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# Changing Concepts in Activity: Descriptive and Design Studies of Consequential Learning in Conceptual Practices

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Concepts and conceptual change have been studied extensively as phenomena of individual thinking and action, but changing circumstances of social or cultural groups using concepts are treated as external conditions. We describe research on consequential learning in conceptual practices, where concepts include representational infrastructure that coordinates meaning and activity across time, setting, and social participation. Consequential learning changes one's relation to conceptual practice, creating access to and valued possibilities for participation in practices at a broader scale. We illustrate our approach to conceptual change with case studies and design research in workplaces, schools, and urban communities. We compare our approach to previous efforts to bridge theoretical perspectives published in this journal, focusing in particular on Greeno and van de Sande (2007). Our efforts provide new constructs and studies that may yet create a span between cognitive and sociocultural theories of learning and conceptual change.

We describe an approach to research on concepts and conceptual change that we have developed in response to theories of situated learning (Lave & Wenger, 1991) and, more broadly, sociocultural theories of learning and development (Cole, 1996). Our approach further develops theories of learning that focus on the meaning of concepts as they are used in social and technical practices that change over time. Concepts are not exclusively mental structures held by an individual; they also exist and depend for their meaning on social and practical activities that we call *conceptual practices*. As described by Hall and Horn (2012) in an analysis of conceptual change at work,

We understand *concepts* as recurring patterns of purposeful activity that are *distributed* over people and technologies in work practice. Related to this, learning is an active process

of *distributing* cognition over people and things. Analyzing the work of concept formation thus requires tracing how these distributions are accomplished. . . . Because concepts in our framework are distributed over patterns of activity and technologies, they are integral to the representational infrastructure of work. (p. 241)

With variations in topic and focus, the idea that concepts exist in distributed cultural practices and change through processes that extend beyond individual thinking is now widely accepted among researchers working on learning and conceptual change in a sociocultural tradition. Notable examples include studies of “learning through intent participation” as children engage in everyday joint activity with adult caregivers (Rogoff, Paradise, Arauz, Correa-Chavez, & Angelillo, 2003), studies of historical change in the form and function of concepts of arithmetic and quantity as they are influenced by participation in practices of currency-based mercantile exchange and Western schooling (Saxe, 1991, 2012), and research on language diversity and heterogeneous cultural resources in classroom learning of science concepts

(Rosebery, Ogonowski, DiSchino, & Warren, 2010). All of these studies approach concepts and conceptual change in terms of learners' shifting participation in and contributions to the valued conceptual practices of communities.

### CONCEPTUAL PRACTICES AS CONSTITUTED BY REPRESENTATIONAL INFRASTRUCTURE

Seen from a sociocultural perspective, conceptual change involves transformations both in individuals' understandings and in aspects of shared conceptual practices that make these understandings possible. This approach requires multiple levels of analysis for understanding what concepts are in practical activity, as well as how conceptual practices change over time. These levels of analysis typically focus on the following:

1. Momentary processes of interaction as people jointly negotiate the meaning of problems and possible solutions (e.g., what Hutchins, 1995, called the "conduct of activity" [p. 372] and Saxe, 2012, called "microgenetic constructions" [p. 192]).
2. Interactive assessments of the utility or accuracy of contributions by individuals with different histories of participation in a conceptual practice (e.g., the "development of practitioners" during team work [Hutchins, 1995, p. 372] or processes that create "disciplined perception" among newcomers as they participate in some conceptual practice [Stevens & Hall, 1998]).
3. Longer term processes through which new resources are discovered, adopted, and fitted to conventional use in communities or work groups (e.g., how "representational forms and functions are reproduced and altered in a community over time" [Saxe, 2012, p. 29] or "deliberate inversion [by] placing collective work practice at the center of concerted efforts to change" [Hall & Horn, 2012, p. 246]).

Taking different levels of analysis into consideration involves recognizing that concepts and conceptual change involve multiple scales of time, space (e.g., activity that is organized across multiple settings), and social participation (Jurow & Shea, 2015; Lemke, 2000). For example, microgenesis of solution strategies in joint problem solving (Greeno & van de Sande, 2007) can lead to an acceptable solution for a student group over the course of several minutes, but durably inscribed aspects of that solution, if picked up by others in the classroom or beyond, could lead to changes in how problems are understood or framed at broader social and temporal scales in a conceptual practice (Saxe, de Kirby, Kang, Le, & Schneider, 2015). Our proposal to analyze concepts and conceptual change as changing participation in conceptual practices takes up these questions about the scale of processes that support

conceptual change and levels of analysis that are helpful in understanding them.

Studying conceptual practices in and across different scales of activity is a complex undertaking. Various approaches have been advanced including the study of moment-to-moment discourse as it relates to what Gee (1990) called "Big D" discourse—"ways of being in the world, or forms of life which integrate words, acts, values, beliefs, attitudes, social identities, as well as gestures, glances, body positions and clothes" (p. 142). Holland, Lachiotte, Skinner, and Caine (1998) introduced the concept of "figured worlds" to describe cultural resources that connect meaning and learning across multiple scales. Their approach also highlighted how discourse positions people in communities of practice and the ways in which individual agency can affect broader social and cultural change. Our efforts to understand conceptual practices and how they change also consider cultural resources and agency, though we focus more closely on the materiality of shared practices (e.g., how technologies coordinate activity across people and settings); the history of how participation in practices is structured over time; and how people use, push back on, and modify conceptual practices as they engage in work together. This approach can also provide practical guidance for conducting design research that could bring about valued changes in conceptual practices.

In this article, we argue for a careful study of the organization and development of *representational infrastructures*—technologies, ways of talking, and materials that support how people engage with conceptual practices in their activity. For example, in a case study of research entomologists (Hall, Stevens, & Torralba, 2002; Torralba, 2006), representational infrastructure included agreements about how coding forms were used to coordinate the collection of material in one setting—bugs and wood in the field—with measurements and symbolic descriptions of those materials carried out in other settings—laboratory and office spaces within a research organization. Understanding how representational infrastructures support conceptual practices and how they change, either implicitly or by deliberate effort over the "social history" (Scribner, 1985) of shared practice, is important both from the perspective of analysts (ourselves as authors or designers) and for participants in these practices:

If representational infrastructure is integral to the manifestation and development of concepts, adequate representations of practice become critical ... materials for considering alternative ways of working in the future. Adequate representations capture and support a "structure of intentionality" for valued activities of a local work group (Goodwin, 1994, p. 609), but they also support coordination across sites and other groups (Star & Griesemer, 1989). (Hall & Horn, 2012, p. 242)

## WARMING UP CONTEXTS AND BRIDGING INFORMATION STRUCTURES IN RESEARCH ON CONCEPTUAL CHANGE

There has been a steady “warming trend” (Sinatra, 2005) in research on conceptual change, a movement away from purely rational considerations of cognitive and information structures, toward considering the broader contexts in which students learn about concepts and what might influence their interest or engagement in learning. These include “affective, situational, and motivational factors” (p. 107) that may influence a learner’s level of engagement with what is taught, their beliefs about what counts as knowledge, the kinds of discussions they have with peers and teachers about concepts, and even the degree to which their teachers feel comfortable with enacting new teaching practices associated with educational reform (Windschitl & Thompson, 2006). Looking back over a decade or more of research addressing the limits of studies of “cold conceptual change” (Pintrich, Marx, & Boyle, 1993), Sinatra (2005) wrote,

No longer do we think of research on learning as occurring in the cold setting of the laboratory, examining the cold constructs of cognitive information processing. The integration of motivational constructs into conceptual change research is an illustration of the new view of learning [Paul Pintrich] helped formulate, one that is more contextual, cultural, social, and affective, as well as cognitive. (p. 113)

The “thaw” in studies of concepts and conceptual change has focused new attention on important aspects of learners’ experiences and engagement. Research from this “warmer” perspective still holds fast to the individual as a unit of analysis for explaining what concepts are (mental contents) and how concepts change (by detecting and replacing underperforming mental contents). Although researchers identify “situational factors” as having a role in conceptual change, how the situation is organized is not part of what makes up the concept, and the operative aspect of “changing” concepts remains within the mind of the individual. In contrast, our approach treats both the meaning of concepts (content as enacted, in relations with others) and efforts to change this meaning in and as aspects of conceptual practice.

We are not alone in this effort. As the “thaw” has progressed in research on conceptual change, there has been an attempt to “bridge” between cognitive and sociocultural perspectives on concepts and conceptual change, culminating in a special issue in *Educational Psychologist* (Mason, 2007) with articles by researchers taking a variety of positions on these broad theoretical traditions. Some question whether such an effort is worthwhile (e.g., Alexander, 2007, argued the effort is “unnecessary,” as each tradition must acknowledge both individual cognition and social influence). In writing this article, we take a more hopeful

stance. In particular, we see valuable connections to Greeno and van de Sande (2007; later updated in van de Sande & Greeno, 2012) on “perspectival understanding” and various types of “framing” as spanning structures that can bridge between cognitive perspectives on mental content and situative learning perspectives on processes that establish shared understandings in the “common ground” (Clark, 1996) of a working group of people.

Greeno and van de Sande (2007) argued that all learning happens in activity systems (Engeström, 1987) or communities of practice (Lave & Wenger, 1991) where knowledge is distributed (Hutchins, 1995) over people and tools that support their activity. People learn through changing forms of participation in the discourse practices of a community. These changes in participation may involve “attunements” to the “constraints and affordances” of discourse in the community, and attunements arise from negotiated alignments between “perspectival understandings” enacted by participants in interaction. In an elementary mathematics classroom, for example, students might learn a concept for what counts as *justification* by participating in classroom discussions (Cobb, Stephan, McClain, & Gravemeijer, 2001). As students work on problems and engage in mathematical activity, they learn through talk and interactions with each other and with their teacher whether computational procedures provide sufficient justification for results and explanations. This is what Greeno and van de Sande would describe as attuning participation to the constraints and affordances of the discourse used in the mathematics classroom. Greeno and van de Sande offered attunements and perspectival understandings as a bridge that connects with cognitive schema theory. These constructs describe how people structure information as they participate in practices. Attunements and perspectival understandings reflect an individual’s history of participation in discourse practices. Looking the other direction along the span, Greeno and van de Sande (2007) argued that processes making up a person’s history are produced at the level of social interaction in the discourse of a community.

Conceptual change, in Greeno and van de Sande (2007) analysis, happens during interactive exchanges in which people make proposals for how to solve problems. Positioned by discourse either as “sources” or “listeners” in these conversations, interlocutors can “problematize” others’ proposals, and in turn, other interlocutors can attempt to “resolve” these disagreements. When resolution involves adopting a perspective offered by a speaker, the authors describe this as a form of schema application. When interlocutors must assemble a new perspective, they engage in a form of constraint satisfaction (e.g., a search process that converts an ill-structured problem into a well-structured problem) that can create a new schema. Joint problem-solving conversations are the engine of conceptual change in the spanning structure offered by Greeno and van de Sande.

Attunements and perspectives change in conversation (i.e., individuals learn), the scope and coherence of what people hold in common ground changes (i.e., shared understandings are established), but the discourse practice in which these joint conversations are conducted largely remains stable. In Greeno and van de Sande's analysis of changing participation in the discourse practices of a community, the time scale of what is learned is relatively short (the duration of a conversation) and there is relatively little analysis of the "social history" (Scribner, 1985) of the classroom practice or the identities of students as participants in that practice. For example, how interlocutors are positioned in conversation (i.e., whether a "source" or a "listener," or whether with "conceptual agency" to define what problem should be solved and how; see also Boaler & Greeno, 2000) is assumed as part of the social context of the classroom but not theorized or studied directly. Still, unlike "thawing" approaches that separate social practices of teaching from the content of conceptual practices, we believe that Greeno and van de Sande mean to include classroom practices in the content of concepts.

The approach we describe is different from Greeno and van de Sande's (2007) proposal but builds on the spanning structure they provide. Our approach extends their emphasis on understanding participants' histories of engagement with concepts and activity systems. **We do this by using ethnographic and participatory design methods to explore how and why learning is relevant from the social actors' point of view when participating in conceptual practices.** Rather than bracketing analysis of conceptual change at the level of problem-solving conversations, typically contained within a single classroom, **we follow learners as they participate in conceptual practices that span multiple sites, and we study systems of representation that coordinate or bind together materials found in and across settings of conceptual practice.** That is, our approach foregrounds the value of **analyzing and following changes in representational infrastructures that support the work and development of conceptual practices.** These choices in focus facilitate an analysis of what becomes, or might become, consequential learning that organizes for people's participation in conceptual practices at different scales.

#### THE CONSEQUENTIALITY OF CONCEPTS AND CONCEPTUAL CHANGE: HOW, WHEN, WHERE, AND FOR WHOM?

The "warming trend" described by Sinatra (2005) invites a more expansive view of conceptual change from the perspective of learners and their social history. Research on situated learning draws critical attention to the idea that what counts as learning depends on **what is valued by participants in a community of practice.** It helps us ask questions about **power relations in communities,** particularly in regards to

who benefits and who suffers from how concepts and learning are defined. To understand concepts and conceptual change from a situated perspective then, we need to appreciate what can become consequential for learners, their practices, and their positions in relation to the communities in which they participate. Consequentiality is not created by individuals alone or given by the practices of a community; it arises as people participate in and change conceptual practices. **When we investigate the consequentiality of learning, we attend to the ways in which it is (a) historically contingent; (b) related to one's changing form of participation in a community of practice that is also changing; and (c) developed and acknowledged through interactions with people and tools, over time, and across settings.** We discuss each of these dimensions of consequential learning in changing conceptual practices as a way to foreground questions about how, when, where, and for whom learning in conceptual practices can become of consequence.

First, what we count as valued learning is historically contingent. Becker (1998), writing about how personal traits become valued, explained, "We all have all sorts of traits, only a few of these are socially marked as important because of the way they are embedded in a system of relations" (p. 135). He went on to admit that he is terrible at drawing. No matter, we might say, drawing isn't that important. And that is Becker's point: In the middle to late 19th century, education policymakers decided that the United States of America was falling behind Germany in industrialization because workers could not make or read mechanical drawings. Schools therefore needed to be reorganized to teach U.S. schoolchildren how to draw well. This, as we know, was not a lasting educational reform, but Becker's example reminds us that what counts as learning is historically contingent. What is valued as learning in one setting because it is genuinely useful to people and is understood as a competent way of knowing might be valued very differently in another setting. Wait long enough and get other kinds of people interested in the problem (Becker, 1995; Hall, 2011) and we may collectively value and evaluate entirely different things as learning. **We can and should pay attention to how the social world is built and maintained by people, tools, and institutions to make certain conceptual practices more or less necessary, valuable, and desired.**

Second, learning can also become consequential when it involves a developmental change in the relation between a person and one or more cultural activities (Beach, 1999; Rogoff, 1994), including when people gain access to activities and are allowed to make valued contributions during participation in those activities. As an example, Beach (1999) studied Nepalese children and adults who moved between institutionalized schooling and work in commercial shops. For each, learning about and using arithmetic involved a different kind of transition, with different developmental pathways for future activity (e.g., shopkeepers valued learning arithmetic to help in their work, whereas

children saw shopkeeping as a separate activity from their further schooling). **Analysis of developmental transitions is possible only when we understand the meaning of shifts in social actors' practices in regards to their own identity trajectories and the development of conceptual practices in which they participate.** As we show later in the article, ethnographic methods including interviewing, participant observation, and historical analysis provide valuable tools for doing this work.

Third, the consequentiality of learning arises in relation to the temporal, spatial, and social scales of a person's activity such that the meaning of learning influences her "scope of possibilities" (Dreier, 2008, p. 25). For example, Jurow, Tracy, Hotchkiss, and Kirshner (2012) described undergraduate participation in a teacher preparation course. The undergraduates studied sociocultural theories of learning that encouraged them to create opportunities for their students to draw on their diverse cultural and linguistic backgrounds to deepen learning. In the university classroom and when the undergraduates attended practicum sites that were designed from principles grounded in these sociocultural theories, undergraduates' learning trajectories were productive. Based on their assignments and teaching activities, the undergraduates appeared to have learned the theories. However, when undergraduates were placed in practicum sites without a design history based in sociocultural theories of learning, their understanding of these theories became inconsequential. The loss of alignment between what counted as "learning" and the social, spatial, and temporal organization of practicum settings for exhibiting this learning was important for an adequate understanding of consequential learning by the undergraduates. That consequential learning depends upon the social history of conceptual practices in which persons engage with each other resonates strongly with Lave's (1988) argument that learning is stretched across activities, people, and settings. It also echoes Latour's (1983) argument that powerful ideas are like trains—they run only where material practices have already created rails along which they can travel. Conceptual practices and their representational infrastructures similarly lay down the tracks on which productive ideas can travel. To understand consequential learning in conceptual practices, we need to examine learning in the material arrangements of practices where this consequentiality is realized.

These three aspects of consequential learning—historical contingency in what is valued, making developmental transitions across cultural settings, and changing scales of participation (in time, space, and social relations)—are important for our understanding of a situated perspective on concepts and conceptual change. We argue that studies of consequential learning should attend closely to the organization and meaning of conceptual practices in which people are participating, how they engage with resources available in these practices, and how these practices and the identities associated with them are made to become consequential in the world.

## CONSEQUENTIAL LEARNING IN CONCEPTUAL PRACTICES

Studying how people learn is a challenge when we step away from the age- and subject matter-segregated container of public schooling (Leander, Phillips, & Taylor, 2010). We have treated this challenge as an ethnographic project, studying what people do and learn at work as a way to see what concepts are and how they are learned in changing social and technical practices. Based on our and others' ethnographic and design studies, we argue that consequential learning in conceptual practices is dependent on representational infrastructure, shaped by access to participation in practices that are also changing, and developed and acknowledged through time and often across multiple settings of work. We are not arguing that people do not learn at school (or in other sites that deploy formal instruction), but we also believe our field stands to learn a great deal about conceptual practices from research outside laboratory settings or the familiar contours of schooling. Ethnographic studies of how people work, learn, and change conceptual practices in a broad variety of settings is one way to do this. Because as Hutchins (2012) noted, "concepts in the wild are manifest in practices" (p. 315), comparative case studies of these conceptual practices are needed.

### Methods for Studying Consequential Learning in Conceptual Practices

If we look outside laboratories or classrooms for what study participants count as valued learning, how can we draw boundaries in a way that helps us to discover new things about learning and changing conceptual practices? How could we bracket what Greeno and Middle School Mathematics through Applications Project (MMAP) Group (1998) called "intact activity systems" (p. 4) in a way that would allow us to see conceptual practices in human activity and the infrastructural resources they offer in support of consequential learning?

One strategy for finding these boundaries is to "follow the representations" (E. Hutchins, personal communication, June 15, 1994), using ethnographic methods to study the social history, organization, and development of representational infrastructures that make up and support the productive activities and learning of work groups. Hutchins's (1995) comparative analysis of representational systems for finding one's way at sea, detailing conceptual practices of Western and Polynesian sailing traditions, is a good example of this strategy in use. Focused studies of representational infrastructure help us to see how learning and conceptual change are organized through time, across places, and through different contributions people make to shared work.

For research we report in this article, we conducted extended ethnographic case studies of activity, learning, and change in conceptual practices. Our research methods

included acting as participant observers where possible (e.g., lugging gear between labs and field research sites, reading and commenting on study participants' manuscripts), interviewing participants about what they have learned (or hope to learn) in their work, making video and audio recordings of their work in progress (often on the move across settings; analyzed using methods of interaction analysis; Derry et al., 2010; Jordan & Henderson, 1995), and gathering work products along with historical documents and artifacts used to make these products. These kinds of studies have been called "cognitive ethnographies" because they focus on knowing in the social history and material practices of its production (Hollan, Hutchins, & Kirsch, 2000). In our research, case studies equally involve forms of inductive analysis and coding that are typical in the development of grounded theory (Charmaz, 2006; Strauss, 1988). Our studies typically extend from months to several years, analysis and continuing data gathering are driven by "theoretical sampling" to test provisional explanations and findings (Charmaz, 2006), and (when practical) study participants are invited to review our preliminary findings and contribute their own perspectives (i.e., both as a form of "triangulation" and in hope of accurately understanding the "social actor's point of view"; Becker, 1996). In this primarily descriptive research, cases are not treated as samples for making inferences about populations, but instead they are used to develop grounded theoretical categories and explore "rival explanations" (Yin, 2000) concerning concepts in activity, learning, and changing conceptual practices.<sup>1</sup>

In the next section, we review two illustrative case studies of scientific work groups, focusing at first on stable forms of representational infrastructure that supported their work and provided an informal curriculum for newcomers to the work team. For a variety of reasons, these stable infrastructures were disrupted or suspended so that the leading activity shifted from ongoing production (doing the job) to finding new ways of working together in the future. These shifts in the purpose of activity as experienced by study participants—from routine production to learning—made the supporting role of representational infrastructure visible and opened spaces for interaction in which a variety of learning opportunities were found. What we have discovered in these case studies, in turn, has helped us think about how to design environments in which similar learning opportunities are likely.

### Learning and Disruptions to Representational Infrastructure

A conceptual practice that has been important in our thinking about learning and representational infrastructure was

analyzed in a multiyear case study of a group of field entomologists (we called them the BugHouse), who studied the chemical taxonomy and foraging behavior of termites (Hall, Stevens, & Torralba, 2002; Torralba, 2006). Their labs were located in a federal research station serving a multistate region of the United States, and they agreed to let us study "naturally occurring chunks" of their work as a research team. Finding and following these "chunks" led us across multiple laboratories, forest and residential field study sites they had constructed, and regular meetings in what we came to call the "center"—air-conditioned office space (unlike gritty lab and field sites) in which they did their analysis, writing, and research planning. Their project was to understand types (species) and behavior (foraging, feeding) of subterranean termites and the conceptual practice they developed created new knowledge about both. Our work was to understand how they did this, but also how their conceptual practices changed to better understand foraging and the phylogenetic classification of insect species living in (and changing) the forest in organized colonies. We followed the entomologists closely as they followed termites over 2 years. We collected video recordings of their work, conducting interviews with them and participating as observers to understand their activities in field and laboratory settings. In addition to 2 years of intensive ethnographic data collection, we remained in contact and followed their publications for a decade. In this case, we had an extended opportunity to study the temporal, spatial, and social scale of their work.

The representational infrastructure supporting work at the BugHouse was built around a "grid" of sampling stations placed in a 2D coordinate system over both a forest arboretum (called the "Wildland") and multiple residential sites. Each station could be filled with wooden baits, and later these baits (with attached termites, busily consuming wood) could be removed, cleaned of termites (saved in the lab) and dirt, and weighed to measure wood lost to termite feeding. The grid allowed the team to model seasonal variation in termite activity, and it provided a schedule of fieldwork for entomologists, who carried wood and termites between the field and their labs on a monthly basis. Following Latour (1987; Latour & Woolgar, 1979), the grid created an "inscription device" that bound termite and entomologist time together tightly. This representational infrastructure allowed the BugHouse team to extend their laboratory into the field (i.e., using the grid to chart foraging "in the wild" at monthly intervals), but at the same time, they created a "remnant model" (Griesemer, 1990) of captured termite colonies in their laboratory and used this model in controlled studies of termite behavior, type, and colony organization.

The grid provided not only a way to model termite activity but also a multisited lattice of work through which newcomers to field entomology joined the group and learned their trade. Just as with the young apprentices to tailoring

<sup>1</sup>This description of our research methods is consistent with what is taught in most doctoral-level, qualitative research methods courses in educational research, including courses we teach.

studied by Lave (2011; Lave & Wenger, 1991) or the quartermasters studied by Hutchins (1995), junior entomologists learned through legitimate, peripheral participation in entomological practice. What they called the “dirty work” of the field (collecting, cleaning, and weighing baits) was exchanged for access to analysis, conversation, and writing in the BugHouse “center.” These transitions within the conceptual practice were highly consequential for the junior entomologists. During our study, new generations of fieldworkers entered through field work on the “grid,” took on greater levels of responsibility for managing insects and data, and began to refine the protocol to make the grid run more efficiently.

This latter activity, taking on conceptual agency for the protocol and teaching newcomers about it, created a form of *stewardship* that juniors clearly saw as an important resource for developing an identity and more expansive agency as a research entomologist. These changes in their relation of participation to the ongoing conceptual practices of studying insect foraging were consequential not only for BugHouse team discoveries about termite foraging but also for members of the team. For example, becoming a steward of the grid allowed up-and-coming entomologists to propose agenda items for conversation in the center and to position themselves as authors in analysis and writing that was planned in those meetings. Although it is common to think of learning as an outcome of teaching, in these emerging forms of stewardship, teaching was often an outcome of consequential learning.

Near the end of our ethnographic fieldwork, BugHouse researchers needed to repurpose the grid protocol when funding for their foraging study ended. As senior investigators spoke of reconfiguring the grid to pose new questions about insect activity (e.g., shifting from a seasonal to a daily time scale for termite foraging and feeding), the juniors’ considerable skill in running a stable grid for the foraging study that was ending actually interfered with their capacity to understand or pose new research questions. That is, their understanding was tightly tied to routine production and interfered with efforts to change representational infrastructure to ask new questions (see Schwartz, Chase, & Bransford, 2012, for similar findings in laboratory studies with university students). In more theoretical language, a stable representational infrastructure supporting research production (the foraging study grid protocol) was suspended, and team activity shifted from research production to research design—repurposing the grid and associated work practices to ask new questions about termites at different temporal and spatial scales. Although the end of project funding was a major event for the BugHouse, there were other occasions in which routine production was suspended to search for new ways of working, and change in the infrastructure of their conceptual practice was ongoing. Our focus now turns to these kinds of disruptions, disturbances, or displacements that lead to change in social and technical aspects of conceptual practice.

We follow Engeström and Sannino (2011) in treating disruptions to work supported by representational infrastructure as a driving force for change in conceptual practices. These disruptions can arise from many sources. Some are internal to a work group (e.g., with loss of personnel, a need to change how work is divided), others are external to the group (e.g., funding for a project ends, or adoption of new classification schemes or technologies are mandated), and still others are driven by circulation and exchange of methods and representational tools across work groups (common in our studies of scientific work). Whatever the precipitating event, continuing processes of production (i.e., using a stable configuration of resources to continue working) can shift following the interruption into a new leading activity—learning to work differently in the future. These shifts are usually easy to detect—routine work is suspended, and meetings are called with the explicit purpose of developing new work capacity, often with invited advice from specialists outside the team. Responding to disruptions in this way creates a reflective space for learning and change in ongoing conceptual practices. Disruptions and subsequent changes in conceptual practice could be described in Greeno and van de Sande (2007) terms as “problematizing” and “resolving” differences in conversation. This is consistent with how we view conversations during periods of disruptions, but the processes we studied were broader in scale and (in some cases) created dramatic changes in representational infrastructure and had lasting consequences for learners.

### Learning by Adapting, Distributing, and Generalizing Conceptual Practices

In organizational settings like the federal research station where BugHouse researchers worked, groups often invited consultants to help them create new infrastructural technologies and related conceptual practices. In these consultations, new concepts were borrowed and adapted from the practices of other communities or work groups—for example, in the form of techniques or methods described in published documents, finished products that could be “reverse engineered” to recover implicit practical skills, and even incorporating people outside the work group who were familiar with new technologies and able to make skilled contributions as new ways of working were being assembled. In this way borrowed methods were fitted to new work conditions, and representational infrastructure was rigged to create new productive capacity. At the scale of social history in distributed work groups, concepts in practice migrated and were adapted through processes that looked very different from “learning transfer” at the level of individual cognition (Dunbar, 1995; Hall & Greeno, 2008; Nersessian, 2012). To study how conceptual practices migrate across scientific work groups, we conducted a series of case studies of statisticians consulting with health science research clients.

In one case we followed a group of epidemiologists who were tracking the seasonal incidence of influenza to create new screening systems for detecting the onset of epidemics (Hall, Wieckert, & Wright, 2010; Wright, 2012). The conceptual practice they had developed solved the problem of counting how many individuals in a population had a particular disease (in this case, influenza) without being able to examine all members of that population. Being able to detect a surge in the incidence of influenza in local hospitals, and then also being able to track these changes through time across a national network of care centers, would give them new and more powerful ways of monitoring the seasonal emergence of pandemic infectious diseases. The epidemiologists had already created what they called a “Cadillac” screen, using expensive DNA testing to actively find and diagnose children with symptoms of influenza (i.e., skilled nursing staff would roam the hospital to find feverish children, swab their noses, and bring mucous back to the lab for genetic analysis). Because researchers could not afford to use this expensive screen widely, they were trying to borrow a capture-recapture estimation (CRE) method originally used to estimate the size of animal populations. The CRE method “captured” and marked a sample of individuals (i.e., children actively tested and diagnosed with influenza), “released” them into the community (i.e., the hospital), and then captured a second sample and counted the number of marked individuals (i.e., passive review of charts might “recapture” already diagnosed children). Comparing the proportion of children marked to those recaptured, researchers used the CRE method to estimate the size of the entire population (i.e., how many children have influenza diagnosed to hospital standards).

The process of borrowing CRE involved multiple consultations with a statistician from another department in the hospital, who was identified by the lead epidemiologist as having used CRE to count fish populations in his dissertation research, decades earlier. At the scheduled consultation, a junior epidemiologist brought research articles with heavily annotated methods sections to the meeting, as well as computer code used to reverse engineer CRE calculations and error estimations reported in previously published studies. After several weeks of intense conversation about modeling alternatives, both in the hospital and at a national organization charged with monitoring infectious diseases, the group created a CRE screening system they recommended as a “gold standard” for national use to monitor influenza and other infectious diseases. The scale of these activities, which Hall, Wieckert, and Wright (2010) analyzed as a process of analogical inference and assembly at the level of a work group, was extended in time (multiple conversations over weeks) but also in space and social participation (two departments in the hospital and a national agency). In close analysis of recordings of consulting meetings across this arc of work, we found a number of discursive practices that supported a fairly rapid change in the group’s conceptual practices for disease screening. These included forms of narrative assembly and simulation of future

work activities (e.g., how to account for time in hospital when combining different screens), use of parables to position conversational partners in ways that made ethics and values clear, and material processes of analogical comparison and inference that enabled adaptive use of tools and methods across different work groups (Hall, Wright, & Wieckert, 2007). The change in conceptual practices for the infectious disease research team was dramatic—from thinking of (and enacting) counting as a local effort to generate precision by active (and expensive) screening, they shifted to an understanding of precise counting as the outcome of multiple, less expensive efforts by multiple, independent screens. Their conceptual practice for counting underwent a dramatic change in scale, from local efforts of the nursing staff to a national network of independent screens, and led them to advocate (in public talks and their research publications) for a new “gold standard” in epidemiology. There were concomitant and consequential changes for members of the research team, with a junior epidemiologist from the team becoming the “go to guy” (in the words of the consulting statistician) in this area of infectious disease monitoring.

Conceptual change in cases of statistical consulting had surprisingly productive “horizontal” mobility as concepts migrated and were adapted over time and across settings. Fitting technologies and work practices developed in one setting to the needs and purposes of work groups in other settings (e.g., the trajectory of CRE in the case of counting influenza cases) created a border or frontier of changing conceptual practices in which core ideas took on new, productive meanings. We argue that horizontal migration is a process of generalizing that distributes (in the active sense) and changes the meaning of concepts (Hall & Greeno, 2008; Hall, Wieckert, & Wright, 2010; see also Kerosuo & Engeström, 2003). At the same time there was also a “vertical” dimension of learning evident when we followed the trajectories of statisticians across consultations. Although serving clients to facilitate horizontal forms of conceptual change and adoption, they encountered recurring structures that led to the design of new methods for statistical modeling and display.

These studies and the grounded theoretical categories they provide for understanding processes of consequential learning in changing conceptual practices “in the wild” are only a beginning, of course. Given the limits of case study research (i.e., our own conceptual practices also operate at a particular scale), we cannot claim with any certainty that these processes of change in conceptual practices would be found in many (or all) cases, within statistics or in other areas of professional work where people learn. But our analysis of consequential learning in conceptual practices is grounded in richly detailed ethnographic cases, and our efforts draw attention to processes operating at multiple levels of analysis<sup>2</sup> that are important for understanding learning as it is distributed across people and

<sup>2</sup>There is not space in this article to present the details of interaction and conversation analysis from our cases, but the articles we cite contain these details.

settings in conceptual practices (i.e., a theory of *distributing cognition*).

Productive conceptual practices are supported by representational infrastructures that are open to ethnographic and other forms of observational study. When the leading activities of work production break down or are disrupted, a space opens for engaging with learning and conceptual change as a new kind of leading activity (e.g., reverse engineering others' methods, inviting specialists to give advice on adapting previously stable routines, and rigging new capacity in representational infrastructures that support conceptual practice). We see these shifts in leading activity as opening a reflective space for learning at the level of the social history of work groups (Hall & Horn, 2012; Scribner, 1985). The conditions for opening these spaces and the resources required to discover or assemble new ways of working in the future provide a new set of questions and challenges for our understanding of how conceptual practices change. But these challenges also present design opportunities for research that seeks to create or support conceptual change at a collective level of analysis. We turn to these kinds of design studies in the next section of this article.

## DESIGNING FOR CONSEQUENTIAL LEARNING

In our case studies of changing conceptual practices in workplaces like the BugHouse, the scale of consequential learning was a question for descriptive analysis in existing conceptual practices (e.g., the temporal, spatial, and social organization of efforts to model termite foraging). We were fortunate to gain access to the activities of scientific work groups, but we were not asked to modify or design their activities to support new forms of learning. In this section of the article, we consider design-based research (Cobb, Confrey, Lehrer, & Schauble, 2003; diSessa & Cobb, 2004) directed toward creating new opportunities for consequential learning in conceptual practices. In these design studies, the scale of conceptual practices is more dynamic and open to negotiation, as are forms of representational infrastructure that hold conceptual practices together and how access to participation in these practices is structured for learners (Engle & Conant, 2002; Greeno & Gresalfi, 2008; Gresalfi, 2009).

We have designed activities to support consequential learning in a variety of settings including school classrooms, workplaces, community centers, professional development activities for school leaders, and sites of preservice teacher education. In keeping with our use of ethnographic research methods, we have sought to gather information about and understand the "social actor's point of view" (Becker, 1996). Our studies usually start with two broad questions. First, what might be consequential for learners, and how could we find out? Because we do not assume we can answer this question at the outset of the study, one purpose of ethnography and participant observation is to make

sense of what people in the study value for their own future. Second, we ask what kinds of social organization, including new representational infrastructure and activity structures, could make consequential learning possible. Answering this question usually involves close analysis of what people do together in existing conceptual practices. In trying to develop answers to these orienting questions, we have in some cases encouraged learners to analyze their own social history in conceptual practices, and we have used methods of participatory design to involve learners in identifying the problems they see as most pressing, what they would value about possible solutions, and how to create conditions for their own consequential learning (Gutierrez & Vossoughi, 2010; Simonsen & Robertson, 2013).

## Designing for Consequential Learning in Classrooms

Our research in classrooms has sought to introduce students to conceptual practices that are important in forms of disciplinary work they might later encounter as alumni of science, technology, engineering, and mathematics learning in school. One example of this approach is the Math at Work Project (Hall, 1995), in which we conducted parallel research in workplaces (e.g., the BugHouse) and in middle school mathematics classrooms where we were simultaneously doing design-based research (e.g., Hall & Stevens, 1995; Jurow, 2005; Stevens, 2000). We were skeptical about whether students would learn much about design-oriented disciplines (e.g., field entomology or architecture) in traditional mathematics instruction (e.g., by solving algebra story problems in which something is designed), but at the same time, we did not fully understand the scale, forms of infrastructure, or types of participation available in the conceptual practices of professional work groups. Based on what we were learning about conceptual practices in these work groups, we conducted design-based research for learning in classrooms by adapting and extending project-based curriculum units developed in earlier research (Greeno & MMAP Group, 1998).

The MMAP curriculum units positioned students as design professionals who used mathematical modeling practices to address problems that the target professionals faced as part of their routine work (e.g., biologists modeling endangered fish populations). These units offered students a "figured world" (Holland et al., 1998; Jurow, 2005) populated with particular types of characters (e.g., biologists), activities and novel technologies (e.g., modeling population change using specialized software), and values (e.g., protecting animal populations). The units were originally designed to help students see the consequentiality of mathematical practices of modeling beyond the classroom and to support their development as people who could use mathematics.

Our design research extended these units to include supplemental reading and media describing professional practices (e.g., physical models simulating population growth),

support for persistent display spaces in classrooms to enable comparative talk across design groups, and new forms of design review that served as benchmark performance assessments for groups (one of these is described next). One of our extensions organized “field experiences” for teachers in scientific and professional workplaces where conceptual practices foregrounded in the curriculum were in active use (e.g., manipulating tables to explore data on seasonal variation in termite foraging at the BugHouse). We codesigned classroom activities that we hoped would invite students to engage in conceptual practices of modeling that we found and analyzed in workplaces, and we expected these to generate new and more powerful ways for thinking about and engaging with mathematics in the classroom. One of these modeling practices was called a “design crit” by architects we studied (Cuff, 1992; Stevens, 2000). In a typical design crit, scale drawings (a model) of a building were presented to peers and visiting (often highly experienced) architects. Critical discussion of the model could be quite intense and often led to productive model revisions. This had a family resemblance to “poster presentations” of models used by research entomologists at the BugHouse. Each form of model review, whether in architecture or field biology, created opportunities for learning that professionals (particularly juniors) reported as being important for their own learning. Comparative analysis of conceptual practices of modeling in architecture and field biology led us to think differently about what might be possible in the classroom.

Because we were studying architects and biologists in parallel with our classroom design studies, we organized the classroom schedule and space so that we could invite participants in our workplace studies (as well as professional students at the university where we worked) to serve as outside reviewers on students’ designs and models. This seemingly simple extension—creating a design review in which visiting professionals interacted with groups of students—had a big effect on students’ engagement and participation in conceptual practices of modeling. When student groups presented models of fish populations to visiting biologists (Jurow, Hall, & Ma, 2008), we found that a conversational structure we called a “recontextualization exchange” (i.e., reviewers asked “what if” questions that challenged modeling assumptions or changed the context for evaluating model behavior) led to intense forms of competitive argumentation in the classroom. Unlike our earlier efforts to “show” modeling to students, when professionals instead met with students to discuss their models (i.e., the students owned the model being discussed), questions about alternative assumptions led to unusually lively classroom conversations. In some cases, even students who were resistant to the curriculum and initially mocked the visiting biologists later took positions in design reviews to argue for what a truly competent biologist *should* do. Recontextualizing models in design reviews was part of a conceptual practice

with models that was common to the biologists and architects but not to the students. Borrowing from Lave and McDermott’s (2002) critical analysis of schooling, visitors’ questions shifted the relevance and purpose of student modeling from familiar relations of “exchange value” (e.g., exchanging finished work for a grade) to more interactive and open-ended relations of “use value” (e.g., comparing alternate models to understand population growth). Talk about models that recontextualized student work in terms that were clearly relevant to practicing professionals also rescaled the classroom activity (Nespor, 2004) in ways that were newly consequential for students.

After we saw this shift in engagement and the purpose of student activity, we built opportunities for these kinds of conversational exchange into curricular activities in the subsequent years of our project (Jurow, 2005). We designed participant structures and classroom events to leverage a discovery made possible in design studies that were conducted in parallel with cognitive ethnographies of learning in professional workplaces. As our team (researchers and teachers) learned what could be consequential for learning in the conceptual practices of professionals, we intentionally designed for it in classrooms.

### Designing for Consequential Learning in Communities

Our studies of consequential learning have investigated concepts in terms of their organization in social and technical practices—their meaning as well as moments and places where they can be productively disrupted—in and across multiple settings or networks of activity. With an understanding that conceptual practices have a dynamic practical organization, we can think of conceptual change as forging new social arrangements that are more productive for communities and for individuals. Because what is valued as productive depends on the social history of participants in conceptual practices, this kind of design work may be most effective when done in partnership with practitioners and community members.

Social and community-based design experiments, rooted in the histories of communities and focused on problems that are most pressing for community members, are efforts in which design researchers attempt to provoke changes that could lead to consequential learning (Gutiérrez, 2008; Gutiérrez & Jurow, 2014). Returning to themes we used to open the article, social design experiments create opportunities for conceptual change at the level of community action, which can create powerfully consequential processes and outcomes for collective engagement. In the following, we share two examples of our collaborative social design efforts.

The first example considers the reorganization of urban spaces through a partnership among young people, urban planners, and researchers. Taylor (2013; Taylor & Hall, 2013) conducted a multiyear, social design experiment focusing on problems of spatial justice in a mid-South U.S.

city with a long history of racial and economic segregation. Their study started with ethnographic research on the activities and learning of urban planning professionals, over a 9-month series of community meetings in which planners took input from city residents about the kinds of development they hoped to see in their neighborhoods. The conceptual practice under way in these planning meetings concerned different understandings of the leading (if not bleeding) edge of community development—weighing what residents wanted for their neighborhood, on one hand, in relation to what local developers saw as economically feasible given the transportation network and distribution of household income, on the other hand. Although planners sought “public” input in working out this charged conceptual terrain for development, there was a nearly complete absence of youth perspectives. At the same time, Taylor was working with the leader of a bicycle-building workshop at a youth-serving community center located in these same neighborhoods.

Because youth were largely silent in city planning processes, and because the neighborhood was also described as a “mobility desert” by parents and community center staff, Taylor pulled together the pieces of a social design experiment to address problems of spatial justice (Soja, 2010). Extending over 5 weeks in a continuing “bicycle workshop” in the community center, a study was designed in which youth built their own bikes from discarded or donated parts and the research team taught them how to map their neighborhoods and to collect information about changing patterns of personal mobility (i.e., gathering and analyzing GPS track data without and then with a bicycle). Youth maps, showing elective mobility on foot and by bicycle, were shared with city and regional planners and representatives from the mayor’s office, who were charged with increasing bike usage in the city. Youth learned effective mapping practices (e.g., making personal map layers with open-source mapping tools), but they also used these tools to engage in a form of “counter mapping” in which their maps were used to challenge official city maps and to share their desires as young people making a transition into adulthood in the city. For example, a high school sophomore mapped bike lanes she hoped to use as a college student, deliberately connecting regions of the city that were sharply divided along racial lines. Youth presented these counter maps on multiple occasions, and several of their proposals for bike lanes were later mapped and marked for general public use by the city. As a matter of consequential learning, youth changed personal mobility and created models for consideration by the city, and the streets of the city were altered (i.e., signage and paint on the ground) to reflect their desires.

On one hand, the bike workshop case study shows the basic components of a social design experiment—working with the historical circumstances of a community to identify genuine needs and create new possibilities, designing learning opportunities in collaboration with community members, and persisting with efforts to have the resulting

product of collaborative activity taken seriously at a larger political and social scale. On the other hand, this example also illustrates a design practice, similar to our description of designing consequential learning in classrooms. As with cases in modeling animal populations describe earlier (i.e., the BugHouse used as an image for modeling animal populations in middle school classrooms), we again studied professionals to discover and craft images of conceptual practices that we felt had great potential value for youth learning. Working with community activists, we designed opportunities for participating in conceptual practices (e.g., counter mapping in the service of modeling for community economic development) within which these ideas and people could develop productively.

Our second case study involves designing with a community-based nonprofit organization, Impact,<sup>3</sup> to increase food access and social justice in a historically marginalized urban neighborhood. In the western U.S. city where this project takes place, the mayor’s policy team wished to bolster the economy through the production, consumption, and distribution of local food. One aspect of their vision involved extending the use of Impact’s “promotora” model to increase food access in the city’s multiple “food deserts” (United States Department of Agriculture Economic Research Service, 2012). Impact’s model borrows and adapts a traditional Latin American public health and community engagement approach in which residents are hired to facilitate community connections to institutional resources and knowledge (Elder, Ayala, Parra-Medina, & Talavera, 2009). Promotoras typically share cultural and linguistic backgrounds with the community they serve, and this is the case with Impact. The Impact promotoras are Spanish-speaking, Mexican residents who help families grow vegetable gardens and offer support related to health, nutrition, and other social services. From the analytic perspective we develop in this article, the conceptual practice identified in this social design experiment (i.e., the promotora model) is the use of densely connected community activists to co-design resources at a neighborhood scale.

Impact modified the traditional model to develop a backyard garden program. A team of 10 promotoras, who are Spanish speaking, Mexican residents hired to make connections between the nonprofit and the largely Mexican immigrant population of the neighborhood, helped families design and grow their own vegetable gardens. Through this program, Impact has grown over 300 thriving and productive backyard gardens. Jurow’s research team, which had been studying learning as part of the local food movement in the region, was invited to study Impact’s model of using promotoras to develop a community-based food system.

This social design research project began with an effort to understand the conceptual practices involved in being a

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<sup>3</sup>A pseudonym.

promotora. In initial interviews, promotoras expressed interest in the city's goals to extend a network of community gardens into other neighborhoods. A higher priority for them, however, was learning to become better advocates for their own community. This contradiction between goals created an opening for reflecting with the promotoras on the meaning of their work for themselves and their community (Engeström, 1991). Put more theoretically, change in the conceptual practices that defined being a promotora was under way and the research team joined these efforts as coparticipants in furthering consequential learning.

Through planning and enacting a series of professional development workshops for promotoras that the research team and the promotoras designed together, observations of the promotoras at work in residents' home gardens, and interviews with the promotoras, the research team identified a tension driving the changing conceptual practices that defined being a promotora. Many of the activities that the promotoras viewed as essential to their work were not documented in data sources the nonprofit collected and shared on the outcomes of their backyard garden program. The research team learned that when the promotoras were in the gardens, they were treated as confidants and resources for issues ranging from education and medical care, to legal troubles, rape, and domestic violence. The promotoras heard in the residents' experiences what Latina feminists would call *testimonios*—an urgent call to action—and tried to respond appropriately. They felt constrained in what they could do, however, because they did not always know of appropriate resources nor how best to support the residents. The promotoras wanted to improve their skills in this arena, but as this work was not visible to the nonprofit leadership, the potential for advancement was largely blocked.

The community advocacy work of promotoras was invisible, at least in part, because the representational infrastructure supporting a conceptual practice envisioned by local food activists did not have a way of gathering or sharing information about this advocacy work. This gap or absence in what was represented became visible in our project's interviews and observational research in the community, and in turn provided an opening for design. The representational infrastructure that Impact had created reflected a partial understanding of promotoras' work that focused on pounds of vegetables grown and changes in families' dietary practices. The promotoras would go door to door to ask garden participants to complete a pen-and-paper survey about the productivity of their gardens. The survey information would then be input and uploaded to a Microsoft Excel file by an Impact staff member. This information was highly relevant for the funders of their agriculture programs, but it did not capture the immense amount of relationship building and community advocacy work that promotoras did to sustain an increasing number of backyard gardeners. Making visible and enhancing the network of social relations and practical skills

involved in the promotoras' work of supporting the community was a different but equally important perspective. From the promotoras' perspectives, this work was foundational to the success of the garden program.

Noticing different perspectives in the conceptual practices of promotoras served as a moment for reflection—a disruption to ongoing work in the network of community gardens that opened an opportunity for codesign. By designing supports to bring these two, different dimensions of the conceptual practices defining the work of a promotora together, the research team took an opportunity to design for conceptual change at the level of the nonprofit organization (Impact), the growing community of promotoras, and the city. If these complementary meanings of conceptual practices could be brought together, the physical and the human (social, relational) resources that supported practical activity in the community could proceed hand in hand. If successful, the newly designed representational infrastructure might also enhance opportunities for consequential learning by shifting the acknowledged and valued concept of what it means to be a promotora.

The research team collaborated with the promotoras to develop possible solutions to what was absent in Impact's representational infrastructure. The idea of modifying the data collection system so that it could more accurately capture information about the promotoras' work was taken up as a design challenge for the group. The change was meant both to streamline the nonprofit's efforts at gathering systematic information about their programs and to allow the promotoras to design a set of questions that could better capture their community advocacy work. The outcome of multiple discussions about how best to enact these changes led to the codesign of a software application that the promotoras could use to document their work and, by reflecting on this new information, improve their work in the future.

By capturing the range of challenges that families faced and the resources promotoras might need to help these families, the nature of the promotoras' work could shift along with its significance for the community. By making the promotoras' community advocacy work visible, the new Promotora App modified the original representational infrastructure used by Impact. Once in use, the Promotora App rescaled the conceptual practice of being a promotora to connect with more powerful and far-reaching networks that included a larger proportion of neighborhood residents, potential funders, and city and state policymakers. Now in use, the Promotora App holds potential to affect the organization of food activism and community support in the focal neighborhood, and it arose as a direct response to Jurow and colleagues' noticing, through their ethnographic fieldwork, that the promotoras wanted to learn to work differently. The Promotora App is not interesting only because it involves mobile, tablet-based computing; it is interesting because it rescales work in the community and opens up new possibilities for consequential learning.

## DISCUSSION

Our intentions in writing this article were to explore and extend the spanning structure offered by Greeno and van de Sande (2007), in which personal “perspectives” were aligned in problem-solving conversations, and the new information structures were established in the shared or common ground of interlocutors. Our approach can be seen as an examination of how common ground is achieved, both in ways that play out in the moment and at larger scales in time, space, and social participation. What Greeno and van de Sande took to be stable surrounding discourse practices in classrooms, we treat as more dynamic representational infrastructures that change during periods of disruption (e.g., the end of project funding at the BugHouse) and in ways that are open to design (e.g., introducing “design reviews” with visiting professionals in a middle school mathematics classroom).

We see our extension as roughly parallel to the distinction made by Greeno and van de Sande (2007, p. 9, Footnote 1; p. 21, Footnote 11) between concepts and “conceptions.” In early use, “conceptions” described the coherence of conceptual systems made up of a collection of related ideas (e.g., Newtonian laws of motion). But as used later by Giyoo Hatano (in conversations leading up to the 2007 special issue of *Educational Psychologist*), conceptions described a shift from procedural to conceptual understanding that supported “adaptive” over more routine forms of expertise. In Hatano’s early writing (Hatano & Inagaki, 1986; Miyake, Miyake, & Shirouzu, 2006), “routine expertise” was taught in formal schooling, and the relatively shallow “procedural knowledge” that resulted could later be overcome by the natural curiosity and personal effort of individuals, who by examining their own problem-solving activity could achieve deeper conceptual understanding and more “adaptive expertise” (e.g., solving genuinely ill-structured or novel problems). As Hatano’s research began to address learning in classrooms that were designed to support “collective comprehension” (Hatano & Inagaki, 1991; Hatano & Oura, 2003), distributed knowledge and the social relevance of problems learners were asked to solve became much more important in his analysis of how to support the development adaptive “conceptions.”

We see Hatano’s more expansive meaning of “conceptions,” Greeno and van de Sande (2007) proposals for aligning perspectives in ways that change what is held in common ground by participants in a community, and our studies of how changing representation infrastructure can support consequential learning in conceptual practices as a similar set of spanning proposals that might yet link phenomena at the level of individuals in activity (the dominant focus of cognitive approaches) with phenomena at the level of learning in changing conceptual practices. As this effort progresses, there are a number of important open questions. One concerns the conditions under which variation or innovation in conceptual practices is generated, whether in

response to changes in social history or as a deliberate, future-oriented activity. Our studies locate sources of disruption as being either external to the group engaged with conceptual practice (e.g., the end of project funding in studies of seasonal foraging at the BugHouse) or deliberately arranged to find and assemble new ways of working (e.g., borrowing new methods for monitoring the incidence of pandemic infectious diseases in our study of statistical consulting with epidemiologists). There are surely other conditions for shifting between production and learning in the ongoing, social history of people working together in conceptual practices. In the cases of design-based research we presented, these included researchers acting as intermediaries to create new forms of interaction between different segments of a broader community (e.g., putting youth counter mapping in contact with city planners) and the explicit codevelopment of new representation infrastructure to expand the scale of activity and opportunities for consequential learning in conceptual practices (e.g., developing software applications that make valued forms of information persistently available across time and space in the case of codevelopment of the Promotora App).

A second open question concerns processes that distribute and stabilize new forms of conceptual practice across scales of time, space (multiple settings), and social participation. In the case studies reported by Greeno and van de Sande (2007), ways of structuring problems for solution were compared and accepted over relatively short periods and within a collaborative student group in an intact classroom. In the case studies we reported, material aspects of representational infrastructure were less clearly contained, because either work was distributed over settings within a working group (e.g., in the BugHouse, field and lab were interleaved through circulations of material and people) or deliberate changes in representation infrastructure had the effect of distributing conceptual practices in new ways (e.g., shifting to a different “gold standard” for monitoring emerging infectious diseases). The scale of learning in changing conceptual practices is clearly broader than problems solved in a classroom lesson, but how are changes in practice realized at these broader scales (e.g., adapting and reassembling representational infrastructure that rig together new, coordinated patterns of work)?

Our provisional answer is that changes in conceptual practices driven by new representational infrastructure are deliberate, in the sense that activity shifts from ongoing production (doing) to focus on infrastructural resources for learning (doing things differently). In our cases, what changes are produced and whether they stabilize as new resources in conceptual practices depended in important ways on organizational supports available during periods of disruption (e.g., calling in a statistical consultant, access to methods sections and computer code from others’ previously published papers, designers who act as brokers to

focus attention on unmet needs in existing practice). As Hall and Horn (2012) summarized a comparative analysis of changing conceptual practices in health sciences research and teaching mathematics:

Practically, processes that contribute to conceptual change at work—suspending production to consider working differently, representing practices for comparison and revision—have more or less traction, depending on organizational supports for reflection and for putting new concepts into broader circulation, where others might have a chance to notice, borrow from, and extend their own work practice. (p. 256)

Changes in conceptual practices may also be implicit or largely unintended, as in Saxe's (2012, pp. 313–321) model of the interplay between “local emergence” of relations between representational forms and cognitive functions (e.g., adapting a counting system to communicate new arithmetic problems in mercantile exchange) and “broadcast” or top-down processes in which new representational forms are mandated by governmental authorities and supported by “brokers” in the community (e.g., naming conventions associated with monetary currency). In Saxe's model, variations in practice continually emerge through attempts to communicate in local interaction and in response to constraints and resources imposed by top-down authority. Variations with communicative advantage in local exchanges are selected and stabilize by spreading across interlocutors through time (i.e., following Croft, 2000), Saxe proposed an evolutionary model of change in the representational infrastructure of conceptual practices. Our studies and arguments in this article have focused on more deliberate processes of change, including efforts to design infrastructural resources that can support consequential learning in conceptual practices. Further research in this area may help us to identify and understand how “increasing conceptual order” (Hutchins, 2012) is created and distributed in the material arrangements of conceptual practice, on one hand, and how design can identify and create possibilities for consequential learning in these conceptual practices, on the other.

## CONCLUSION

Situated learning emerged in response to a need to identify a unit of analysis that was more encompassing and livelier than the lone individual and her cognition, solving problems in a given task environment and learning while that environment largely remained the same. Persons acting in settings (Lave, 1988) and structural provisions for gaining access to participation in social and technical practices were ideas developed in response to existing cognitive and information processing accounts of cognition, concepts, and learning.

Research from a situated perspective underscores the need to ask questions about learning that unfolds not just in one setting and in one moment, but as people live historically and culturally across the contexts of their lives (Dreier, 2008; Engle, Lam, Meyer, & Nix, 2012; Gutiérrez & Rogoff, 2003; Jurow & Pierce, 2011; McDermott, 2010; Shea, 2013). Following from this, situated studies of changing conceptual practices must consider seriously how these changes become consequential for individuals, communities, and practices. Consequential learning is historically contingent and so not uniformly positive or even benign. What we value as learning and the resources for it to happen can change through time, sometimes severing the meaning of concepts from practices in which they were originally useful (Brown, Collins, & Duguid, 1989). Learning is consequential when it creates opportunities for learners to change the temporal, spatial, and social scale of their participation in and across practices. Consequential learning in conceptual practices can also change those very practices in ways that learners desire and value. It follows that if consequential learning is historically contingent, then it is also open to design. We can design to invite forms of consequential learning in which people change their relations to activity in conceptual practices that may span multiple settings, fitting, or rigging infrastructural resources developed in one conceptual practice to new ways of taking action and sense making in other conceptual practices.

For this special issue, we were invited to relate our work to existing theories of learning and to show how our approach created some kind of practical or theoretical advantage. As an approach to this task, we decided to build from a theoretical proposal for research on concepts and conceptual change developed a decade ago and detailed in a special issue of *Educational Psychologist* (Murphy, 2007). Some commentators on original articles in that issue were not convinced that bridging between theories was possible—either the constructs authors proposed were not different enough, or authors took incommensurable epistemic stances toward what concepts were and how they could be learned (Alexander, 2007). From our perspective, the more interesting differences concerned the units of analysis authors chose for studying concepts and how they change, and how these choices might lead to conducting research that is productive, not only for educational psychologists but also for the people whose learning might otherwise be invisible or suffer from a lack of public resources.

Taking a lead from one of the articles in the previous special issue, we described an approach to research on how material practices support what Greeno and van de Sande (2007) called “perspectives” and “framings” in the discourse of a community that uses disciplinary concepts to solve problems. Their approach draws our attention to interactive processes in conversation that help to establish information structures in the “common ground” as shared understandings about problem structure and strategies

among conversational partners. Whereas individuals may be attuned to these common structures, the structures themselves cannot be defined by individual mental content. It follows that to understand concepts and conceptual change, one must seek different units of analysis (e.g., as Lave, 1988, argued, persons acting in settings) and processes that play out at multiple scales in time, setting, and social participation.

Careful analysis of representational infrastructure, as it changes over the social history of working groups, offers a powerful perspective on seeing concepts and conceptual change differently. Drawing from case studies conducted across a wide variety of settings, we argue that concepts are patterns of coordinated, purposeful activity that are distributed across people and technologies in conceptual practices. From this view on concepts, understanding conceptual change requires an analysis of processes for distributing cognition over time, across people, and through the settings for their work.

Our research on conceptual practices in contexts outside of laboratories and single-classroom settings has underscored the extent to which the problems people grapple with are not limited to the particular places and times in which they act. Problems have origins in history and social organization that affect individuals but cannot be solved only by looking at individuals. Some of these problems arise in processes that operate at very large scales and raise critical questions about what is valued in learning, by and for whom? For example, processes of curriculum reform, poverty, and inadequate access to funding for housing, health care, and the upkeep of the physical infrastructure of a city shape the problems that individuals confront in their daily lives, as well as resources available for finding or enacting solutions (see Orfield, 2002; Soja, 2010; Tate, 2008). As Mercer (2007, p. 75) proposed in his commentary in this journal's special issue on reconciling cognitive and sociocultural accounts of conceptual change, researchers have bracketed these "confusing elements of the social" from attention in order to gain analytic clarity about what counts as concepts. A situated perspective on learning offers a different view of this bracketing problem. It begins with the assumption that the individual and the social world are mutually constituted and as such, both need to be considered as we try to understand or design for learning. From this view, the unit of analysis for studying learning needs to include the person acting in the world (Lave, 1988), and in our approach, that world includes conceptual practices that operate at scales broader than momentary interactions.

Studies of consequential learning focus on the historical and social contingency of conceptual practices, on individuals' developmental transitions across cultural activity systems, and on the changing scale relations defining learners' engagement with cultural practices (Beach, 1999; Jurow & Shea, 2015). Our efforts to design for learning that could become consequential for individuals and communities

have required that we attend to the value-laden dimensions of practices, our own as well as those of the people with whom we study. If we are to take seriously that learning involves both participating in and changing conceptual practices (Lave, 2012), we need to develop theories and methods that can help us choose and make progress on problems that are consequential, both for our field and for the research participants who choose to work with us.

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