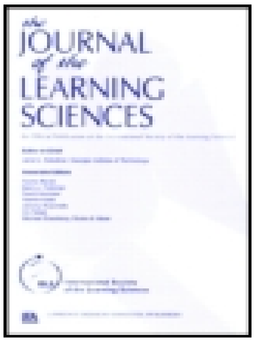

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REPORTS AND REFLECTIONS

Infrastructuring as a Practice of Design-Based Research for Supporting and Studying Equitable Implementation and Sustainability of Innovations

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This essay presents infrastructuring as a useful construct for guiding efforts to support more equitable implementation and sustainability of resources developed to support student learning in design-based research. *Infrastructuring* refers to activities that aim to redesign components, relations, and routines of schools and districts that influence what takes place in classrooms. It can take place within ongoing, long-term research–practice partnerships, where teams can follow the contours of problems that arise from introducing innovations into classrooms, particularly as they relate to equity of implementation of those innovations. When we support and study infrastructuring in partnership with educators, we can create improvements to educational systems that last.

In the late 1990s, the anthropologist Susan Leigh Star was studying a distributed community of biologists sequencing genomes of a nematode. She had partnered with an information systems developer to ensure that a new system for electronic data sharing the biologists were trying out was meeting the needs of the scientists. Many scientists told her over the phone that they were users of the system, and they agreed to in-person interviews with her about how they used the system to support their

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work. When she visited their laboratories, however, most scientists could not describe how it fit into the flow of the work or even show her where they had installed the system. It was not, in fact, a tool that any of the biologists considered an essential resource for their work. As Star (2010) would later write, "The users liked the interface when they were sat in front of it. Yet, they did not know how to *make a reliable working infrastructure* out of it" (p. 610, emphasis added).

Star's observations are likely to sound all too familiar to the many learning scientists who have designed social and technical infrastructures to promote collaborative learning in classrooms and out-of-school settings. Although students and teachers may tell us that our innovations are both appealing and compelling, many educators are unable to "make a reliable working infrastructure" of our innovations that they can use without our prodding and support. We are good at creating hothouse conditions in which our innovations can grow and flourish for a while but not as good at creating innovations that can be sustained on their own (Fishman, Marx, Blumenfeld, Krajcik, & Soloway, 2004; Kolodner, 2012). When innovations are sustained, it often within schools that have more resources and that have fewer racially minoritized students (Anderson et al., 2018; Fishman, Penuel, Hegedus, & Roschelle, 2011). Improving the sustainability of innovations in ways that disrupt the reproduction of inequality of educational opportunity is a central problem for design-based researchers to address. To address this problem, we as a field need to develop theory that can help us understand implementation, scale, and productive interactions between research and practice (McKenney, 2018).

In this essay, I argue that the concept of infrastructuring can provide practical guidance for design researchers to develop knowledge and theory about the configurations of conditions needed to support and sustain educators' equitable implementation of innovations. As in other forms of design research, in infrastructuring, design involves the creation of tools for the improvement of practice and for theory development and knowledge building (Edelson, 2002). As the name *infrastructuring* implies, the focus of design efforts is on creating conditions that support educators in making innovations into working infrastructures for organizing learning activities.

When we study how resources for infrastructuring are taken up, and where and when, we develop theory and knowledge related to how innovations can be implemented equitably across an educational system and sustained over time—both with and without the direct support of researchers. In addition, the tools we design to support implementation can be useful to educators in other places and contribute to our knowledge base about learning.

To illustrate the potential value of infrastructuring as a name for a certain kind of design activity, I offer a first-person account of the experiences of a design team composed of learning scientists from the University of Colorado Boulder and Northwestern University who are working in partnership with educators from Denver Public Schools to develop new science curriculum materials for high school biology that seek to embody the vision for equitable science teaching and learning outlined in *A Framework for K-12 Science Education* (National Research Council, 2012). I describe some of our infrastructuring efforts to support teachers in using these materials to support students in racially and linguistically diverse classrooms. The materials are intended to help students gain a grasp of how to use science and engineering practices to explain phenomena that students find interesting and solve problems students perceive as relevant to themselves and their communities. I also describe what we are trying to learn from these efforts, as well as our methods for studying them, to illustrate how such efforts can contribute to the knowledge base of the learning sciences while also building capacity for engaging in equity-focused change efforts in complex school systems.

(RE)DESIGNING A WORKING INFRASTRUCTURE FOR AN INNOVATION IN SCHOOLS

According to Star and Ruhleder (1996, p. 113, italics in the original), infrastructure is a relational concept; that is, something can be an infrastructure only in relation to a particular set of work practices. They write,

> Within a given cultural context, the cook considers the water system a piece of working infrastructure integral to making dinner; for the city planner, it becomes a variable in a complex equation. Thus we ask, *when*—not *what*—is an infrastructure.

Teachers are a little like the cook in Star and Ruhleder's example in that they draw on resources made available through an infrastructure that others have designed (e.g., a system for selecting and distributing materials), and they acquire and make use of recipes (e.g., curriculum materials, lesson plans) that are essential to guiding their work with students. When the infrastructure breaks down or when teachers encounter a situation in which the recipes cannot support them, the components of the infrastructure and their relations become visible. An opportunity for repairing the infrastructure presents itself and can become an object of design and study.

Of course, if we want to answer the question of "when is infrastructure" for a teacher in a classroom, we can benefit from a set of theoretical concepts for characterizing the relations between educational infrastructures and specific teaching practices. We also need such concepts to help guide the process of redesigning infrastructures, to help us identify potential leverage points for change. The term *redesign* here is more appropriate than *design*, because infrastructuring efforts must always wrestle with what is already there in place in systems—that is, existing infrastructures and practices that are products of past design efforts and that persist in their influence on practice (Bowker & Star, 1999). And we need to be prepared for changes from redesign to take time to emerge because of the multiple local actors who must negotiate how new infrastructures will be integrated with or require changes to existing infrastructures and practices (Star & Ruhleder, 1996). Change efforts tend to be focused and incremental within layered infrastructures that comprise large school systems, even if they ultimately result in transformational shifts in systems (Bowker & Star, 2001).

For ideas about infrastructure, we can turn to our colleagues in education who study local policymaking and implementation in complex education systems, who have recently been developing theory and knowledge related to relations between infrastructure and work practice in educational systems. In particular, Hopkins, Spillane, and colleagues' (Hopkins & Spillane, 2015; Hopkins, Spillane, Jakopovic, & Heaton, 2013; Hopkins & Woulfin, 2015; Spillane & Hopkins, 2015) framework for studying instructional guidance infrastructures can help us analyze educational change efforts across a range of contexts and levels of systems. Such a framework can offer learning scientists a theory that can begin to "do real design work in generating, selecting and validating design alternatives" (diSessa & Cobb, 2004, p. 77) for transforming learning in educational systems. After presenting this framework, I describe how theories and findings from implementation research helped our research–practice partnership generate and select design alternatives for supporting new curriculum implementation and informed our research on how to support equitable enactment of a novel approach to teaching science.

Components of Educational Infrastructures and Their Relations

Though the functioning of any medium-size or large educational system consists of so many interconnected components that it would be impossible to map them, a smaller number have a direct influence on what teachers do in the classroom and on what and how students learn in those classrooms. Moreover, the key components of contemporary instructional guidance infrastructures are found across many states and districts. These components include

- standards for student learning;
- curriculum materials;
- student assessments;
- teacher professional development;
- instructional techniques and routines (e.g., for promoting productive talk in classrooms);

- building- and district-level policies (e.g., regarding the posting of standards, submission of lesson plans that follow a particular format);
- school schedules that allocate instructional time for different subjects;
- roles and positions focused on instructional support (e.g., coaches);
- organizational routines, such as grade-level meetings, in which instruction is a focus; and
- personnel evaluation systems, including the forms of evidence that contribute to assessment of a teacher's performance (Cohen, Peurach, Glazer, Gates, & Goldin, 2013; Hopkins & Spillane, 2015; Peurach & Neumerski, 2015; Smith & O'Day, 1991; Spillane, Parise, & Sherer, 2011; Woulfin, 2015).

It takes coordinated activity—across organizations and levels of an educational system—to bring these different components into being and into relation with one another, that is, to make them into a working infrastructure for teaching. Some forms of activity that policy researchers have identified include sensegiving (Gioia & Chittipeddi, 1991) by leaders to help teachers navigate the multitude of conflicting messages that teachers face every day about what and how to teach (Coburn & Woulfin, 2012). Teachers use routines such as grade-level and department meetings to engage in collective sensemaking with colleagues to negotiate how to enact policy guidance given to them by leaders in their school or central office (Coburn, 2001; Spillane et al., 2011). Leaders in larger districts also design and lead targeted professional development sessions to help teachers make a working infrastructure of district-led or external initiatives (Johnson, Severance, Penuel, & Leary, 2016). Schools and districts also often convene groups and reorganize systems that are focused on increasing the coherence of the existing infrastructure (Elmore & Burney, 1997; Kirp, 2013).

How Redesign Can Reveal and Bring About Conditions for Making a Working Infrastructure for Teaching

External research partners can join in and also shape endeavors districts undertake to help create a working infrastructure for teachers to undertake significant changes to practice or implement an innovation. Many of these endeavors are ones in which education leaders already turn to research and researchers for guidance, and having a research partner who is willing and available to help can support leaders in making decisions that are meaningfully informed by research evidence (Henrick, Jackson, Henrick, & Smith, 2018; Penuel, Farrell, Allen, Toyama, & Coburn, 2018). As learning scientists, we too can develop new knowledge from participating in infrastructuring efforts, just as we develop knowledge when we design new social and technical infrastructures for classrooms (Edelson, 2002). This is so because, as Hopkins and Woulfin (2015) wrote, "rather than serving as fixed scaffolds or supports that fade into the background, infrastructures emerge only when they are built up, tinkered with, and leaned on in teaching and leadership practice" (pp. 375–376).

Of course, to participate in infrastructure redesign, we have to be invited to do so by those with the authority to shape infrastructural components, and this is likely only possible in the context of a relatively mature research–practice partnership, that is, a long-term, ongoing, and equitable collaboration between researchers and educators that is focused on addressing persistent problems of practice (Coburn & Penuel, 2016; Coburn, Penuel, & Geil, 2013). In such partnerships, it is common that the search for and testing of solutions to address those problems tends to reveal new conditions that turn out to be important for solving the problem at hand but that were not apparent at first. In such cases, researchers can and often do follow the contours of these problems in their research and design activities, which leads to new insights into conditions needed to support learning in large educational systems (Donovan & Snow, 2018).

When we as researchers participate in infrastructuring work within a partnership, we have to remember that infrastructuring aims at much more than sustaining any single innovation. Leaders' motivations for inviting research partners to help with infrastructuring are likely to reflect typical goals for infrastructure redesign that already are present in educational systems. These include strengthening capabilities of people and the system as a whole (Bryk, Gomez, Grunow, & LeMahieu, 2015; Hopkins et al., 2013; Hopkins & Woulfin, 2015); supporting greater instructional coherence (Forman, Stosich, & Bocala, 2017); tightening the coupling between local policies and practice (Woulfin, 2015); and challenging practices in classrooms, schools, and districts that reproduce inequities of opportunity for specific groups of students (Hopkins & Woulfin, 2015). To be relevant to practice, then, researchers need to consider how their interest in discovering conditions for sustaining a particular innovation can serve their partners' larger goals of building capacity, increasing coherence, and promoting equity at the system level.

To date, some of the best examples of how infrastructuring can reveal and bring about conditions for making a working infrastructure for teaching come from stories of successful district reform that did not involve partnerships with researchers. Kirp (2013) described the efforts of leaders in Union City, New Jersey, to turn around the district's schools, which were disproportionately failing Latinx students. As many leaders do, the superintendent prioritized literacy goals. However, he did not focus narrowly on curriculum or on test preparation. Instead, the district pursued a strategy of coordinating supports for literacy on the district's youngest children, particularly those students for whom

English was a second language, embracing both a new instructional approach (bilingual education) and a different approach to engaging parents in their native languages. The district invested in coaches whose work focused on supporting the new instructional approaches, as well as technologies to enable students to write, edit, and produce multimedia reports. Gradually and steadily test scores improved significantly within the district, and researchers who studied the reforms revealed the power of combining focus, coordination, and teacher and parent involvement in producing these gains (Chang et al., 1998; Kirp, 2013). It could be argued that each of these elements might have been anticipated by a careful review of research on effective schools; however, infrastructuring revealed how particular coherence-making actions of a leader to redesign the district infrastructure could produce significant system improvements at the scale of the district.

Other examples of infrastructuring involve research teams designing and bringing instructional guidance supports to schools and districts without necessarily redesigning district infrastructure at all. One example comes from Success for All, an intervention that has shown through effectiveness studies to be a powerful, reliable way of improving achievement on standardized tests (Borman et al., 2007). For example, Peurach and Neumerski (2015) highlighted the essential role that the Success for All Foundation has played in supporting implementation by bringing different instructional guidance infrastructures to districts, such as mechanisms to support school-to-school collaboration, structured professional development and coaching, and supports for educational leaders learning about and monitoring implementation. Another example comes from Anderson et al. (2018), who supported teachers in multiple distributed networks to implement new curriculum materials in science by creating and directly making available to teachers coordinated instructional guidance in the form of professional development and a system of assessments for monitoring student learning. Both of these examples represent efforts by external partners to replace existing infrastructures rather than redesign existing ones. In this essay, I take up the question of what we can learn from studying infrastructure redesign within a research–practice partnership in which external partners are engaged over the long term in work to support change throughout a school district.

INFRASTRUCTURING ACTIVITIES IN THE INQUIRY HUB RESEARCH–PRACTICE PARTNERSHIP

In this section, I describe infrastructuring that initially aimed to support equitable implementation of curriculum materials in high schools but transformed into an effort focused on creating more inclusive classroom cultures across a school district. The work has taken place within an ongoing, 11-year research–practice partnership between the University of Colorado Boulder and Denver Public Schools. The infrastructuring described here involves other partners in the community and at other universities and nonprofit research centers (most notably Northwestern University and BSCS Science Learning). The initial problem we set out to address was to enhance the district's capacity to implement the Next Generation Science Standards, a set of standards that are based on the vision for equitable science teaching and learning laid out in the National Research Council's (2012) consensus report *A Framework for K-12 Science Education*. As a first line of work toward accomplishing this aim, we developed new curriculum materials for high school biology. Those curriculum materials provide supports for teachers to engage their students in science and engineering practices to explain phenomena and solve problems that connect directly to students' interests and identities. Details about the curriculum units and the collaborative design process used to develop and test them are presented elsewhere (Penuel et al., 2018; Severance, Penuel, Sumner, & Leary, 2016).

The particular infrastructuring effort I describe here had its genesis in the first year of this line of work within the partnership, when a teacher received a low rating from a peer observer who visited their classroom. The teacher who received the low rating contacted the researcher about it; they felt that the rating was unfair, particularly with respect to the low ratings given for planning and for rigor. The lesson had not gone as planned, and the teacher struggled to accomplish the objectives set out in the lesson. We were concerned, because we knew that the observation was an enactment of an organizational routine of the Leading Effective Academic Practice (LEAP) system, a system for evaluating and providing feedback to teachers that relies on a set of trained observers who are teacher leaders and administrators and who conduct classroom visits and rate teaching practice on a core set of dimensions. As a research team attuned to the importance of infrastructure, we treated this observation as an early warning of bigger challenges to come, as a site where the iterative testing and refinement was going to regularly push up against an infrastructure and potentially create a barrier to widespread implementation of our curriculum materials. We could not create a buffer for teachers from these evaluations either: Our district partners insisted that we engage with the system and its processes rather than attempt to interfere with it. If we did create such a buffer, moreover, we would only be creating a potential problem for sustaining implementation over the long haul.

In order to support our teachers implementing initial versions of curriculum materials, we began by creating resources for linking the LEAP framework dimensions to what an observer should expect to see in an Inquiry Hub classroom, which we provided to observers and teachers alike. These were intended to guide observers' and teachers' sensemaking about—that is, give sense to (cf. Coburn & Woulfin, 2012)—how our materials related to the LEAP framework. Initially to support this aim we created a simple crosswalk tool showing links between the images of equitable teaching and learning presented in *A Framework for K-12 Science Education* (National Research Council, 2012) and the LEAP expectations that could be used by teachers to help explain the rationale behind their teaching moves to different observers visiting their classrooms, particularly their LEAP evaluators. For example, we emphasized how opportunities for student discussion and collaboration in building models using tools like NetLogo aligned with a key dimension of the LEAP framework related to instruction called "Promotes Students' Communication and Collaboration Using Digital Tools and Other Resources."

We also created a 2-page guide relating to how to present a daily lesson objective by focusing on how students would use science and engineering practices and crosscutting concepts of science to figure out disciplinary core ideas rather than defining the day's objectives in such a way as to give away what students would be figuring out (Penuel, Novak, McGill, Van Horne, & Reiser, 2017).

Simply sharing these resources did not prove sufficient to address the need for greater coherence with the district protocol, as was evident by continued challenges with their observers faced by teachers. So we set about to create a routine involving the district secondary science coordinator, in which he repurposed regular visits to classrooms to use a more formal observation protocol that we created that matched our own instructional model. He used the protocol in conjunction with a coaching routine adapted from the district's own LEAP coaching protocol to support teachers in making shifts in practice to allow students to have a greater say in the direction of the day's lesson, as called for in the curriculum materials. His observations were low stakes in comparison to the LEAP observations, but they nonetheless had some effect on teachers, who through feedback from these observations came to appreciate the value of creating and updating a public record of student questions for their teaching.

Through these observations and through the use of another instrument we had created for eliciting student experiences of Inquiry Hub classrooms, we discovered significant disparities across classrooms with respect to student experiences. In a handful of classrooms, students were excited and engaged and could see the connection between the day's lesson and the phenomenon that the class was trying to explain or the design challenge the class was trying to meet (Penuel, Van Horne, Severance, Quigley, & Sumner, 2016). But in many others, teachers had not adjusted their practice to reflect the new approach to science teaching and learning the curriculum materials sought to support. In observations, when asked why they were doing what they were doing that day, students would respond, “Because it is today’s lesson,” or “We are learning about photosynthesis,” instead of describing how the lesson’s activities were helping the class make progress on questions they had set out to answer related to an anchoring phenomenon. In other words, students were doing the lesson rather than doing science (cf. Jimenez-Alexandre, Rodriguez, & Duschl, 2000). Also, when we observed classrooms, we found that some teachers were struggling to build strong relationships with their students, focusing on content delivery in ways that minimized opportunities for students to make meaningful contributions to classroom activities grounded in their own interests, experiences, and identities. The initial problem we as a partnership had set out to solve had transformed into something different, and we conjectured that to reduce variability in the quality of student experience across classrooms, we would need to devote more attention to what was happening in classrooms.

Although learning scientists who study problem- and project-based science classrooms have documented similar issues faced by teachers (Fogleman, McNeill, & Krajcik, 2011; McNeill & Krajcik, 2008), our partnership enabled us to act on knowledge of these issues to address them as they arose. Because we were part of an ongoing research–practice partnership, we were able to pursue a solution to what had become a problem that both district leaders and researchers felt was important to address. We had an ongoing commitment to solve such problems in collaboration with the district. To inform the design of solutions to those problems, we used findings about implementation variation formatively to adjust the guidance we provided teachers. When our attempts to adjust this guidance did not yield the desired result and revealed additional challenges, we were able to change course again.

What happened at this point was a major shift in focus in which we recentered our efforts as a partnership away from curriculum design to focusing on transforming the student experience of classrooms. We developed an aim statement that reflected our equity commitments. Our aim statement emphasized the need to create inclusive classroom cultures in which the level of perceived coherence, interest, sense of belonging, and contribution to community could not be predicted by knowing a student’s race, gender, and home language. For us, naming the student experience was important, because we wanted to hold ourselves and teachers accountable to the goal of students gaining a sense of how science and engineering practices might be useful in investigating phenomena they were interested in and in solving problems relevant to them and their communities. Naming race, gender, and home language dovetailed with broader district and partnership concerns relating to the experience of African American and immigrant students, as well as girls, in science classrooms.

In addition, we developed several new infrastructuring strategies to tighten the coupling between policy guidance to teachers and classroom practice and to disrupt inequitable practices that contribute to some groups of students experiencing classrooms as less welcoming and inclusive. First, we identified and began working with a community partner that had been working closely with the district on creating more culturally responsive and inclusive classrooms. Second, we decided to stop simply trying to defend teachers who received poor evaluations on the LEAP and instead moved to create new supports that could help observers and teachers see connections between the LEAP and the intentions of our curriculum. Accordingly, we took the step of developing a professional learning pathway for teachers across the district to develop a positive classroom culture and climate in their classrooms, a dimension of the LEAP framework that our new community partner had helped the district develop. This pathway leveraged the existing resources of another new partner, the developers of the Next Generation Exemplar System (Reiser et al., 2017). As part of a week-long workshop, a group of 50 teachers from across all grade levels throughout the district learned new strategies for creating dialogic classrooms in which student voices can be heard and students partner with the teacher to set the direction for each day's lesson in phenomenon-based units. Finally, we sought to strengthen supports for teachers to meet the LEAP expectation that they use knowledge of students' interests and culture to promote equity and plan instruction by supporting teachers' use of the practical measure of student experience we had developed and by working with a team of youth to develop a bank of design challenges to accompany our curriculum units that would relate the science they were learning to matters of concern to youth and their communities.

These new lines of work are still under way, but some have already led to the development of new knowledge related to how students experience phenomenon-based teaching in science classrooms. For example, research to develop validity evidence for our measures of student experience has helped us to identify distinctions students make about when curriculum is relevant to themselves and their communities and helped us identify aspects of student experience that predict subsequent student learning outcomes (Penuel, Van Horne, Jacobs, & Turner, 2018). Our colleagues and partners at Northwestern University have made use of this measure to explore relationships among students' sense of epistemic agency, feelings of excitement, and identification with science (Zivic et al., 2018). Their research has found that when students perceive that the day's lesson is personally relevant to them, they are also more likely to feel like a scientist that day. These examples illustrate how this line of infrastructuring is contributing to our understanding of how to support a particular form of personally and culturally relevant science learning. In addition, this line of infrastructuring is helping us add to emerging lines of learning sciences research on affect and science learning (Jaber & Hammer, 2016) and on how to develop practice-linked identities within disciplinary learning opportunities as a strategy for promoting equity (Nasir & Hand, 2008; Tzou & Bell, 2010).

Important for the district is that this work has laid the groundwork for the sustainability of our joint work in several respects. First, it has developed a cadre of leaders inside and outside the classroom who can recognize and support teachers in creating more inclusive cultures. Second, the reach of the project has expanded to many more schools and grade levels of science, thereby expanding students' opportunities to be exposed to new materials and ways of teaching. Third, the work has led to the creation of new tools for monitoring and supporting equity in the district's science classrooms in ways that support, rather than come into conflict with, existing systems of teacher evaluation.

WHAT'S NEW AND WHAT'S NOT ABOUT INFRASTRUCTURING AS A FOCUS OF DESIGN RESEARCH

The infrastructuring activities of our partnership represent a novel direction for learning sciences research to pursue toward the aim of promoting equitable, sustainable innovations in three key respects. The work has unfolded within a long-term research–practice partnership in which lines of research emerge from problems that arise in implementation and new, often more ambitious goals for improving learning. This stands in contrast to design research that develops and tests an innovation with no plan for how to support its implementation after the research ends. Moreover, the work has focused on the redesign of and coupling of innovations with the existing educational infrastructure of large systems. Instead of attempting to create a portable package of materials and guidance for teachers, infrastructuring involves a kind of mangling of innovations within varied educational contexts. Some of the mangling is a consequence of implementers' sensemaking and adaptations of materials, a kind of mangling that policy research in education has documented (e.g., Coburn, 2001). But in the context of our work, researchers working with district leaders purposefully modify our own materials to fit better within the existing infrastructures, to ensure the materials' viability in the context while attempting to preserve the integrity of the principles that underlie their development.

At the same time, we do not just seek to fit within existing contexts; rather, infrastructuring directly addresses the need for redesigned infrastructural components that can support the broader aims that innovations are intended to support. Many learning sciences innovations would be difficult to sustain and scale if we did not develop new infrastructural components or redesign old ones to support them. This does not mean that they are not worth pursuing, because they cannot work within the conditions that typically obtain in contemporary schools and districts. Often schools that are underresourced—particularly those with high concentrations of students from nondominant communities and from low-income communities—are the sites where implementation integrity is most challenging to achieve (Anderson et al., 2018). Therefore, to promote equitable implementation, it is necessary to adopt a more proactive stance toward infrastructure redesign, allocating more and targeted resources to schools and teachers than might be provided to schools with more privileged students.

Also new is the idea of learning about systems by directly pushing up against them and learning how and when they push back. As our work to develop resources for teachers who were being judged by nonscience observers illustrates, infrastructuring does not always succeed, and through failures we can generate new knowledge about the conditions needed to support learning and for teachers to sustain implementation of an innovation. As an example, the study of Success for All by Peurach and Neumerski (2015) described earlier called out the importance of the temporal dimension of infrastructuring: The researchers noted that it took a minimum of 4 years for the kinds of instructional guidance infrastructures to emerge that were required for implementing the intervention schoolwide. Our struggles with the LEAP point to the need to attend to how infrastructure intersects with daily practice in a cyclical manner. LEAP observations occur on a regular cycle, and when they occur, the dimensions of the protocol and what observers see in classrooms have a heightened influence on teacher practice. Through related work to help redesign science assessments, what has repeatedly challenged us is being able to attend to and align our workflow with regularly scheduled cycles of redesign of these assessments. Thus, our observations lead us to conclude that it is not enough to study and support the long-term development of infrastructures; we must also be aware of the multiple cycles that shape when infrastructures become salient for classroom practice.

An important caution is that research–practice partnerships such as ours require extensive effort to maintain, and infrastructuring efforts can require sudden bursts of activity that are not easy to anticipate. The level of synchronization needed between the timelines of researchers and decision-making cycles of practice is extraordinarily high in such circumstances (cf. Farrell et al., 2018). It is not likely that all learning sciences teams will have the inclination or capacity to support the redesign of instructional guidance infrastructures of a district partner, but we can learn from infrastructuring efforts of those research-practice partnerships who do engage in them. As noted above, infrastructuring efforts in particular settings can help us develop or refine theory related to conditions related to scale and sustainability. These conditions might be created by researchers working in partnership with leaders in other districts, or they might be created by district leaders such as those who led reforms in Union City, New Jersey. No matter who leads the effort, though, the work of crafting coherent and equitable instructional guidance infrastructures is likely to be characterized by both intensity and uncertainty.

In addition to producing usable knowledge for other researchers and education leaders, intensely localized efforts to produce viable curricula and support their implementation can yield practical tools for improving practice that others outside the partnership find useful. For example, a 2-page guide we developed to support teachers struggling with how to present learning objectives to students in a way that was consistent with the curriculum's intent and that met requirements of the LEAP has been downloaded several thousand times from the STEM Teaching Tools (http://stemteachingtools.org) website. Other resources our partnership has created as part of our infrastructuring efforts—related to assessment design and to selecting anchoring phenomena for units aligned with the Next Generation Science Standards—have also been popular on this site.

I conclude with a reflection about how infrastructuring represents continuity with traditions of design-based research in the learning sciences. At some level, what we are doing in our partnership is just attempting to adhere to a principle that Brown (1992) named more than two decades ago when she provided a definition and scope for design-based research. She argued that design researchers should follow the "Reality Principle," by which she meant that design researchers must "consider dissemination issues" and that it was "not sufficient to argue that a reasonable endpoint is an existence proof" for how to support a new form of learning (Brown, 1992, p. 171). In her own work, she embodied this principle by describing differences between the kinds of innovations that she thought teachers could implement and sustain on their own. She observed that reciprocal teaching, a powerful strategy for supporting reading comprehension she had developed with a colleague (Palincsar & Brown, 1984), had spread widely and fit easily within the existing infrastructures of schools. She worried that one innovation central to fostering equity of participation within communities of learners, complex instruction, was not scalable:

> The prognosis for the widespread dissemination of communities of learning is pessimistic. The desired participant structures of this program … would require fundamental changes in the roles of both students and teachers, disrupting

> "practice as usual," and we know that historically teachers have been resistant to such disruptions. (Brown, 1992, p. 172)

She admitted, too, that she "needed to know a great deal more about school restructuring, teacher training and support … the sociology of dissemination … public policy, and so forth" (Brown, 1992, p. 173) that her own preparation as a psychologist had not provided her in order to theorize and support communities of learners.

What Brown and her colleagues needed to support complex instruction at scale was something akin to infrastructuring, a set of conceptual tools and practices for engaging the systems that made complex instruction difficult for teachers to implement. It is important to note that infrastructuring efforts do not need to succeed for us to learn from them and to generate knowledge that can benefit others. We should remember that it is through documenting the failure of our designs that we often learn and contribute knowledge that is of benefit to others (O'Neill, 2012, 2016). Such failures allow us to see the limits of designs as well as to appreciate the contingency of efforts to scale and sustain new designs in real contexts (Cole & Packer, 2016). We would do well to focus more effort on promoting sustainable, equitable changes to education, even if we are met with complex political, technical, and social challenges throughout our work.

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