. The two students in the video, however, had a more expansive experience.

Using sailing as a source of information

In addition to an object (a video with data displays) and potential source of information for a scientific discussion, the video was also a record of a sailing experience. While students who did not appear in the video also did not appear to treat it as such, the video did index the sailing experience for the two focal students.

At one point in the discussion, Amelia (one of the focal students) pointed out that she remembered that it was difficult to get back to the dock on that day, and arguing that that meant the wind was from the north. She thus drew on her memory of sailing, as indexed by the video, and oriented toward it as a source of information. Furthermore, she coordinated her ideas about sailing (it's easy to go downwind and difficult, or impossible, to go upwind) with her understanding of the geography of the lake (where the sailing center was in relation to the part of the lake they were sailing on)—something not explicitly available in the video.

Amelia's assertion was offered as a final solution to the question, however, as though her memory were both simpler to interpret and possibly more reliable than the video record. In this sense, while she was asserting the sailor's perspective where other students were not, she appeared to be privileging it over the scientist's perspective adopted by the rest of the class, rather than coordinating the two.

Confronting the disconnect

Instead of taking Amelia's observation as definitive (privileging one epistemic practice over the other), I posed the question back to the group. I attempted to model negotiating between knowledge cultures by revoicing her contribution, first saying, "Amelia remembers that day" and then asking the group whether that constituted good enough evidence. In addition to highlighting Amelia's unique contribution, I was attempting to encourage the students to acknowledge a disconnect between the two practices. In general, the students either dismissed her claim, or agreed that it was worth taking under advisement but verifying with the record. In some ways this appears to be progress toward coordination, though in others it suggests that for the majority of students the task was seen as being consistent with the original framing of camp—the sailing portion provided a context for exploration, but science was the ultimate arbiter of truth.

Connecting across the boundary

Finally Noel, Amelia's sailing partner, took the connection a step further. She used the video to reanimate her own experiences in the boat, which she was then able to draw on as part of the discussion, as Amelia had done. Noel was more engaged in the discussion than Amelia, however. She repeatedly made references to information not available in the video, such as narrating moments when she remembered trying to help her sailing partner to calm down ("I'm telling Amelia to rely on her fears"). She was also the only student to use the video representation to push back on her memory of the experience: presented with the display indicating their path over time (see figure 3, upper left corner) she exclaimed, "I did not think we did that much twists!"

Noel appeared especially focused on the video as a record of her physical experience. Several times she attempted to direct others' attention to aspects of the video that showed her own physicality, saying things like, "Look at my arm, though, look how uncomfortable that looks," though generally these bids were unsuccessful. Instead of focusing exclusively on the video as an index to her sailing experience, however, she also coordinated across all four versions of the object—video as object (image with GPS augmentation); video as source of science-relevant data (generally from the GPS displays); video as index to sailing experience (most frequently signaled by pronoun use and inclusion of information from memory/not available in the video); and finally, sailing experience as data source.

At one point Noel noted—based on the movement of the dot across the average speed line—"We're gonna get a huge gust of wind in just a sec." With this, she coordinated the data display across time (anticipating a jump on the graph) with the image as indexing herself in a boat (using the pronoun "we" as she did throughout). She also drew an inference from it based on her knowledge of sailing (that a jump in speed might indicate a gust of wind). Later in the discussion, while rewatching the video, she also picked up on Amelia's comments about "that day", repeating the assertion that it was hard to get back to the dock, thus beginning to use both types of data to address the question. The video was thus able to act as a boundary object for Noel, bringing her reanimated sailing experience into contact with the predominantly science-oriented discussion in the ISI classroom.

Discussion: The functional emergence of a boundary object

Based on expert interviews, the element of beginning sailing practice that was conjectured to have the most potential as a boundary object was the wind clock—a ubiquitous inscription used by sailors to describe proper sail position with respect to the boat's orientation toward the wind. In practice, however, the wind clock itself appeared to be relatively inert. Perhaps because the diagram is already such an enduring piece of representational equipment, even for beginning sailors it acts largely as an ossified "final form" (Duschl, 1990) icon. This function may yet be interruptible, but in this camp we were unsuccessful at reanimating it and instead capitalized on two different but related potential boundary objects—model boats, and a masthead video with GPS display.

Both the model boats and the masthead video had some functional resemblance to the wind clock, being opportunities to look at a boat from above. This third person perspective is a significant part of what appeared fruitful about the wind clock—more in keeping with an *outside* or *etic* perspective on the phenomenon rather than the *emic* perspective of a sailor. Each potential boundary object highlighted a different challenge, however.

The episode with the model boats demonstrates that a shared problem space is not enough to encourage boundary crossing. Instead, students need support in attuning to the potential boundary object as an information resource. Furthermore, it appears that paralleling young children's object play, middle-grades students need time to establish the thing-ness of an object *and* the local information potential before being encouraged to make use of it in more expansive ways.

Building on those observations from the model boats, in the video episode the sailing portion of camp was more directly turned into an object for observation by creating and then displaying video of it in the science portion. As with the parallels to object play from the model boats, I argue that establishing the "video as display" was a necessary step in the creation of a boundary object—the "what does it do?" phase (Hutt, 1966). Once the students had oriented themselves collectively toward the display, they began to orient toward it as a potential source of data to address the driving question ("what can I do with it?" (Hutt, 1966)). Based again on the model boat episode as well as the video example, I argue that this reorientation toward the object as data source is also a necessary precursor to establishing a boundary object.

In keeping with the norms of the science part of camp, students treated the particulars of the video as exemplary versions of more general phenomena that were thereby made available for study. Logical reasoning from jointly available data was privileged in conversation over personal experiences. This suggests that the video was able to objectify the experience of sailing and make it available for a more traditionally science-like treatment. Successfully treating sailing as the object of study raises this episode to the level of the original curricular intent, but does not yet constitute a successful boundary negotiation.

At the same time, rather than an abstract representation, the video was also a record (and index) of a personal, embodied experience that belonged to the focal students. While the other students appeared to experience this only in passing (often when they appeared on screen) Noel's case was different.[51] Being the subject of the video appeared to offer a final push, allowing the sailing to be reanimated as a real contributor to her experience of the discussion.

In this discussion of the video, students were participating across multiple planes—video as object; video as source of science data (/GPS as data source); video as index of sailing experience; and sailing experience as data source. Generally, students used the video as object to build to using GPS as data source. This finding is consistent with the argument from the model boat episode that given more time Wally appeared ready to build to more concerted investigation. But Noel was also able to build a bridge between video as index of personal experience to *sailing experience* as data source, thus completing the connection between the two halves of camp. I argue, therefore, that this video was able to act as a boundary object between the sailing and the informal science.

Conclusion

There are many reasons to think that integrating school subjects with out-of-school experiences might be fruitful for children. I have argued previously that the potential for this kind of integration goes beyond motivation and interest (Chapman, 2021). Specifically, bringing different meaning-making practices to bear on a shared problem has the potential to develop robust and personally relevant disciplinary concepts, as well as to provoke reflection on the epistemic practices of different communities (Chapman, in preparation). In order to promote this

[51] Arguably Amelia was as well, though she was generally quiet during the discussion except for the one contribution noted.

kind of boundary work, I am advocating for OST programs to design for experiences where epistemic negotiation can happen in situ (c.f. Chapman, 2021). In this paper I have presented one possible approach to creating space for this kind of negotiation: focusing on boundary objects.

Specifically, this design worked backward from a shared space to a relevant problem. Doing so involved several phases, beginning with disrupting the "zero point" (Mignolo, 2009) of the disciplinary gaze. As with previous ethnographic work, the original camp design focused on content that appeared relevant to sailing *for a physics teacher*. By contrast, developing boundary objects necessarily reorients us analytically to the perspectives of *both* communities, and ultimately to which aspects of those perspectives become meaningful in interaction *for students*.

Beyond this local disruption, preparing for boundary objects to emerge involved identifying potential objects in expert practice (both science and sailing), and co-designing goal-directed tasks with local educators. Both of these preliminary steps took considerable local expertise (in this case, multiple interviews leading into the co-design work), thus supporting my contention that this is work well suited to informal spaces, rather than being thrust on teachers.

Facilitating the emergence itself further involved 1) giving students time to orient themselves toward the thing-ness of the potential boundary object (in activity) before 2) supporting them to orient toward it as a source or organizer of information from first one community and then 3) the other. Depending on the familiarity of the object as a particular type of thing, the second and third may be more or less difficult (i.e. the video with GPS overlay was more easily seen as a source of information than was the model boat activity).

In this camp, a meaningful overlap for students was not specific principles of physics, but rather helping them develop a broad understanding of the *no go zone*, and how to avoid it. This finding highlights another corollary of the disciplinary gaze: wanting to understand a phenomenon in the abstract is not enough to motivate approaching it from both communities. In contrast with "understanding how to move a boat" the learning goal of "avoiding the no go zone" is legitimately useful to sailors.[52] It is also one for which "immutable mobiles" (Latour, 1986) may be invaluable. In terms of connecting to school science, then, the use of representations appears to be a more fruitful overlap than simply applying settled science to boats.

Finally, this study suggests that it is reasonable to design for boundary objects to emerge in a mid-duration nonformal setting. Since camps like this do not generally take place during the school year, that suggests that doing so would also be possible during nonformal programming such as an after school club, and may be possible in a field trip with lead-in and follow-on activities.

Limitations

Throughout this analysis I have relied on a very general notion of what counts as "sailing" or "science". I contend that the two episodes here—the opportunities for student-designed investigations that appear just within reach of the model boat task, as well as the lively argument about wind direction and interpreting GPS information—are more meaningful as contributors to

[52] This parallels a student in another study who revealed to us that our assumed shared problem—"calculate how many stitches you need"—was really more like "figure out how many stitches to use" from a knitting perspective, and might have involved though did not require calculation (Chapman, in preparation).

science than the original curriculum. Even so, I acknowledge that these are broad strokes and there is considerable room for more meaningful contact with science practice. Even so, the existing practices of the two communities dictate much of what can be drawn together. One week is not enough time to develop science practices where none have existed before. I have argued that the ISI is typical of many U.S. K–12 classrooms and thus provides a reasonable proxy for connecting to school. Even so, the design work would likely need to be adjusted to connect to a class that had different norms, and might be more immediately productive if the classroom had stronger norms around scientific practice.

Next steps

One thing these two episodes suggest is that an even more fruitful knowledge practice in this shared space might be examining different representations and their strengths and weaknesses for providing usable information to sailors and scientists. In other words, this camp and spaces like it may be well suited not for memorizing and applying concepts from physics, but for developing metarepresentational competence (diSessa, 2004). Future designs will also encourage the development of new forms of representation, as well as more formal comparisons across different versions.

References

Akkerman, S. F., & Bakker, A. (2011). Boundary crossing and boundary objects. *Review of Educational Research, 81*(2), 132-169. DOI: 10.3102/0034654311404435

Bain, R. & Ellenbogen, K. M. (2002) Placing Objects Within Disciplinary Perspectives. In Paris, S. G. (Ed), *Perspectives on Object-Centered Learning in Museums* (pp. 161-176). Routledge.

Bakker, A., & Akkerman, S. F. (2014). A boundary-crossing approach to support students' integration of statistical and work-related knowledge. Educational Studies in Mathematics, 86(2), 223-237. DOI: 10.1007/s10649-013-9517-z

Banks, J., Au, K., Ball, A. F., Bell, P., Gordon, E., Gutiérrez, K., Heath, S. B., Lee, C. D., Lee, Y., Mahiri, J., Nasir, N. S., Valdes, G., & Zhou, M. (2007). Learning in and out of school in diverse environments: Life-long, life-wide, life-deep. The LIFE Center. http://www.life-slc.org/docs/Banks_etal-LIFE-Diversity-Report.pdf

Bhabha, H. K. (1994). The location of culture. Routledge. DOI: 10.4324/9780203820551

Chapman, K., Jasien, L., Reimer, P., & Vogelstein, L. (2019). Designing for Productive Problem Posing in Informal STEM Spaces. In Lund, K., Niccolai, G. P., Lavoué, E., Hmelo-Silver, C., Gweon, G., & Baker, M. (Eds.), *A Wide Lens: Combining Embodied, Enactive, Extended, and Embedded Learning in Collaborative Settings, 13th International Conference on Computer Supported Collaborative Learning (CSCL) 2019, Volume 2* (pp 791-798). Lyon, France: International Society of the Learning Sciences. https://repository.isls.org//handle/1/1670

Chapman, K. (2020). "I Did Not Think We Did That Much Twists": Using Video to Reanimate Embodied Experiences for Use in Scientific Discussions. In Gresalfi, M. and Horn, I. S. (Eds.), *The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020, Volume 3* (pp 1685-1688). Nashville, Tennessee: International Society of the Learning Sciences. https://repository.isls.org//handle/1/6399

Chapman, K. "Wait—it's a math problem, right?": negotiating school frames in out-of-school places. Educ Stud Math (2021). https://doi-org.proxy.library.vanderbilt.edu/10.1007/s10649-021-10099-0

Chapman, *in preparation*. Designing for Confluence Spaces.

Christiansen, E. (2005). Boundary objects, please rise! On the role of boundary objects in distributed collaboration and how to design for them. In *Workshop of Cognition and Collaboration,* Portland, OR.

Cobb, P., Confrey, J., DiSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational Researcher, 32*(1), 9-13. DOI: 10.3102/0013189X032001009

diSessa, A. A. (2004). Metarepresentation: Native Competence and Targets for Instruction, *Cognition and Instruction, (22)*3, 293-331, DOI: 10.1207/s1532690xci2203_2,

diSessa, A. A., & Cobb, P.. (2004). Ontological Innovation and the Role of Theory in Design Experiments. *Journal of the Learning Sciences, 13*(1), 77–103. https://doi.org/10.1207/s15327809jls1301_4

Dowling, P. (1998). The sociology of mathematics education: Mathematical myths. Routledge.

Duschl, R. A. (1990) Restructuring science education: The importance of theories and their developments. New York: Teachers College Press.

Falk, J. H., & Dierking, L. D. (2018). *Learning from museums*. Rowman & Littlefield.

González, N., Andrade, R., Civil, M., & Moll, L. (2001). Bridging funds of distributed knowledge: Creating zones of practices in mathematics. Journal of Education for Students Placed at Risk, 6(1–2), 115–132. https://doi-org10.1207/

Greeno, J. G., & Hall, R. P. (1997). Practicing representation: Learning with and about representational forms. Phi Delta Kappan, 78, 361-367.

Guba, E. G., & Lincoln, Y. S. (1982). Epistemological and methodological bases of naturalistic inquiry. ECTJ, 30(4), 233-252.

Gutiérrez, K. D., Baquedano-López, P., & Tejeda, C. (1999). Rethinking diversity: Hybridity and hybrid language practices in the third space. Mind, Culture, and Activity, 6(4), 286–303. https://doi-org.proxy.library.vanderbilt.edu/10.1080/10749039909524733

Hestenes, D. (1992). Modeling games in the Newtonian world. *American Journal of Physics, 60*(8), 732-748. DOI: 10.1119/1.17080

Lakoff, G., & Johnson, M. (2008). *Metaphors we live by*. University of Chicago press.

Latour, B. (1986). Visualization and cognition: Thinking with eyes and hands. *Knowledge and Society, 6*(6), 1-40.

Lave, J., Murtaugh, M., & de la Rocha, O. R. B, (1984) The dialectic of arithmetic in grocery shopping in Rogoff, B. & Lave, J. (Eds), *Everyday cognition: Its development in social context.* Harvard University Press, Cambridge, MA.

Lehrer R., & Schauble L. (2010) What Kind of Explanation is a Model?. In: Stein M., Kucan L. (Eds) *Instructional Explanations in the Disciplines*. Springer, Boston, MA.. DOI: 10.1007/978-1-4419-0594-9_2

Lehrer, R., & Schauble, L. (2021). Stepping Carefully: Thinking Through the Potential Pitfalls of Integrated STEM. *Journal for STEM Education Research, 4*(1), 1-26. DOI: 10.1007/s41979-

020-00042-y
National Research Council (2014). STEM integration in K-12 education: Status, prospects, and an agenda for research. National Academies Press.
NGSS Lead States (2013). *Next Generation Science Standards: For States, By States*. The National Academies Press.
Nunes, T., Carraher, T. N., Schliemann, A. D., & Carraher, D. W. (1993). *Street mathematics and school mathematics*. Cambridge University Press.
Philip, T. M., Way, W., Garcia, A. D., Schuler-Brown, S., & Navarro, O. (2013). When educators attempt to make "community" a part of classroom learning: The dangers of (mis) appropriating students' communities into schools. *Teaching and Teacher Education, 34*, 174-183. DOI: 10.1016/j.tate.2013.04.011
Povis, K. T., & Crowley, K. (2015). Family learning in object-based museums: The role of joint attention. *Visitor Studies, 18*(2), 168-182. DOI: 10.1080/10645578.2015.1079095
Saxe, G. B. (1988). Candy selling and math learning. *Educational Researcher, 17*(6), 14-21. DOI: 10.3102/0013189X017006014
Schauble, L. (2002). Cloaking objects in epistemological practices. In Paris, S. G. (Ed), *Perspectives on object-centered learning in museums* (pp 235-241). Routledge
Sfard, A. (2007). When the rules of discourse change, but nobody tells you: Making sense of mathematics learning from a commognitive standpoint. *The Journal of the Learning Sciences, 16*(4), 565-613. DOI: 10.1080/10508400701525253
Star, S. L., & Griesemer, J. R. (1989). Institutional ecology, "translations" and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907–39. *Social Studies of Science, 19*, 387–420. DOI: 10.1177/030631289019003001
Stevens, R., & Hall, R. (1998). Disciplined perception: Learning to see in technoscience. In Brown & Heath (Eds), *Talking mathematics in school: Studies of teaching and learning*, 107-149.
Trompette, P., & Vinck, D. (2009). Revisiting the notion of Boundary Object. *Revue d'anthropologie des connaissances, 3*(1), 3-25. DOI: 10.3917/rac.006.0003
Tsurusaki, B. K., Calabrese Barton, A., Tan, E., Koch, P., & Contento, I. (2013). Using transformative boundary objects to create critical engagement in science: A case study. Science Education, 97(1), 1-31.
Tytler, R., Symington, D., & Clark, J. C. (2017). Community-school collaborations in science: Towards improved outcomes through better understanding of boundary issues. *International Journal of Science and Mathematics Education, 15*(4), 643-661. DOI 10.1007/s10763-015-9711-9
van Oers, B. (1998). The fallacy of decontextualization. *Mind, culture, and Activity, 5*(2), 135-142.
Vygotsky, L. S. (2016). Play and its role in the mental development of the child. *International Research in Early Childhood Education, 7*(2), 3-25.
Wager, A. A. (2012). Incorporating out-of-school mathematics: From cultural context to embedded practice. *Journal of Mathematics Teacher Education, 15*(1), 9-23. DOI 10.1007/s10857-011-9199-3

Walker, D., & Nocon, H. (2007). Boundary-crossing competence: Theoretical considerations and educational design. Mind, Culture, and Activity, 14(3), 178-195.
Walkerdine, V. (1988). The mastery of reason: Cognitive development and the production of rationality. Taylor & Frances/Routledge.
Warren, B., Vossoughi, S., Rosebery, A. S., Bang, M., & Taylor, E. V. (2020). Multiple Ways of Knowing*: Re-Imagining Disciplinary Learning. In *Handbook of the cultural foundations of learning* (pp. 277-294). Routledge.
Wisittanawat, P., & Gresalfi, M. S. (2021). The "tricky business" of genre blending: Tensions between frames of school mathematics and video game play. *Journal of the Learning Sciences, 30*(2), 240-278. DOI: 10.1080/10508406.2020.1817747

Figures

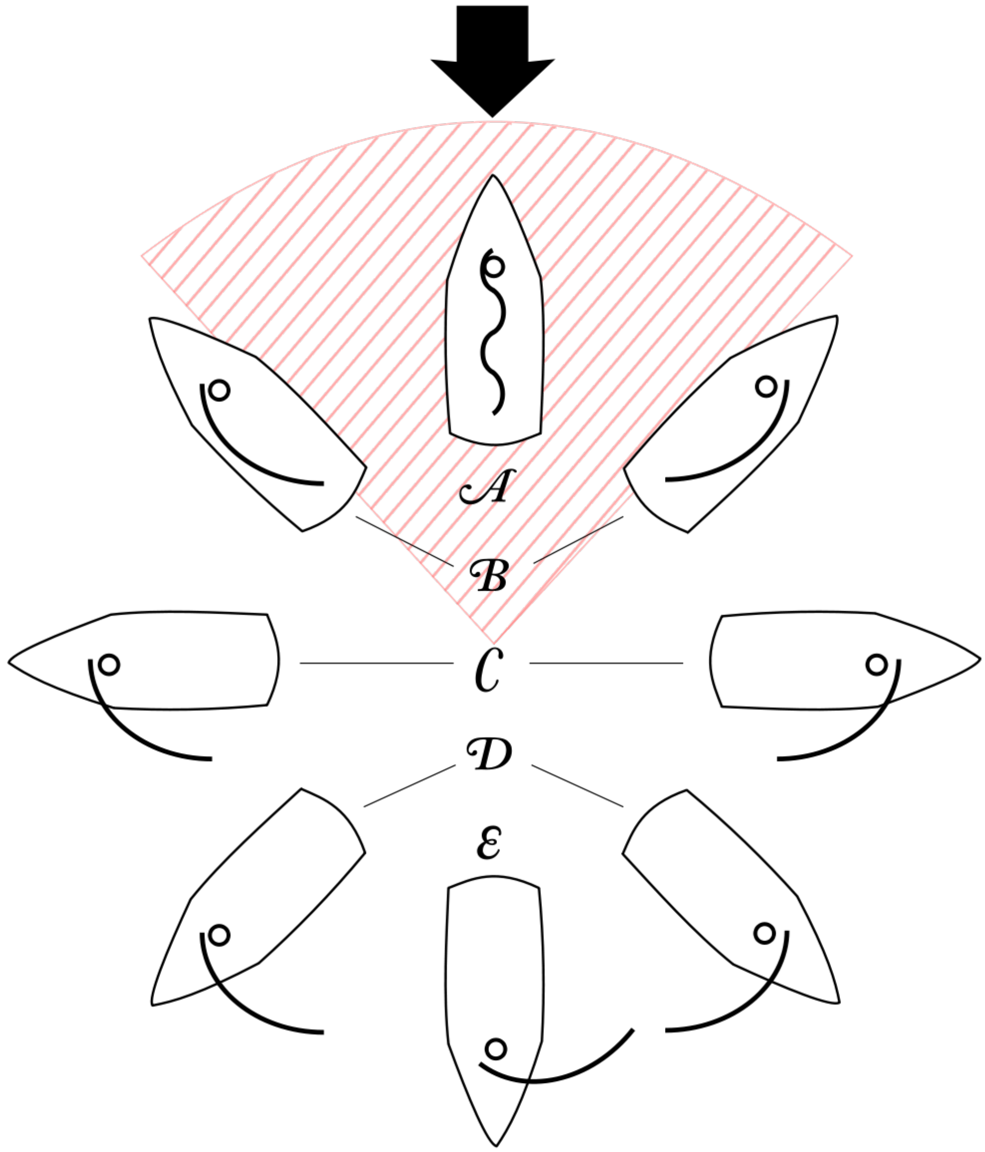

Figure 1: A typical wind clock or "points of sail" diagram.
Image retrieved from https://en.wikipedia.org/wiki/Point_of_sail 8/13/21

Figure 2: The model boats.

Figure 3: Top-down video of student boat with GPS overlays.

References

Akkerman, S. F. (2011). Learning at boundaries. *International Journal of Educational Research, 50*(1), 21-25. DOI: 10.1016/j.ijer.2011.04.005

Behrendt, M., & Franklin, T. (2014). A review of research on school field trips and their value in education. *International Journal of Environmental and Science Education, 9*(3), 235-245.

Carraher, T. N., Carraher, D. W., & Schliemann, A. D. (1985). Mathematics in the streets and in schools. *British Journal of Developmental Psychology, 3*(1), 21–29. DOI: 10.1111/j.2044-835X.1985.tb00951.x

Chapman, *in press*. "Wait, it's a math problem, right?": Negotiating school frames in out of school spaces. *Educational Studies in Mathematics*. DOI : 10.1007/s10649-021-10099-0

Chapman, *in preparation*. Designing for Confluence Spaces.

DeWitt, J., & Storksdieck, M. (2008). A short review of school field trips: Key findings from the past and implications for the future. Visitor studies, 11(2), 181-197.

Falk, J. H. (1983). Field trips: A look at environmental effects on learning. Journal of Biological Education, 17(2), 137–142.

Knutson, K., Crowley, K., Lin-russell, J., & Annsteiner, M. (2011). Approaching Art Education as an Ecology: Exploring the Role of Museums. *Studies in Art Education, 52*(4), 310-322.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.

Lehrer, R., Schauble, L. (2000). Modeling in mathematics and science (pp 101-159). In Glaser (Ed.) *Advances in Instructional Psychology, volume 5*. Lawrence Erlbaum.

Lehrer, R., & Schauble, L. (2006). Scientific Thinking and Science Literacy. In K. A. Renninger, I. E. Sigel, W. Damon, & R. M. Lerner (Eds.), *Handbook of child psychology: Child psychology in practice* (pp. 153–196). John Wiley & Sons Inc.

Ma, J. Y., & Hall, R. (2018). Learning a part together: Ensemble learning and infrastructure in a competitive high school marching band. *Instructional Science, 46*(4), 507-532. DOI: 10.1007/s11251-018-9455-3

Ma, J. Y., & Munter, C. (2014). The spatial production of learning opportunities in skateboard parks. *Mind, Culture, and Activity, 21*(3), 238-258. DOI: 10.1080/10749039.2014.908219

Mignolo, W. D. (2009). Epistemic disobedience, independent thought and decolonial freedom. *Theory, Culture & Society, 26*(7-8), 159-181.

Miller, E., Manz, E., Russ, R., Stroupe, D., & Berland, L. (2018). Addressing the epistemic elephant in the room: Epistemic agency and the next generation science standards. *Journal of Research in Science Teaching, 55*(7), 1053-1075. DOI: 10.1002/tea.21459

Nasir, N. I. S. (2002). Identity, goals, and learning: Mathematics in cultural practice. *Mathematical Thinking and Learning, 4*(2-3), 213-247. DOI: 10.1207/S15327833MTL04023_6

Nasir, N. I. S., & Hand, V. (2008). From the court to the classroom: Opportunities for engagement, learning, and identity in basketball and classroom mathematics. *The Journal of the Learning Sciences, 17*(2), 143-179. DOI: 10.1080/10508400801986108

Orion, N. (1993). A model for the development and implementation of field trips as an integral part of the science curriculum. *School Science and Mathematics, 93*(6), 325-31.

Paris, S.G., & Ash, D. (2000). Reciprocal theory building inside and outside museums. Curator, 43(3), 199-210

Rosebery, A. S., Ogonowski, M., DiSchino, M., & Warren, B. (2010). "The coat traps all your body heat": Heterogeneity as fundamental to learning. *The Journal of the Learning Sciences, 19*(3), 322-357. DOI: 10.1080/10508406.2010.491752

Saxe, G. B. (1988). Candy selling and math learning. *Educational Researcher, 17*(6), 14-21. DOI: 10.3102/0013189X017006014

Scarce, R. (1997). Field trips as short-term experiential education. *Teaching Sociology, 25*(3), 219–226. DOI: 10.2307/1319398

Schauble, L., Gleason, M., Lehrer, R., Bartlett, K., Petrosino, A., Allen, A., Clinton, K., Ho, E., Jones, M., Lee, Y., Phillips, J., Siegler, J., & Street, J. (2002). Supporting Science Learning in Museums. In Leinhardt, G., Crowley, K., & Knutson, K. (Eds) *Learning conversations in museums*.