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Talk and Conceptual Change at Work: Adequate Representation and Epistemic Stance in a Comparative Analysis of Statistical Consulting and Teacher Workgroups

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In this article we ask how concepts that organize work in two professional disciplines change during moments of consultation, which represent concerted efforts by participants to work differently now and in the future. Our analysis compares structures of talk, the adequacy of representations of practice, and epistemic and moral stances deployed when workgroups in clinical health sciences and secondary mathematics teaching seek to improve their work in discussions with colleagues and experts. Our comparative analysis highlights interactional supports for identifying, elaborating, and stabilizing relatively small-scale innovations in joint work that contribute to development at multiple timescales. These supports include comparisons over accounts of practice that borrow and extend method or technique, negotiating adequate representations of practice, use and uptake of epistemic stance toward what can be known about shared work, and surrounding organizational structures that provide for (or inhibit) the circulation of new concepts across workgroups.

The comparative study of [peoples’] work learns about doctors by studying plumbers; and about prostitutes by studying psychiatrists. [ . . . ] I believe that in the study of work, as in that of other human activities and institutions, progress is apt to be commensurate with our ability to draw a wide range of pertinent cases into view. The wider the range, the more we need a fundamental frame of reference. (Hughes, 1971/2009, p. 316)

Following Hughes’s recommendation, we compare two very different forms of work to arrive at a multilevel, developmental theory of workplace learning. We bring together two independent lines of research on learning at work—Hall and colleagues following uses of mathematics in technical and design-oriented work, and Horn and colleagues following how mathematics teachers learn on the job. Here we focus on consultations at work, settings in which leading activities of production are suspended to find ways of working more effectively in the future, inviting advice from specialists in related fields or coworkers. Hall’s studies of statisticians consulting with biological and health science research clients provide one set of grounded theoretical categories.

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for understanding conceptual change at work; Horn’s studies of secondary mathematics teachers’ workplace learning provide a second, related set of theoretical categories. Our purpose is to juxtapose and extend these findings into a grounded theory of conceptual change at work.

Our approach draws from cultural-historical activity theory (Engeström & Sannino, 2010) by treating concepts and their use in work practice as a particular historical accomplishment of human actors. 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.

We draw from studies of distributed cognition (Hutchins, 1995, 2010) and attend to the changing capacities of functional systems that coordinate activity across people and tools, and studies of change in cultural practices as people pursue emergent goals in shifting relations with mediating artifacts (Saxe, 2002; Saxe & Esmonde, 2005). We also draw from research on the organization of learning opportunities in different types of work (Grossman et al., 2009; Hall, Stevens, & Torralba, 2002; Horn, 2005; Little, 2003), with a focus on varied supports for learning (Cobb & McClain, 2006; Coburn, 2006). We introduce ideas from these literatures as we work through a comparative analysis of our own empirical materials.

First we review what our projects have discovered about conceptual change at work, drawing out similarities and commensurable theoretical categories that may be productive in other studies of learning in the wild. We identify and explore differences between efforts to change statistical modeling in health sciences research and mathematics teaching practices oriented toward student thinking, as these projects illuminate a multilevel model of conceptual change at work. We end the article by posing new questions about conceptual change at work concerning the adequacy of representational practices to support change and differences in epistemic stance at play in consulting activity.

**REPRESENTATIONAL INFRASTRUCTURE AND WORKPLACE CONSULTATIONS**

Because concepts in our framework are distributed over patterns of activity and technologies, they are integral to the representational infrastructure of work. As Star (1999; Bowker & Star, 1999) argued, infrastructure is invisible when it operates smoothly, becomes visible when it breaks down, and requires methods of inversion to be studied systematically. In studying conceptual change at work, we have been led by observation and analysis of workplace activity to recognize that learning always occurs at multiple temporal and social scales. Just as Hutchins (1995, p. 372, Figure 9.1) argued that any moment of work intersects multiple lines of development—the conduct of activity, the learning of practitioners contributing to that activity, and the historical

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1We learned a great deal about cognition in relation to representational technologies through Hutchins’s (1995, 2010) studies of distributed cognition. In studying conceptual change at work, we shift the focus toward the agency learners exercise in actively distributing cognition, something we propose as an extension to Hutchins’s earlier work (Hall, Wieckert, & Wright, 2010).

2In keeping with Hughes’s (1971/2009) framing of comparative social inquiry, just what counts as “work” or the “wild” is an open horizon for our field. What frames our common inquiry is the notion that ongoing work has been suspended to compare alternative ways of working in the future. This deliberate, reflective investment in learning may be commonplace or quite rare, depending on the setting. For example, Beach (1999; see also Tannock, 2001) describes workplaces in which production does not stop for learning.
development of the practice—we treat consulting encounters as opportunities to make the conceptual infrastructure of work visible, permitting the study of conceptual change at multiple temporal and social scales. How do workgroups change the way they understand and conduct their practice? How does learning at a collective or social level of analysis articulate with learning by individuals? We start with cases that illustrate the theory of conceptual change at work we are proposing.

Conceptual change is visible in our data when production is suspended during consultations. For statisticians, production entailed teaching and work on computational tools, whereas for health science researchers, this included in-progress data gathering and, sometimes, related activities of providing clinical care. For teachers, production involved the commonplace and valued activities of lesson planning, instructing, and assessing.

If representational infrastructure is integral to the manifestation and development of concepts, adequate representations of practice become critical during consultations, as they provide the 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). How are adequate representations of work—problems of teaching or of statistical modeling and inference—produced, used during consultations, and circulated across workgroups?

In the following sections, we present two excerpts from our corpora to illustrate how we view consultations as supporting conceptual change at different levels of development. The details of that analysis follow, taking up the bulk of the article.

LEARNING TO COUNT CHILDREN HOSPITALIZED WITH INFLUENZA

In Hall’s study of statistical consultations, a group of researchers studying infectious disease invited a statistician to help them use a new (for them) capture–recapture estimation (CRE) method to count children hospitalized with influenza. Originally developed to estimate the size of animal populations that were too onerous to count directly, this method captured and marked a sample of individuals, released them, then recaptured a second sample and counted the number of marked individuals. Using a simple algebraic proportion, CRE supported an indirect way of calculating the entire population.

Alberto, a junior member of the medical research team, met with Ted, a statistician, to extend CRE to a study of childhood influenza, hoping to combine an active screening procedure (expensive, using DNA testing) with a passive screen (less expensive) of hospital charts. To pursue the analogy between marked animals (children are “marked” with influenza diagnosis) and capture–recapture (children “captured” in each screen), Alberto and Ted each brought to the meeting a set of heavily annotated, published articles that employed CRE. Each had also already written computer code to calculate the population estimate and surrounding confidence intervals, and Alberto had even reverse-engineered tables of reported values in published articles to check calculations in his own study. As we explain, these served as important representational resources in their meeting.

During the consultation in Ted’s office, Alberto leaned over his in-progress analysis and marked up copies of other researchers’ publications, worried that nonmatched calendar days
would violate a CRE assumption of a closed population (i.e., some children might not be available to a screen operating only four days a week). As shown in transcript Excerpt 1, Alberto’s exclusion of nonmatching days was not clear to Ted (Turn 2), even after almost an hour of work on the problem.

Excerpt 1 (Flu screening): Statistical consultation to combine active and passive screens when counting children with influenza.

1 Alberto: The- this one is the system that was working just four days a week, and this was working seven days a week. (pointing at manuscript table) In order to obtain these numbers we . . . used just the same numb- the patients that were caught in the SAME days for both these things. That is, four days a week.

2 Ted: Oh, I see.

(Alberto clarifies use of matching days, 40 sec)

Ted then challenged Alberto’s assumption, proposing instead that he use all days from both screens (Turns 3 and 5), as the method “doesn’t CARE” if screens had different probability of capture. Pointing into the stack of annotated documents, Ted showed how this would “increase your numbers” and simplify calculations.

3 Ted: Why not use the seven day numbers here= (pointing at manuscript table)

4 Alberto: =Mm hm=

5 Ted: =and the four day numbers there?
As far as the method’s concerned, I mean the- It doesn’t CARE about the fact that one method has a smaller probability of capture than the other. (3 sec)
I mean there’s no reason why you can’t.

6 Alberto: Mm:: (head on hands, 5 sec)

7 Ted: And I would- I would think that would be uh, it’s gonna increase your numbers for one thing.

8 Alberto: Mm hm.

9 Ted: And uh, it’s in some sense simpler.
(pointing at manuscript table) You’re gonna get a higher number here [than you] would get there.

10 Alberto: [Right . . . ]

11 Ted: But you KNOW that that’s going to be the case because you know that you’re only sampling for four days here and you’re sampling for seven days there. (pointing at manuscript table)

12 Alberto: But, how could we interpretate the results after that estimation?

((Ted explains that CRE does not assume equal probability of capture, 98 sec))

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3 Turns at talk are numbered for identified speakers, and we break some extended turns into thematic units for ease of analysis. Continuous speech at turn boundaries is shown with =equal signs, whereas onset of [overlapping talk is shown with left brackets. EMPHATIC talk is shown in caps, and elong:::ated enunciation is shown with repeated colons. ((Activity descriptions)) appear within double parens and in italics. Alberto (the client) spoke English as a second language.
Alberto followed Ted’s proposal closely, but his murmured assent (Turns 6 and 8) did not mark agreement. He persisted with the problem of nonmatching days, eventually describing an extreme case in which the screens matched only 1 day each week (Turns 13 and 15). Would it still be possible, he asked, to combine the screens?

13 Alberto: I wou- I thought about that uh a little bit, that- It was a little difficult to me to understand. For example, you’re uh if they- if there were no data for four days, just one day. ((pointing at manuscript table))

14 Ted: Yeah.

15 Alberto: And the other system would be working the whole- the whole week. Do you think it would be still possible to apply?

16 Ted: Sure.

17 Alberto: Mm::: ((rests head on hands))

Even for this extreme case, which from Alberto’s starting position (use only matching calendar days) could lead to uninterpretable results, Ted was casually positive (“Sure”) about using all screening days. As the consultation continued, Ted used a concrete example to convince Alberto to use all screening days, with the result that his estimates of the population of children with influenza had tighter confidence intervals and were more informative.

Still, Alberto’s senior research colleagues were skeptical. Over a period of several weeks in phone and e-mail exchanges, Ted managed to convince the team to use multiple, independent influenza screening systems. Six months after the consulting meeting, Alberto’s team published new estimates of influenza rates for children in the study region, and they argued to the standards of peer review that expensive screens could be used sparingly (only 1 day a week) when combined with less expensive screens operating continuously in a new, national influenza surveillance network. What started as a local “bug” in a consulting conversation—Alberto’s skeptical challenge on using unmatched days—later became a “feature” in a proposed public health surveillance system for influenza.

We expect and intend this brief summary to be read as a successful case of conceptual change at work. Before the consultation, Alberto’s group used and understood counting to consist of exhaustive and often expensive screening of children with influenza. Afterward, they understood counting quite differently, and their population estimates were stronger as a result. A nimble combination of expensive and relatively cheap screening procedures replaced exhaustive counting, yielding, in the words of Alberto’s team leader, a new “gold standard” for estimating how many people (no longer just children) were hospitalized with influenza each year. A new concept of counting was clearly in progress, but what processes, at what temporal and social scales, led from one understanding and practice of counting to a quite different practice?

Excerpt 1 illustrates processes of conceptual change operating at multiple temporal and social scales shared by all of our cases of statistical consulting (Hall, Wright, & Wieckert, 2007). Although the transcribed talk spans only a moment of consulting practice, the following are under way:

1. At a microgenetic level of analysis, clients and statisticians produce utterances that animate nonpresent research participants, the activities of investigators in both past and
future time, and even the intentions of methods, frozen over historical time into assumptions and schemes of calculation (Turn 5, “As far as the method’s concerned [. . . ], it doesn’t CARE”). These animations, typically expressed as narrative fragments, support efforts to assemble new ways of working by clients that deliberately compare existing and imagined activity (Turn 11, “If there were no data for four days, just one day. [. . . ] Do you think it would be still possible to apply?”). Processes of animating, comparing, and assembling work practice are supported by durable representational forms (e.g., journal articles) that are adequate for highlighting aspects of practice judged relevant for assessments of current and future activity.

2. At an ontogenetic level of analysis, individuals’ understandings of concepts are made visible for assessment through how they animate and assemble the entities and relations involved in practice, leading to exchanges in which more experienced participants discipline the perception and actions (Stevens & Hall, 1998) of less experienced interlocutors. Both clients and statisticians learn new ways of engaging with concepts in these exchanges. In Excerpt 1, for example, Alberto repairs a misalignment of CRE assumptions onto clinical practice (i.e., CRE does not assume equal probability of capture on matching calendar days), whereas Ted manages to extend CRE to an extreme case (i.e., Alberto’s skeptical offer of 1 and 7 calendar days) in a way that has significant implications for national screening procedures.

3. The creation of a new “gold standard” for counting people hospitalized with influenza is a clear illustration of conceptual change at a collective level of analysis (sociogenesis, or change in the social history of a research group). But focusing only on this new concept of counting would hide other processes that operated at a larger social scale over a longer temporal horizon. Alberto visited Ted as an individual, but he was a spokesperson (and lead author) for a single study inside a larger research group. The leader of that group arranged the meeting with Ted, after learning that Ted’s dissertation (more than 20 years before) involved an extension of CRE methods. In this sense, Alberto and Ted met as one phase of a process of analogical comparison that extended, both in time and in the surrounding research organization, far beyond accepted theories of learning by analogy available to us from cognitive and educational psychology (e.g., Gentner, Loewenstein, & Thompson, 2003; Lobato, 2006; Tuomi-Gröhn & Engeström, 2003). The completed analogy in the flu case both transformed local work practices under way as Alberto entered the meeting and extended future meanings for CRE as a gold standard concept of counting in the often contentious organizational world of screening for infectious diseases.

Excerpt 1, understood against this broader distribution in time and social organization, presents one case for empirical grounding of a multilevel theory of conceptual change in workplace consultations. By suspending existing practices for counting in their research on infectious diseases, then also by inviting Ted (and his history with CRE) into a meeting to work on a different conception of counting, Alberto’s group shifted the objective of activity in ways that changed relations between different lines of development in practice.

Alberto was a junior member of a larger, highly accomplished research group in epidemiology. His study to count children hospitalized with influenza was a small part of this larger group activity, undertaken with the expectation that Alberto would learn by participating more fully in activities of data collection, analysis, and writing for publication. In this sense, the study, prior to consultation with Ted, was a matter of routine production in which a publication (the object
of production) and a more experienced team participant (Alberto, as an object of reproduction) were anticipated outcomes. In Hutchins’s (1995) sense of multilineal development, the conduct of activity and development of a practitioner were both progressing apace, whereas organization and understandings of the surrounding practice changed little, if at all.

By attempting to borrow a new concept of counting (CRE) from the published literature and inviting Ted to give advice on the in-progress analogy, routine practices of production in Alberto’s research group were suspended. During the consultation and in Ted’s continuing efforts to counter skepticism by other members of the research group, the future organization of collective practice became the object of work. In this sense, coordination among typical scales of time and social participation were inverted, and the available history of things (e.g., published papers and code fragments) and biographies of participants were arranged as resources for assembling a new way of working—sociogenesis became, if only briefly, the object of work in a newly configured team. These phases of deliberate inversion of lines of development (i.e., placing collective work practice at the center of concerted efforts to change) provide a window onto conceptual change at work as an active process of distributing cognition (Hall et al., 2010).

This inversion of objectives and associated ways of coordinating temporal and organizational scale are not unique to statistical consultations. In the following excerpt, from a corpus of teachers consulting with one another and with outside experts to learn at work, we find similar, multilevel processes of conceptual change at work (animating and comparing ways of working, assembling new work practices, borrowing from other practitioners). We first illustrate these processes in the teaching corpus, and then we draw out similarities and differences in possibilities for conceptual change at work.

**LEARNING TO USE CONFUSION WHEN ORCHESTRATING HIGH SCHOOL MATHEMATICS TEACHING**

As a part of a 6-year project aimed at improving mathematics teaching in U.S. urban high schools, Horn and colleagues worked collaboratively on the professional development of teachers. Typically, teachers conceptualized their work as presenting mathematical ideas clearly. The new form of teaching required them to work with rich representations of the content and engage students’ thinking, using methods based on complex instruction (Cohen, 1994; Horn, 2012).

Using inquiry-based and situated forms of professional development such as video clubs (Sherin & van Es, 2009), the project sought to problematize conventional forms of teaching. At the same time, teachers were provided with resources to develop a more challenging form of practice that required responsiveness to ambiguity, improvisation, and problem solving, including daily collaborative time and in-class coaching.

The math coach, Lisa, had a long history with complex instruction, both as a classroom teacher and teacher educator. In the following consultation, she met with two in-service teachers, Betty and Claire, who were designing a lesson on proportional reasoning. About 20 minutes into the meeting, Betty explained their in-progress lesson plan but also reported that she and Claire were perplexed about how to move between small-group and whole-class activity in the lesson. The teachers anticipated that students working in small groups would be “confused” about the meaning of proportions and what these quantities referred to in the given problems, if they had not already been taught definitions for these terms in whole-class discussion.
**Excerpt 2 (Confusion is fabulous): Shifting between group and whole class work.**

1. Betty: How do we - how do we, how do we do this ((hands sweep over lesson materials)) having them work alone, coming back together as a class, then separating it out again. I’m not quite sure how to structure it both in the task card and in what we want them to do.

2. Lisa: Why do you want to do it as a whole class? (((discussion of ratio task omitted, 1 m 10 sec))

3. Betty: So if they’re getting stuck there can we ask the question as a teacher. Like when they get there, they can say, “What are we supposed to answer for this?” “Okay, so what are those numbers talking about? Don’t just give me the number but show me what it’s comparing. What is in that ratio? What is in the other ratio?” (((discussion of ratio task omitted, 43 sec))

Teachers consistently used reported speech to represent classroom practice with one another, providing a basis for consultations (Horn, 2005, 2007, 2010). Teachers conversationally constructed both students’ and teachers’ voices in past, generic, or future teaching situations, in ways that were strongly similar to processes of animating, comparing, and assembling new work practices in Excerpt 1. Reported speech took the form of replays and rehearsals, representing classroom practice by not only describing what had happened or might happen but also revealing the purposes and understandings of speakers; that is, teachers portrayed interactions that they deemed relevant to the problem at hand. Lisa could thus assess Betty and Claire’s grasp of concepts in teaching by attending carefully to how they animated classroom situations, just as Ted was able (eventually) to understand how Alberto grasped and intended to use CRE in his research. By framing these replays and rehearsals differently and in comparison, Lisa offered Betty and Claire a new way to conceptualize and imagine acting in response to students’ potential confusions.

4. Lisa: So. Yeah. What do we expect them- what do you THINK they’ll think? (((2 sec))

5. Claire: (((shrugs))

6. Lisa: We want to push them toward corresponding parts.


8. Lisa: But=

9. Betty: =That’s why we were thinking as a class it needed to be done.

10. Lisa: (((2 sec)) So, oh. Okay, so this. ((leans back)). This is FABulous. Because this is where I think you let them get confused, you let them muck around with it, and you come in, and you ask a question, ((puts finger on lesson plan)) knowing what the learning objective is, you ask a question, if it’s needed, some of them might not even need it. But if it’s needed, to help them think about these corresponding parts.

11. Claire: Just give it to them, and?

12. Lisa: I think, well, I think this is your task card. It’s pretty busy but I don’t know.

To successfully compare the proportions in the problem, students needed to make sure numerator and denominator values represented the same category of thing in ratios they set up, what teachers referred to as “corresponding parts” (Turn 6). This was a challenge because the task did not make sense otherwise. The teachers worried the activity would fall apart if the students missed the setup, and they wanted to provide explicit instruction on this point.

The students’ confusion was “FABulous” in Lisa’s framing because it provided evidence that teachers found a conceptual issue to work on, and students were engaged in sense-making enough to express puzzlement during group work. This, in turn, would permit the teachers to use student-posed questions as the basis for developing understanding. Similar to Alberto’s challenge to the consulting statistician in the Flu case (i.e., Would CRE work if screens operated only 1 and 7 days), student confusion was not a “bug” but a “feature” in the reconceptualization of teaching with group work offered by Lisa. Lisa offered a shift in the objective of teaching, from a focus on covering material and minimizing overt confusion to processes that encouraged student engagement with ideas, even when they became muddled. Trouble in a group setting was recast as an opportunity to learn. Instead of an outcome of bad teaching, trouble became a mediating resource to support future learning (Stone & Gutierrez, 2007).

14 Lisa: Taking it to the whole class means you’re going to feel more comfortable because you’re going to lead them through something.

15 Betty: But it doesn’t mean they’re going to get it.

16 Lisa: But it doesn’t mean they’re=

17 Betty: =Right=

18 Lisa: =gonna get it=

19 Claire: ((nods))

20 Betty: Right.

21 Lisa: And I think they’re going to get it more if they go, ‘What the heck is this? We don’t understand it.’ And you come over and ask a question. And you build from whatever they’re giving you until they understand this relationship.

22 Betty: Okay.

The problem Betty and Claire initially brought to Lisa involved transitioning between individual and group activity structures. Lisa probed their reasoning for moving to a whole-class discussion in the first place. When it became evident that the teachers were concerned about students’ confusion, Lisa seized upon an opportunity to illustrate an important aspect of the teaching approach she was helping them to develop: In Turn 10, she declared, “This is FABulous.” As the turn progressed, she then animated a teaching routine they were already familiar with—“you let them get confused [. . . ] and you ask a question, knowing what the learning objective is” (elaborated further in Turn 21)—verbally modeling how teachers used student confusion as the springboard for instruction. In Turns 14 to 18, Lisa and Betty co-constructed a related teaching principle: Taking it to the whole class means you are going to feel more comfortable, but it does not mean the students will get it. The co-construction (in talk) of this idea indicated that Betty had heard about the principle before, and in Turn 15, she stated the conclusion of the principle a moment before Lisa.
Excerpt 2 illustrates a process of conceptual change that emerged through a grounded analysis of similar moments of consultation across teacher workgroups (Horn, 2010; Horn & Little, 2010). Specifically, teachers’ consultations provide a means for conceptual change about the work of teaching in the way they represent instances of practice and link them to each other or to general principles about teaching. Horn’s corpus includes several forms of interplay between principles and representations in conversations that support conceptual change.

These processes typically unfolded as follows. First, a teacher presented a problem for consultation. Because consultations were almost necessarily asynchronous with instruction, the adequacy of representations not only delimited the visibility of critical facets of the issue but also communicated assumptions about the trouble itself. Here, Betty and Claire proposed a problem about timing different classroom activity structures. Then, a coach or colleague prompted the speaker for elaboration. At times, prompts signaled an alternative conceptualization of the problem itself. Sometimes, they were probes that rested on the listener’s unfolding conjectures about alternative explanations for the trouble that was being shared. Teaching was a complex endeavor, and the same generic description (“the class was noisy”) could mean radically different things depending on other contextual details (“the students couldn’t focus” vs. “they were all arguing about the problem”). In Turn 4, Lisa’s question probed the teachers’ expectations about the students’ confusion, ultimately revealing that the teachers viewed the confusion as a source of concern rather than a resource for instruction.

Next, an alternative approach to the problem was proposed. The problem framing was often embedded in or linked to the representation of the classroom in the first conversational phase. Based on additional details provided during the elaboration, a new representation of the problem was proposed using a revised representation of the classroom. This new story proposed an alternative vision of teaching: a reconceptualization. In Turn 10 of Excerpt 2, Lisa’s rehearsal of the classroom activity reconceptualized the role of students’ confusion. It was no longer an obstacle to instruction but a critical—and even desirable—component of it. Finally, the new approach was linked to a general principle about teaching. Principles were not equally distributed across all workgroups in Horn’s data. They had roots in well-articulated pedagogies like complex instruction and traveled across teachers through ongoing collaboration. In this way, principles supported a group identity through a linking of selves to a set of values: We are this kind of teacher because we believe all kids can learn, with this last phrase illustrating a principle of teaching. In Excerpt 2, the teachers and Lisa had prior conversations about the difference between covering content and teaching students. They knew, in an abstract sense, that coverage did not equal student learning. Just as Lisa encouraged the teachers to build on students’ authentic questions to develop understanding, she too built on the teachers’ authentic question about activity structures and seized the opportunity to help them reinterpret the issue of student confusion.

Principles in the analysis of Horn’s corpus provided teachers with an epistemic stance—a perspective on what could be known, how to know it, and why it was of value—that contributed to multiple levels of development in the practice of mathematics teaching. Principles often had their roots in broader systems of educational practice. For this group of teachers immersed in complex instruction, many of the teaching principles came from Elizabeth Cohen’s (1994) work.

1. At a microgenetic level, Betty visibly changed her understanding of teaching for understanding. Although she had previously demonstrated and articulated a commitment to student sense making, this value had not been integrated into every aspect of her practice.
As she and Claire deliberated on the lesson prior to the consultation, they viewed the students’ potential confusion as an obstacle toward this goal. After the conversation, she co-constructed the analysis of an alternative way to imagine the relation between the whole-class and small-group activity structures (Turns 14 and 15) linking the concept to her future teaching practice.

2. At an ontogenetic level, principles contributed to development by becoming tools for teacher identity—*I am a teacher who values and builds on student confusion*—while helping them bootstrap new practices (microgenesis serves the development of practices that value student confusion) by serving as resources for reinterpreting and reimagining classroom interactions. As a more experienced other in this instance, Lisa worked to discipline the perception (Stevens & Hall, 1998) of Betty and Claire, leading them to see how avoiding confusion, as a goal, conflicted with sense making. Practitioners and practice were clearly coevolving.

3. Sociogenesis in teaching is complicated to the extent that teaching practices are famously recalcitrant in the face of innovation (Cuban, 1993), with secondary mathematics considered the site of the least change (Stodolsky & Grossman, 2000). Unlike Hutchins’s (1995) navigation teams or the health science researchers studied by Hall, the schools Horn studied were not organized to support collaborative work, nor was there a well-distributed professional infrastructure for disseminating innovations. On the contrary, infrastructure was organized so that teachers regularly performed work that was redundant with that of their colleagues (such as individually planning lessons on similar topics or working alone to support a difficult student). Supports for sociogenesis—organizational capacities for noticing, borrowing, or extending conceptual practices—were missing or unevenly distributed (Cobb & McClain, 2006).

Despite restrictive conditions, evidence for sociogenesis in this case was present, if on a more modest scale than in the CRE innovation of Excerpt 1. As was described earlier, Lisa had taught in and headed a department that adopted complex instruction for secondary mathematics, developing a set of principles and practical routines fitted to that setting and curriculum (Boaler & Staples, 2008; Horn, 2005). In a new school, she brought those conceptual practices to her colleagues (the setting for Excerpt 2), much as Ted’s prior expertise with CRE traveled with him into the consultation with Alberto. Likewise, in Horn’s role as an educational researcher, she documented these teachers’ practices, yielding yet another representation of this form of teaching in a book for practitioners (Horn, 2012), seeking to spread these practices and related concepts still further. In this sense, consultants (Lisa and Ted, as well as Horn) acted as brokers, traveling across work settings to offer services in the development of new concepts, but also gathering materials that would support new developments further along their moving trajectory (Hall, Wright, & Wieckert, 2007; Kerosuo & Engeström, 2003).

**CONCEPTUAL CHANGE IN TWO DIFFERENT WORK PRACTICES**

We isolate the moments of consultation in our respective data sets as a way of comparing conceptual change in two different work practices. Our comparative analysis across our larger set
Conceptual Change Advances over Multiple Temporal and Social Scales

The cases in Excerpt 1 (Flu screening) and Excerpt 2 (Confusion is fabulous) illustrate similarities in multilevel processes of conceptual change at work. Earlier in her career, Lisa taught in and headed a department that adopted complex instruction for secondary mathematics, developing a set of principles and practical routines fitted to that setting and curriculum (Boaler & Staples, 2009; Horn, 2005). On moving to another school, she brought those conceptual practices to new colleagues (the setting for Excerpt 2), much as Ted’s prior expertise with CRE traveled into the consultation with Alberto (Excerpt 1). For teachers, principles associated with complex instruction (e.g., all students should grapple with challenging mathematics) were brought into consultation with the histories of participants (e.g., Lisa’s role as an early adopter and innovator) and fitted to particular, problematic examples of practice (e.g., concerns over students getting confused in group work). Concerted processes of animation (replays, elaborations, rehearsals) were used to assemble alternative ways of working in the classroom, and shared routines of teaching began to emerge over time.

Similarly in the case of Flu Screening, a new concept of counting came into the consultation along multiple biographical trajectories (e.g., Alberto, a relatively junior researcher, carrying others’ past publications; Ted, a senior statistician who had published on the CRE method), and alternative ways of working with the new concept were assembled in talk, both about actual and hypothetical data collected with children. Again, a shared routine for counting, using a variant of CRE that was fitted to the influenza-screening project, emerged over time.

Conceptual Change Relies on Mutual Understanding, So Representational Adequacy Matters

In productive consultations, people construct a shared understanding of problems at hand. They find ways to model work practices and then consider new ways of doing things. The adequacy of these models—what we view as representationality adequacy—is a locally negotiated judgment of sufficiency. In our cases, judgments about representational adequacy came out in interactions, depended on standard practices in the field, and depended on what clients and advisors believed was knowable and valuable in the practices under consideration. At the same time, representational adequacy was constrained by organizational resources such as funding for disease screening or time allocated for teacher collaboration.

Resources for and expectations of representations varied across our teaching and statistical cases, but they had one commonality: People and activities central to the problems at hand were
typically absent (e.g., hospitalized children being tested for influenza or confused student groups). These missing activities, people, conceptual entities, and their relations had to be conversationally or otherwise constituted.

In Hall’s statistical consulting and health sciences corpus, judgments of representational adequacy were more standardized, as representations often arrived at consultations as spreadsheet files or heavily annotated research articles. A weekly “biostatistics seminar” offered by a senior statistician best illustrated the conventions of representation in biomedical consulting. All researchers in the facility were invited, treated to a free lunch, and asked to hold up a flash drive with data if they wanted on-the-spot consulting. After selecting a walk-in client, a public consultation lasting the hour ensued, often with lively exchanges benefiting the selected “client” and other researchers. The standardized representations supported these spontaneous conversations and, in these conversations, were sometimes reassembled in ways that were genuinely novel. Alberto, for instance, did not simply bring published articles (adequate representations of knowledge for the field), he also reverse engineered published methods, and with critical assistance from Ted arrived at a more powerful, technical method of disease surveillance.

In teaching, consultation was not a typical form of work and standardized modes for representing problems of practice did not exist in the same way as the commonplace representations of journal articles and spreadsheets in statistical consulting. The individual interactions around representations such as lesson plans and student work became more critical in understanding problems. Discourse routines that excavated or imagined interactional details of classroom life supported the development of a shared understanding and were critical to the work of teaching consultations (Horn, 2010; Horn & Little, 2010).

**Negotiating Adequate Representations Provides for the Reification of New Concepts and Practices**

Representations were adequate in consultations to the extent they provided material for comparing, evaluating, and assembling new ways to work. In all of our cases, there were similar processes of animation and comparative assessment in talk between clients and consultants. Although these exchanges were interactive sites for assembling new ways of working, focusing only on conversation would hide dramatic differences in the scale and standardization of representational infrastructures across our cases.

In statistical consulting, reported speech played a supporting role in providing adequate representations of practice. In contrast, prior publications and clients’ in-progress efforts to borrow methods or findings from these publications (e.g., marginal annotations, reconstructions of method, identification of specific tests or instruments) served as adequate representations of research practice, both of work by other research groups and in the imagined future of the client’s group. Borrowing others’ methods and fitting them to the client’s current projects did not always proceed smoothly, and new practices were developed as the methods were repaired in the consultations.

In teaching, there is a dearth of technical language to represent and describe problems (Lortie, 1975/2002), and the nature of expertise is hotly contested. As suggested earlier, standards for representational adequacy varied across workgroups. Teachers posing problems might represent them with student work or lesson plans, but these were often supplemented with animations of
classroom talk—which also sometimes stood alone as representations of problems. Details of these animations revealed teachers’ conceptions of their work. Groups more adept at consulting (and using student thinking as the basis for instruction) more frequently represented teacher and student voices, whereas those who were newer to consulting (and student-centered forms of teaching) typically represented teacher or student voices, reflecting different ideas about what matters in understanding problems of teaching.

These stories provided material for comparing different approaches and routines of teaching. Suitably elaborated to get at contextual details, teachers and advisors generated alternative accounts of what to do next and differently. Unlike the outcomes of the statistical consulting, however, the new concepts and practices in teaching stayed, for the most part, close to their site of development. Stories, as a form of reification of concepts and practices, had little reach by comparison to methods sections of research articles, commercial software tools, and international professional networks.

Sociogenesis Follows the Circulation of Reified Concepts and Practices

The action in consulting meetings (talk, disagreements, alternative accounts of how to work) both drew from and circulated back into participants’ networks of practice. Conditions for these forms of conceptual change varied across the workplaces and were one of the most significant points of contrast.

In statistical consulting, statisticians participated in research projects as a condition of funding, information and software infrastructure was provided for clients and statisticians (including training in use), and highly valued products of consulting activity—peer reviewed journal publications and new informational objects (e.g., modeling software, shared data sets)—went rapidly into circulation at national and even international scales. In teaching consultations, in contrast, meeting and talking about practice was, itself, an innovation without widespread adoption or organizational resources provided in advance. Under these conditions, products of consulting activity went into circulation more slowly, if at all. This question of conditions points to relations between individuals, work groups, and surrounding organizations.

To illustrate from our two excerpts, Ted assisted in building a more powerful way to count children with influenza, producing computer code that was reused by Alberto and his group in subsequent studies, whereas Alberto and his research team completed a regional study of child influenza and argued for a new “gold standard” in disease screening systems. On the other hand, there was less infrastructure for travel in the teacher workgroups. Lisa may have gathered new, story-able examples of why “confusion is FABulous” to aid in the assembly of future replays, whereas the teachers moved forward in their collaborative effort to use complex instruction. Horn, as a researcher, collected vignettes to support a systematic description of the practice (Horn, 2012). Deeply knowledgeable coaches and educational researchers are not commonplace in schools, highlighting the more typical lack of resources for concepts to travel in these settings.

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4 We are not claiming that circulation of these objects at large scale involves no labor in distribution, simply that participants in statistical consultations assume the availability of these resources, which increasingly operate as invisible aspects of modeling infrastructure.
Differing Epistemic and Moral Stances Infuse Conceptual Change at Work

Locally negotiated standards for adequate representation were strongly linked to differences in epistemic and moral stance. During consultations, tensions around representational adequacy and the epistemic stance deployed by different participants were always in play and sometimes in conflict. Just as a teacher focused on effective teaching of mathematical procedures might be challenged by a stance on classroom talk as a medium to support students’ learning instead of simply conveying information, a research client might discover that their approaches to asking research questions, planning studies, or exploring data were substantively at odds with how a consulting statistician viewed that work. Values and ways of knowing rooted in practice, sometimes from different professional communities, persistently collided during consulting meetings.

In statistical consultations, variable epistemic and moral stances manifested as different expectations about publication review, ethical conduct of research, and proper statistical description and inference, particularly as people worked across disciplines. In the Flu case, Alberto’s understanding of CRE assumptions was tied to problems of recruiting feverish children in hospitals and scrutiny of resulting clinical records. Using screens that operated on different days threatened to erase these contingencies. For Ted as a methodologist, CRE was powerful because of this erasure and assumptions the clients did not fully understand. A part of the bridging work in the consultation involved aligning epistemic ideas about how to know alongside moral concerns with accurate diagnosis and care for suffering patients.

In teaching consultations, participants built locally negotiated standards for representational adequacy using epistemic and moral stances on how to know and pursue valued forms of practice. For instance, if teaching involved presenting ideas clearly, a univocal replay or rehearsal (one that represented teacher or student voices) sufficiently portrayed this work. On the other hand, if teaching involved building on student ideas, univocal animations were inadequate; instead, participants needed multivocal representations with student and teacher voices to represent that work. Likewise, a problem dispatched quickly using a thin representation might signal a stance on teaching knowledge as a collection of tips and tricks (“Those problems don’t work with some kinds of kids”). In contrast, drawing out additional details to elaborate a teaching problem might reflect a stance on teaching as a contingent practice, dependent on classroom context. Not surprisingly, in Horn’s analyses, workgroups more adept at consultations and related teaching practices spent significantly more time on drawing out and analyzing problems during their conversations.

Epistemic stance and related values also operated at different temporal and social scales. At the level of talk-in-interaction, epistemic stance was a joint accomplishment of speakers and hearers in consultations (an intersubjective and dynamic process, not just a subjective experience; see Kärkkäinen, 2006) and a production of speakers’ bodies in relation to the material and semiotic environment of working together (postural or facing formations between people and over surfaces teeming with texts, graphs, etc.; see Ciolek & Kendon, 1980; Goodwin, 2007). In some instances, colleagues quickly dispatched with problems they felt were well understood and easily solved. Alternatively, they asked for additional details (“Did this happen through the entire class period?” “Does having a fever change who gets screened?”) or proposed alternative interpretations, seeking grounds for other framings (“Do you think the kids lost it because the activity involved rubber bands?” “Will sponsors understand that under counting by multiple, independent screens is better than counting with a single screen?”).
Locally negotiated standards for representational adequacy were tightly linked to epistemic stances on work but, as described earlier, variably supported by surrounding organizational arrangements. Representational practices and epistemic stances infused local scenes of consulting but also operated at the level of organizations and professional communities. Following Knorr Cetina (2004), teaching, research on teaching, health sciences research, and statistics cohered as epistemic cultures operating “different machineries of knowing” (p. 67)—distinctive ways of seeing phenomena in the professional domain of scrutiny, comparing and evaluating accounts of these phenomena, and assembling new ways of working with them. This epistemic machinery concerned not just the what of professional interest (e.g., children “marked” with a diagnosis of influenza, types of student confusion with mathematical concepts) but also the how of seeing or finding these things, comparing them, and making consequential decisions about what to do with them, next. In health sciences research, practices like peer review and the standardization of methods settled questions about epistemics, whereas constraints like limited grant monies and moral obligations could open up questions of adequacy anew. In teaching, the orientation toward lesson planning and limited time for collegial exchange underresourced and cast as counternormative the very practice of consulting, whereas the moral imperative to better serve children pushed teachers to persist despite these institutional pressures. As illustrated across these cases, differences in epistemic stance and associated values involved meanings that extended well beyond consulting conversations.

THEORETICAL AND PRACTICAL IMPLICATIONS

We started with Hughes’s (1971/2009) advice to compare different forms of work, in hopes of further developing a grounded theory of conceptual change at work. We asked how concepts that organize work change in talk that is produced during efforts by participants to work differently, now and in the future. Our analysis compared structures of talk, representations of practice, and epistemic stances deployed when work groups in clinical health sciences and secondary mathematics teaching sought to improve their work on their own and in consultation with experts.

Theoretically, our analysis contributes to an understanding of how concepts are developed and distributed in workplaces. We found that consultations, which bring together people with different perspectives and expertise, are productive places to investigate this phenomenon. By comparing two different forms of work, we see the interactional supports for identifying, elaborating, and stabilizing relatively small-scale innovations in how people worked together. These supports included comparisons over representations of practice that borrowed and extended methods or principles, taking and shifting epistemic stances toward what could be known about shared work, and provisions in surrounding organizations that supported (or inhibited) the circulation of new concepts across work groups. Similar interactive processes in workplace consultations had widely varying consequences, largely because of differences in the scale, standardization, and distribution of resources for representing and changing work practice, rather than in personal qualities of teachers, researchers, or statisticians as individual thinkers. At the broadest level, our approach provides an alternative to the view that concepts (i.e., of expert statistical modeling or mathematics teaching) are already “out there” in substance and that local work groups learn simply by
complying with these concepts as ideal types. Instead, we argue and show empirically that concepts must be brought to life in local work practices, conceptual change suspends reproductive aspects of learning to open up possibilities for new concepts and meanings, and what is general about a concept depends substantively on processes of local assembly and circulation.

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. From a perspective on sociogenesis, the organization of teachers’ work tends more toward inhibition than support for the circulation of innovative teaching practices. Not surprisingly, innovations in teaching often collapse after a few years of intense effort, and the profession tends toward conservatism (Cuban, 1993; Lortie, 1975/2002). Organizational supports for representing practice and for suspending production to consider working differently were much more extensive in health sciences research and statistics, even including organizational policies that brought practitioners together as a design enterprise. At the same time, whereas the scientific method is often touted as a rational form of knowledge production based on certain epistemic stances, our analysis reveals common forms of interactional work and a deeply moral dimension that comes into play as participants negotiate the allocation of resources and concerns for representational adequacy.

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