Infrastructuring As a Practice for Promoting Transformation and Equity in Design-Based Implementation Research

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Educational design research aims for big transformations to current educational practice, not small ones. We seek not just to develop better tools to meet current goals and standards for student learning. Design studies are, as Cobb and colleagues (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003) argue, "test-beds for innovation," in which the purpose "is to investigate new possibilities for educational improvement by bringing about new forms of learning in order to study them" (p. 10). Design studies require a certain "measure of control" over the educational setting to bring about new possibilities to study, since the forms of learning that are the focus of design research are unlikely to be observed in a naturalistic study. To the extent that design studies are successful, some argue, the practices we develop in controlled settings "become images that drive the reorganization of schooling in fundamental ways" (Shaffer & Squire, 2006, p. 691).

To date, there are only a few arenas where the forms of learning that design studies have provided images that have had a broad influence on policy and practice. New educational standards in the United States are a good case in point, where the concepts of learning trajectories and learning progressions have found their way into policy documents and conversations among educational leaders (McDonnell & Weatherford, 2013; Penuel & Spillane, 2014). But standards alone are insufficient guides for the improvement of practice (Sadler, 2014), and designing coherent sequences of instruction that build on and progressively develop student thinking implies different approaches to the design of curriculum materials and courses of study than are typical in today's schools (Lehrer & Schauble, 2015). We might take hope that design studies can and have influenced the design and development of technology platforms that reach large numbers of students directly through the internet (e.g., Koedinger, McLaughlin, & Heffernan, 2010; U.S. Department of Education, 2013), but students' opportunities to learn from these opportunities will still be mediated by teachers and constrained by how schools organize access to technology (Murphy, Gallagher, Krumm, Mislevy, & Hafter, 2014).

Today I want to outline an approach to design research that embraces a commitment to organizing and studying new forms of learning and that adopts a stance of hope and possibility for the transformation of educational practice. This approach is likely to require us to give up, however, the notion that we can gain a "measure of control" over the educational systems we seek to influence and adopt a collaborative stance toward the improvement of practice. In addition, it will require us to engage directly with the very systems we decry today as incoherent and inequitable, targeting our design efforts more directly to promote coherence and equity and to help local actors engage in the work of transformation through coordinated, collaborative activity.

My colleagues and I call this approach "Design-Based Implementation Research" (DBIR; Fishman, Penuel, Allen, & Cheng, 2013; Penuel, Fishman, Cheng, & Sabelli, 2011), because it blends the interventionist stance of design research with the focus of implementation research on how and when local actors transform policies and practices through their enactment of them. Its aim is not just to study how and when efforts to organize new forms of learning do work, but rather how to make them work equitably under a wide range of conditions (Bryk, 2009). A commitment to collaborative, iterative design is a key feature of DBIR, and as I elaborate today, this commitment is rooted in the same goals of equity and systems transformation that animate the Scandinavian tradition of participatory design of sociotechnical systems. I will draw particular attention to how the ideas of *infrastructure* and *infrastructuring* from that tradition can help us understand what is distinctive about DBIR as an approach to educational design research that aims for broad and equitable implementation of new visions for teaching and learning.

I will illustrate how these ideas are useful for interpreting collaborative design activities within a research-practice partnership called the Inquiry Hub, of which I am a part. At one level, the Inquiry Hub is a design project with external funding from both the National Science Foundation and the Gordon and Betty Moore Foundation, with some specific design and research goals to which we hold ourselves accountable. But if you want to understand how the Inquiry Hub really functions as an example of DBIR inside a research-practice partnership, *infrastructuring* is a far better name for how we go about our design work. As the term implies, infrastructuring focuses on building a foundation for change, attending to who and what is already there, while seeking to build networks that can take on the difficult work of making significant and broad changes to educational practice.

Commitments and Concepts of Participatory Design for DBIR

The origins of participatory design lie in Scandinavia, where initial efforts were focused on supporting workers and researchers to cooperate on design projects that were designed specifically to support workers' activities and better their working conditions (Ehn, 1992). Participatory design grew as part of a movement for workplace democracy, in which concerns about workplace conditions and potential negative effects of new technologies on social relations in the workplace were raised by labor unions (Muller &

Kuhn, 1993). Since its inception, the field of participatory design has developed a range of methods for confronting conflicts between management and workers and for building sociotechnical systems that expand the agency and voice of workers in the improvement of their own practice (Ehn & Kyng, 1991; Kensing & Blomberg, 1998; Spinuzzi, 2005).

Organizing for agency and the opening up of new possibilities remains an object of participatory design (Björgvinsson, Ehn, & Hillgren, 2012; Ehn, Nilsson, & Topgaard, 2014), but the focus of some efforts has expanded to encompass more than just the design of products, objects, and things and to designing "Things," that is "common place[s] where conflicts can be negotiated" at intersections marked by "a diversity of perspectives, concerns, and interests" (Björgvinsson et al., 2012, p. 102). This focus hearkens closely to Dewey's (1927) characterization of the public sphere as intersection of diverse persons, claims, and values. One way of characterizing efforts to design Things is as practices for marshaling resources to constitute new publics and new public spaces (Le Dantec & DiSalvo, 2013).

Infrastructuring is also about making "reliable working infrastructures" (Star, 2010, p. 610). A working or work infrastructure refers to the network of tools, relationships, standards, and protocols in which an individual or groups relies to carry out day to day tasks and accomplish particular goals (Pipek & Wulf, 2009). Where traditional design projects might focus on the design of a single tool or sociotechnical system that addresses a single aim, infrastructuring focuses on multiple tools and their relation to one another in support of multiple goals actors might have. As such, as I elaborate below, the success of infrastructuring depends on the ongoing engagement of people brought together to address evolving matters of concern. It exists also in relation to social practices, which themselves are continuously changing (Star & Ruhleder, 1996).

Infrastructuring as Organizing Conditions for Social Innovation

Infrastructuring is the name for a mode or practice of participatory design that is focused on organizing conditions for social innovation. Social innovation, from the perspective of participatory designer, is not meant to be the province of a "creative class" (Florida, 2002) of design elites. Rather, designers seek create conditions in which diverse actors can "exploring new possibilities to create a more sustainable, equal, and just world" that "really affect the causes of social problems rather than merely relieve the symptoms" (Emilson, 2014, p. 22). Designers who may initially be outsiders to system aim to become part of it, cultivating long-term relationships with actors inside the system and building a network that designs together (Emilson, Hillgren, & Seravalli, 2014).

Relationship building takes primacy in the work. Instead of following "pre-defined plans," design teams often engage in "patchwork efforts" focused on "continuously match[ing] different stakeholders and their respective agendas" (Emilson et al., 2014, p. 55). When a match does not work, design teams try another. As Emilson (2014) argues,

> Conflicting interests, values, or ways of working often threaten to cause projects to collapse, and at times projects are closed down because the different actors do not match with each other as intended. But, we will argue, this is not a reason for giving up; instead it is a reason to see the matching of people and the creation of constellations as a kind of prototyping process: if one match doesn't work, try another. (pp. 19-20)

Infrastructuring as the Ongoing Re-design of Infrastructures

When bringing people together around matters of concern, patchwork efforts can also involve activities to create what Star and Ruhleder (1996) call a "working infrastructure." They note that while we often think of infrastructures as part of the invisible background of work—that is, a "system of substrates" embodied in such forms as electrical power grids and highways—in fact infrastructures in organizations can and do become part of the foreground when they present obstacles to people trying to accomplish particular goals. Infrastructures are not static, either, but constantly evolving in ways that expand human capacities in some directions, while creating new challenges and possibilities for breakdown in others. Focusing design on creating a "working infrastructure" around a particular system being designed means making sure it "plugs into" other infrastructures and tools in a standardized way.

Though future-oriented, infrastructuring acknowledges the necessity of "wrestl[ing] with the inertia of the installed base" (Star & Ruhleder, 1996, p. 113). Designers aim to learn from and plan for how organizational structures will influence the design and use of innovations by making visible the existing infrastructures and the work that people do to maintain it (Bowker & Star, 1999; Holtzblatt & Jones, 1992; Pipek & Wulf, 2009). Study in advance of infrastructuring, however, is not sufficient, because the work of maintaining infrastructures is continuous (Star & Ruhleder, 1996) and not under the control of any single actor (Bowker & Star). In this connection, *transforming* systems through infrastructuring is both a challenging and elusive aim, requiring teams to enroll other actors in endeavors to construct more equitable workplaces and communities. Design teams must start someplace and with some group of actors, with the full knowledge that the work will require them to evolve the focus of their efforts and the teams that are engaged in the work.

In infrastructuring, design is continuous with the process of implementation. In other words, there are not distinct phases of projects in which design and development precede implementation (Emilson et al., 2014). Instead, infrastructuring imagines that design activity will be required as new concerns emerge from trying out designs in the field (Björgvinsson et al., 2012; Fischer, 2009). As new designs introduced into practices bump up against infrastructures, the designs may need to change or other components of the organizational infrastructure may need to be modified. New designs inevitably create “residual categories” (Bowker & Star, 1999) of people and activities, that is, people for whom the infrastructure is not transparent but problematic when they seek to accomplish their goals in activity. Promoting equity in infrastructuring requires identifying these residual categories, making visible the work that goes into maintaining infrastructures and its consequences for different groups of people, and working to address the concerns of people who face difficulties navigating the new infrastructure.

The Role of Theory

While infrastructuring is a way to characterize the nature of our collaborative design work and its focus, but we need a more refined set of theories that can help guide our design decisions and that we are seeking to test, refine, or elaborate. In DBIR, there are always two layers of theory to engage. The first is organized around a theory of how students learn. In our partnership, we are guided by conceptions of disciplinary learning in science that are reflected in research reported in *A Framework for K-12 Science Education* (National Research Council, 2012). The ideas represent a synthesis of research on science learning drawn from a range of sociocognitive and sociocultural perspectives on learning. They are transformative, though, in that if the vision of the *Framework* were broadly implemented, it would represent a major change to how teaching and learning are organized in U.S. schools today. The *Framework* promotes a vision of equity in which all students are expected to meet demanding goals for science proficiency and a vision of diversity that emphasizes the need to link instruction to students' everyday experiences and interests, so as to help them identify with science and engineering as cultural endeavors (see also National Research Council, 2009). The tools we employ to facilitate design are intended to scaffold our joint attention to the vision of the *Framework* and its commitments to promoting both equity and diversity in science education (Severance et al., 2015).

What is distinctive within DBIR is the attention to a second layer of theory, related to the organizational contexts in which designs will be implemented. In our project, we draw on concepts from institutional theory as developed within studies of local policymaking in education (Burch, 2007; Meyer & Rowan, 2006; Spillane & Burch, 2006). One concept is that of *sensemaking* in organizations (Weick, 1995; Weick, Sutcliffe, & Obstfeld, 2005). Sensemaking refers to the social processes by which local actors seek to resolve ambiguity and conflict among different sources of policy guidance. The way local actors make sense of policies directly shapes how policies are implemented; in most cases, their sensemaking actually transforms those policies' meanings (Coburn, 2001; Spillane, 2004).

From our team's perspective, developing an understanding of how teachers in school districts make sense of guidance from documents like the *Framework for K-12 Science*

Education is critical in design, because like all policy documents, it is ambiguous in the guidance it provides to teachers regarding curriculum, instruction, and assessment. Moreover, it is only one source of guidance within the larger ecology of policies that are intended to guide teachers' practice in a district or state. In their conversations with other teachers and with school and district leaders, they will need to reconcile conflicting goals and directives, if they are to successfully implement new practices that align to the *Framework.* As a design team, it is not possible to anticipate how teachers' own varied beliefs and experiences will shape their sensemaking, but the past suggests that we will need to provide occasions where we can engage in constructive and collaborative *sensegiving* (Gioia & Chittipeddi, 1991) that is, we will need to propose potential ways through conflicting goals and ambiguous guidance to transform practice and promote equity.

Policy theories also suggest to us where to look for potential sources of conflict in guidance to teachers and provide a focus for infrastructuring activities. American schools and districts today share a number of common components that make up what Hopkins and colleagues (Hopkins & Spillane, in press; Hopkins, Spillane, Jakopovic, & Heaton, 2013) refer to as the *instructional guidance infrastructure*. A district's infrastructure includes components such as standards, curriculum, and assessments and their relations to one another. Increasingly, in large school districts, the infrastructure also includes interim or benchmark assessments intended to provide feedback to central office curriculum staff on student performance and pacing guides that tell teachers what to teach when. These components are increasingly significant sources of guidance to teachers in school districts, and there is evidence that teachers use them to make decisions about what components of innovations to implement and how much time to devote to them (Allen & Penuel, 2015; Furtak & Heredia, 2014).

A more coherent district infrastructure aligned to a particular vision for teaching is one that can facilitate productive sensemaking, and it is also one that we posit is a condition for equitable transformation of systems. This implies the need for a design team to attend to how different components of that infrastructure fit together, no matter where the focus of their design efforts is. Instructional guidance infrastructures—just like other infrastructures—are layered and constantly evolving, so aligning design activities with them requires continuous activity with different district units to make adjustments to our designs and, where possible, to other components of the infrastructure. The success of any DBIR effort, then, demands adaptation to changing organizational environments (Glazer & Peurach, 2013).

Of course, institutional theory is an insufficient guide to help us decide how to respond to specific changes in the environment. As is typical in design research, our theories are underdeveloped, and there is a need to improvise and anticipate significant failures (O'Neill, 2012). As in other forms of design research, our aim is to produce both knowledge and more refined theories that others might find useful, and one form of knowledge that DBIR can develop is understanding of the conditions for equitable implementation of transformative visions for teaching and learning in school districts. In this talk, I will describe our activities through the lens of infrastructuring, with the aim of illustrating how this lens helps build a more refined set of concepts about sensemaking and redesigning instructional guidance infrastructures in school districts.

Some of what I describe will sound to some people like ways we allowed our designs to be “mangled” by conditions in the district that could undercut the efficacy of the curriculum materials we were seeking to design. Still other activities I will describe might seem like tangents and diversions from the core work we set out to do. But I see the adjustments we made to designs and to components of the district infrastructures as activities aimed at creating a “working infrastructure” for our new curriculum materials and as necessary for creating conditions for equitable implementation of the vision of science education presented in the *Framework*. They are, I claim, distinctive and essential features of the DBIR approach.

Infrastructuring in the Inquiry Hub

As noted at the outset, one way to characterize the Inquiry Hub is as a project that is focused on designing and studying new high school biology curriculum materials. The National Science Foundation (IIS-1147590) and the Gordon and Betty Moore Foundation have provided funding for our efforts to build a fully open and digital curriculum aligned to the *Next Generation Science Standards.* As part of our project, we are conducting research on student encounters with the curriculum materials, teacher implementation, and student learning outcomes. As part of the project, we have plans to make these materials widely available and share research findings with our colleagues.

Circumscribing our account of activity in the Inquiry Hub in this way, however, misses much of what makes our project and DBIR different from many other projects. As in other research-practice partnerships, our commitment to working with our district partners is much more open-ended than the projects might suggest. We have been working continuously with the school district since 2007. And, we carry out “patchwork efforts" regularly with our partners that address emerging matters of concern to district leaders and teachers that pertain to both the instructional guidance infrastructure and to what is happening in classrooms. Some of these efforts directly support our collective goal of bringing our curriculum materials to scale within the school district. But other efforts support the endeavors of central office leaders to bring about broader changes to science in the district or to respond to emerging demands they face. Still other efforts are intended to support teachers directly in their efforts to secure more resources for their students or to make it safe for them to trying out new approaches in the classroom in the face of heightened accountability pressures.

Analyzing the project only through the lens of our project goals would also obscure the diversity of concerns of administrators and teachers that relate directly to district infrastructures. We work closely with curriculum leaders and science teachers whose responsibilities include supporting broader district reform agendas and initiatives. These agendas include innovations in district governance focused on granting greater autonomy to schools in matters of curriculum and instruction in exchange for accountability for outcomes (Gross & Denice, 2015), linking teacher pay to performance (Fulbeck, 2014), and an effort to develop building- and district-level teacher leaders who act as peer observers of instructional quality (Curtis, 2013). Each of these initiatives has its own set of standards, tools, and practices that implicate teachers and leaders in various ways in them. The larger state policy context is also relevant to interpreting our efforts. The science leaders in the school district were committed to preparing the district's teachers to implement a new set of standards based on the *Framework,* the Next Generation Science Standards (NGSS; NGSS Lead States, 2013). However, when we began the arc of work now underway to design curriculum materials aligned to the NGSS, the state was beginning implementation of a different set of standards that had been adopted in 2009. There was little to no movement evident toward NGSS, and the district made no move to formally adopt the NGSS. We were allied as researchers with district leaders in our own commitments, but we also recognized that developing new materials aligned to standards that the state had not adopted would present teachers with conflicting messages about what to teach.

Organizing Conditions for Social Innovation

In organizing a design process for our leading activity, designing curriculum materials, we sought to organize a "design network" comprised of teachers, research staff, and district curriculum leaders. We hoped that teachers would form the majority of people initially in the network and that the process would allow them to play a leading role in deciding on the sequence of lessons that would be developed and in writing lessons. We anticipated, though, that teachers would need at least three forms of support to engage in the design process with us: (1) funding for their time, since collaborative design would require hours of work engaged in discussing unit structures, writing and revising lessons, and participation in research on implementation; (2) opportunities to learn about the *Framework* and *NGSS,* since the few teachers in the state had been exposed to the ideas in those two documents; and (3) protection from threats from misalignments with standards for holding teachers accountable for teaching in a certain way and for student learning standards emphasized in state standards but not in the *NGSS.* While the first form of support was easy to provide through our grant, it was primarily through organizing conditions for innovation—rather than through our co-design activities—that we were able to partially provide the second two forms of support, as we elaborate below.

Connecting district leaders to external professional development providers. As we were beginning to plan our design activities, the secondary science coordinator was planning to convene a "Dive Team" of teacher leaders who would engage in study of the *Framework* and NGSS, to ready the district for NGSS adoption. As part of his planning process, he discovered a hybrid professional development model, the Next Generation Exemplar System (NGSX; Moon, Passmore, Reiser, & Michaels, 2014). He was impressed with the materials, and he thought it might be an anchor for the Dive Team he hoped to create. Some members of our team knew the developers of NGSX well, and we brokered a connection with the developers. We helped the developers and district negotiate a modified plan for implementing the professional development across two school years, which was necessary to accommodate the limited district professional development time available. With some internal funds, the secondary science coordinator was able to purchase the program for use with a district team that would be comprised of K-12 teachers. We volunteered to study the implementation, and we were able to secure an internal grant at the University of Colorado to support a graduate student's research on the project.

We imagined that NGSX would support our planned co-design process by helping build a robust understanding of the vision of the *Framework* through a sustained professional development program created by trusted colleagues in the research community. We planned to develop a new high school biology curriculum, and if a handful of teachers took part in NGSX, then we would have a core team of teachers with similar kinds of understandings of the *Framework* to our own. In fact, four biology teachers signed up for NGSX and took part in several sessions; three of these teachers agreed to join our design team in the summer between the first two parts of the professional development. However, only one of the four teachers completed the NGSX professional development, participated fully in our design process, and implemented the materials we developed in our first iteration of the curriculum materials. Uneven communication about the NGSX professional development sessions led a number of teachers to drop out, especially between the spring and fall. Changes to teacher assignments between spring and fall meant that of the three biology teachers who had signed up to participate in co-design, only one taught biology in a district high school in fall.

I highlight this example because it shows both an aspect of infrastructuring emphasized in the participatory design literature—the emergence of new concerns arising from efforts to organize conditions for social innovation—and a substantive issue with transforming science education in districts that my colleagues have encountered before. That is, that a major challenge to efforts to build human capacity in districts is the organizational practice of shifting assignments without regard to the background and experience of teachers, but in relation to turnover in other positions and circulation of the teaching force across schools in large urban districts. These lead not just to high levels of attrition in research studies; they undercut investments by district and school leaders in subject-matter focused initiatives aimed at improving teaching and learning (Shear & Penuel, 2010).

Building a support network to allow teachers to take risks with new approaches to teaching science. In human services professions like teaching, professionals depend heavily on the constructive engagement of clients (students) for success; when asking professionals to try out new practices, the risk of failure is heightened because it is not easy to anticipate how clients will respond (Cohen, 2011). When heightened risk is coupled with heightened accountability and little room for failure without consequences, innovation is stifled (Bryk, Gomez, Grunow, & LeMahieu, 2015). In our partner district, the new teacher leadership observation program made teachers accountable for certain instructional practices, and so we expected teachers were at increased risk for being marked down if our instructional materials were not aligned to the observation framework or if they presented unforeseen challenges to teachers that resulted them in being marked down on the protocol.

We took several steps to organize conditions for teachers where it would be safe for them to try innovative practices. First, we created space during our very first meetings with teachers for them to identify concerns related to school and district policies as they arose for them. They wrote these concerns in a virtual "parking lot" and each day, we visited and discussed them while district leaders were present. One set of adjustments we had to make to address teachers' concerns was to the structure of the lessons. Some teachers' principals required them to have a "Do Now" or daily warm up that students could complete independently. The "Do Now" is a technique promoted by charter school leader Doug Lemov (2010), whose methods many district principals had embraced in the past year after receiving training through his Uncommon Schools organization. Several teachers also were required to post "Content Learning Objectives" written in a specific format and that were intended to focus attention on learning needs of emerging bilingual students. We worked carefully to develop ways of writing these objectives so as not to "give away" the disciplinary core ideas of science that student activities were intended to help develop.

One dimension of risk we were unsuccessful in reducing for teachers pertained to the district's teacher evaluation program. When we were first forming our design network, each teacher in the district was required to submit to observations by principals and trained peer observers, as part of a relatively new teacher evaluation system mandated by state law. The district had received a large grant from the Bill and Melinda Gates Foundation to develop their own evaluation system to comply with the law; its system included a rubric that peer observers and principals were to use to rate teachers' instructional practices and learning environments along several dimensions. The new evaluation system has received mixed reviews from teachers across the state, with fewer than half believing the system provided for accurate ratings of their effectiveness (New Teacher Center, 2015). We feared that our own teachers might be observed by peers when implementing new curriculum materials and given a low rating, because the day's lesson either did not feature components emphasized in the district rubric or because the experimental lesson did not work. In fact, one of our teachers did receive a low rating for a lesson, and although we were able to provide some back channel support through district leaders to this particular teacher, we could not get the rating adjusted. So far, we would say we have not been successful in reducing the risks teachers implementing new materials face from the teacher evaluation system.

Our efforts to limit the risk to teachers of trying out new curriculum materials reveal the limits of efforts by a small network in a school district to influence aspects of the instructional guidance infrastructure that affect teacher practice. In school districts, as in other large organizations, infrastructures are layered, and there are multiple sets of decision makers for any given component. Some groups may have authority for some components but not others. No district leader in our group had authority to influence principals' demands for "Do Nows" or the teacher observation system, and so our approach had to be tactical rather than strategic. That is, we had to make adjustments to our own designs to conform to the constraints of the system. Some of these adjustments "mangle" the designed materials, as in the case of our lesson plan templates, and the materials would likely therefore need to be adapted differently to fit within different systems.

Patchwork Efforts at Infrastructure Redesign

Our work in the Inquiry Hub has involved a number of "patchwork efforts" where our network members have authority to make adjustments to components of district infrastructures. I call them "patchwork efforts," because they do not entail major shifts to these components but small ones that we make in response to perceived threats to the success of our major design activities. They are a distinctive feature of DBIR efforts, insofar as they focus principally on issues that emerge early in implementation and are directly responsive to those issues. Developing accounts of these patchwork efforts in DBIR is important, just as it is important in classroom-based design research to describe iterations in the design of features of classroom learning environment. Such accounts help to build understanding of the conditions required in real districts for implementing innovations, that is, to realize the third element of DBIR, developing theory and knowledge related to both classroom learning and implementation.

Although researchers can initiate some kinds of patchwork efforts, the ability of a team to engage in such patchwork efforts depends critically on the skill and authority of educators with whom researchers are partnered. As we elaborate below, the patchwork efforts we have undertaken in the Inquiry Hub have all been initiated by and mostly carried out by district leaders and teachers. Our account underscores the ways in which the collaboration of partners is essential to the design process, and it reinforces the importance of attending to instructional guidance infrastructures in districts when engaging in design for transformation of systems.

Patchwork effort #1: Adjusting the district's pacing guides. Early in our design process, we decided to begin the development of a new biology curriculum with a project-based unit focused on ecosystems. In the Next Generation Science Standards, ecosystems standards (or performance expectations, as they are called in NGSS) make up 8 of 24 standards. Though the proportion of standards is not intended to indicate how much time students will devote to these standards, our network of district leaders, researchers, and curriculum writers from BSCS believed that addressing this many performance expectations would require significant time. We settled on eight weeks as a target length for the unit, with the idea that the other three disciplinary core ideas (related to cellular structures and processes, evolution, and heredity) would each require 8-week units. We also agreed that ecosystems would be the first unit in the new biology curriculum and that the unit would move from a macro-perspective to a micro-perspective over the course of the school year.

The district secondary science coordinator had to make several adjustments to the district's pacing guide, in order to create space in the school year for the new ecosystems unit. The existing pacing guide was developed with the district's current adopted textbook in mind. In that book, a much smaller proportion of content was devoted to ecosystems, and ecosystems was to be taught at the end of the school year for only 10 instructional days, well short of the 40 days we had planned for the unit. In addition, the district did not wish to require all teachers to adopt the not-yet developed or tested materials, so the pacing guide would need to reflect two different tracks for teachers through the biology curriculum.

Adjusting the pacing guide was important, not only because teachers made decisions about what to teach when on the basis of the guide, but also because the pacing guide was linked to required accountability tests. The pacing guide provides guidance as to when units are to be taught and how much time teachers should devote to different topics. In our partner district, it also specified when required district interim tests were to be administered to students. The standards assessed on each interim test were those that the pacing guide required teachers to have taught up to that point in the school year. Thus, if a teacher had not covered the material at the right time or devoted either too much or insufficient attention to particular topics, their students would not perform well on district accountability tests.

Though we were aware of the possible need to adjust the pacing guide, no one at the district had undertaken the process of revising it ahead of our first major design workshop. We worked for four days with a team of nine teachers to outline an eight-week, project-based ecosystems unit, and then reviewed with them the district pacing guide that showed just 10 days at the end of the year devoted to ecosystems. For the first year of the pilot at least, teachers planned to teach ecosystems at the end of the year, so its placement was not problematic. But teachers immediately expressed concern that it would be impossible to teach the unit without adjusting the pacing guide significantly. They noted, too, that there were few topics to be assessed in ecosystems in comparison to other topics in biology. We paused our work to begin to outline as a team how some additional days at the end of the year could be added after the final interim test; teachers then worked backward to figure out when they would need to start the unit to devote sufficient time to it.

After the workshop, the district science coordinator set to work to expand the number of days for ecosystems. He created a special pacing guide for the pilot teachers, too, so that teachers could begin to teach the unit at the earliest date teachers indicated they might start it in the spring. Although these adjustments helped, as we fleshed out lessons for the unit, our initial draft included more than 40 days of instruction. We pared down some lessons, but it proved insufficient. Teachers began teaching the new ecosystems unit later than expected, and none taught all the lessons in the unit by the end of the school year.

Between the first pilot year and the second pilot year, we knew additional adjustments to the pacing guide would be required. On the basis of the pilot, we revised the unit significantly, shortening it to fit better within an eight-week cycle. Plus, for the second year, the pacing guide would need to shift ecosystems to the beginning of the school year. Initially, the district secondary science coordinator shifted ecosystems to the start of the school year for all teachers in the district, even though just 13 teachers were slated to teach the revised ecosystems unit. Teachers not participating in the pilot complained to him, wondering why their had been a shift. Eventually, two different pacing guides were developed, one for the pilot teachers and a second for the remainder of the biology teachers in the district.

Patchwork effort #2: Developing interim assessment items. When we learned about the number of items devoted to ecosystems on the district interim assessments, I asked to see the actual assessment items from last year's test. Most items were multiple-choice items, with a few constructed response tasks and one extended performance task that required students to evaluate conditions for human survival inside a fictitious Martian science laboratory. Nearly all of the items elicited students' ability to recall facts, and only a few demanded that students construct explanations of scientific phenomena or even analyze patterns in complex datasets. As the teachers suspected, too, there were few items related to ecosystems.

The district process for writing items for interim tests was to engage teams of teachers in writing, editing, and reviewing items together. The schedule partly overlapped with our own design workshop, such that teachers involved in our design work could not participate. Only the secondary science coordinator attended both, as he he was responsible for leading the item development for assessments. The coordinator agreed to allow an outside writer from our team to develop some new ecosystems items, provided those items address Colorado science standards that all teachers were required to teach and that they followed the required template for all items. He also stipulated that the teachers designing the district interim tests would need to review and approve the items we developed, along with the other items that team was developing. I took on the development of the items, since no one was available from the curriculum design team to do so on such short notice.

One reason that we undertook this patchwork effort was to provide teachers with a justification to devote sufficient time to the new ecosystems unit we were developing together. Teachers were particularly worried that by focusing so much time on a topic that accounted for only a small percentage of the content tested, they would have to shift attention away from topics that made up the bulk of the test. As a result, their students would not perform well on the district test. By expanding the number of ecosystems items, they would be able to justify to those monitoring their instruction—namely their principals—devoting the time required to implement the project-based unit.

A second reason why we devoted time to designing new assessment tasks was that the items on the test did not assess science proficiency in a way consistent with the vision of the *Framework for K-12 Science Education,* which had guided our unit design. Assessments of proficiency that are consistent with the vision require students to engage in science and engineering practices and connect understandings to crosscutting concepts in science when answering questions about core ideas about science (National Research Council, 2014). By writing a new set of multi-component tasks that focused on core ideas that were in both the NGSS and Colorado standards, we could improve the alignment of two key components of the district instructional guidance infrastructure, curriculum and assessment. In addition, we could likely increase the chances that students in the pilot classrooms would do well on the assessment, since the curriculum would have prepared them for the more cognitively demanding, three-dimensional assessment tasks.

Patchwork effort #3: Strengthening connections to student interest and experience. A design principle we established ahead of our first design workshop was that the units should build upon students' interests and experiences. We adopted this principle, because it is a core principle of the *Framework:*

> in order for students to develop a sustained attraction to science and for them to appreciate the many ways in which it is pertinent to their daily lives, classroom learning experiences in science need to connect with their own interests and experiences. (National Research Council, 2012, p. 28)

The *Framework* advocates for framing curriculum around the kinds of questions students are likely to pose at different ages, as a strategy for connecting to students' interests and experience and for communicating the relevance of science to students. Research also suggests that connecting to students' interests and experiences is an important strategy for promoting equity, a fact highlighted in the *Framework.* Students' diverse family and community practices provide young people with opportunities to engage in practices that closely resemble science and engineering practices (e.g., Hudicourt-Barnes, 2003) and to develop deep connections to particular scientific phenomena that can serve as resources for organizing instruction (e.g., Bang & Medin, 2010; Cajete, 2000). Leveraging these experiences in classroom learning activities can help students develop a strong identification with science as an enterprise (Tzou & Bell, 2010).

In our first design workshop, we sought to instantiate this principle by identifying a driving question for our curriculum unit that we—as adults—thought would interest students. We also constrained ourselves to anchoring our unit in phenomena that could be observed by students living in a city, that is, an urban ecosystem. After some deliberation, we settled on a design challenge to anchor the unit that would engage students in deciding on a species of tree to plant in their schoolyard that would enhance biodiversity and provide the most beneficial ecosystem services to people. Teachers pushed us to find a partner, too, that could provide a tree that students could plant, and we developed such a partnership with the local Parks and Recreation Department. Teachers, the Parks and Recreation Department, and we were enthusiastic about the potential for the challenge to excite students and help them feel as though learning science was also a way to contribute to their school community. We were not sure, however, whether the challenge would succeed in actually exciting students or result in a greater identification with science.

Students' experience of interest varied across the different lessons and across classrooms. On the one hand, we were relieved to find that students' reaction to learning about the challenge was uniformly positive. When we observed classrooms on the days the challenge was introduced, students were amazed and delighted at the prospect of planting a tree. At the same time, data we collected from student surveys on a regular basis told us that students found some lessons boring; those were ones that students rated as weakly related to the overall challenge. They said they "felt like a scientist" in only 20 percent of the lessons. We knew we needed to do better by making the lessons cohere more effectively around the central design challenge and by finding out directly from students what topics might captivate and sustain their interest for multiple weeks of science teaching.

As we started work on a second unit focused on evolution, we adjusted our design process to incorporate the perspectives of students into the design process. As we had done in the first year, we generated a list of driving questions and anchoring phenomena we thought could anchor the unit. But instead of selecting them based solely on our own intuitions about what students might find interesting, we conducted a survey with the students in design team teachers' classrooms at the end of the school year to find out their views on what could sustain their peers' interest for multiple weeks. We aggregated the data from the survey, and we used it to inform our selection of anchoring phenomena. We changed the wording on some of the driving questions as we designed the unit, but the students' top choices were reflected in all three sections of the unit we developed, which is organized around another community challenge, developing messages for the community related to how to reduce the evolution of antibacterial resistance through personal health behaviors.

Though this particular effort to solicit the input of students into the design of new materials is not part of the district's instructional guidance infrastructure, we would propose that it should be crystallized as a practice within design of NGSS-aligned materials in the district. The need for it arose out of a sense of contradiction between our desire to connect curriculum to student interest and our initial design practice. Though we wanted to anchor our ecosystems unit in a phenomenon that excited students, we did not invite students to participate in the selection of the materials at all. There is certainly more we can do, too, to include student voices in design in the future and good models for doing so (e.g., Bonsignore et al., 2013; Druin, 2002; Druin et al., 1999). That will require, however, a different kind of wrestling with the "installed base" of school systems, which present few opportunities for youth to have a say in designing or redesigning components of the instructional guidance infrastructure.

What We Learn When We Infrastructure

Some years ago, Danny Edelson (2002) wrote a paper entitled "What We Learn When We Engage in Design." In it, he argued that design research can be used to develop and refine three types of theories: theories of domain learning, design frameworks, and design methodologies. I'd like to summarize some of the ways we are developing and refining theories through the infrastructuring activities of the Inquiry Hub, using Edelson's categories to organize my summary.

Domain theories. Edelson (2002) defines domain theories as generalizations about how learning is supported through a particular design. He argues that it can be about students and how they learn, teachers and how they learn, or learning environments' influence on learning. He further distinguishes between what he calls "context theories," which pertain to issues or challenges associated with a particular class of design contexts, and "outcomes theories," which pertain to outcomes linked to particular intervention designs.

With respect to *domain,* much of what we learned helps refine a theory of conditions for supporting the successful engagement of teachers as co-designers and implementers of curriculum materials aligned to the Next Generation Science Standards. We began with a broad theory that the components of a district's instructional guidance infrastructure would shape implementation decisions. We conjectured that the more coherent the theory with the vision of science teaching and learning the materials sought to embody, the more likely teachers would be to embrace the collaborative design process and implement materials with students. Now, we can say that efforts to promote coherence can help develop teachers' sense of ownership over the design process, when district leaders work to make adjustments to infrastructural components to facilitate implementation. At the same time, we can also say that efforts to re-design infrastructures can meet “resistances” that circumscribe the agency of design networks to transform systems.

With respect to equity, we find that applying the principle of building connections to student interest and experiences surfaced a contradiction in our co-design process that engaged primarily adults. We opened up the design process to student input, albeit to a small degree. In so doing, the team gained another important source of information to inform design that could help us develop materials with the potential to realize a key principle underlying the vision of the *Framework for K-12 Science Education.*

Design frameworks. A design framework is a prescriptive set of design principles. Edelson (2002) defines a framework as describing “the characteristics that a designed artifact must have to achieve a particular set of goals in a particular context” (p. 114). In DBIR, the object of design principles is not a single artifact, but might be thought of as a “working infrastructure” for implementing a new vision of teaching and learning as we have defined it here.

If there is a design principle that has emerged for us as robust enough to recommend to others, it is that the design network must work to create supports for teachers to allocate the necessary time to realize the *Framework’*s core principle that understanding develops over time. The necessary supports that must be adjusted will be the key components of the instructional guidance infrastructure (see also National Research Council, 2015). In our district and in many others, teachers’ decisions about time allocation depend in part on district pacing guides and in part on what is assessed in district and state tests to which they are accountable. Therefore, these are the most likely components of infrastructure that will need to be adjusted.

Design methodologies. A design methodology describes a process for realizing a class of designs, the forms of expertise needed in design and the roles to be played by different participants in the design. DBIR draws upon participatory design methodologies, though different teams vary in their approach to it (see Fishman et al., 2013, for examples). Design networks in research-practice partnerships such as our own also elaborating or refining such methodologies in the context of instructional reform efforts at the level of the school district.

In our project, we have been elaborating what the practice of infrastructuring can look like within this particular design context. As we see it, infrastructuring is somewhat different here from how it is being developed within community-based initiatives in Scandinavia and elsewhere. In many ways, our efforts to work within existing institutional structures more closely resembles the early efforts of participatory designers to instantiate principles of workplace democracy in the context of technology design. But infrastructuring does better capture how we go about deciding what must be designed and our approach to allowing the agency of users to elaborate upon designs. Moreover, the particular components of infrastructure are defined by the organization of school districts in the United States. It may be that we need a different term from infrastructuring to characterize the participatory design methodology that we and other DBIR networks use, but for now, we find it generative as a concept and descriptive of certain aspects of our work.

Conclusion

I have presented Design-Based Implementation Research as an approach to design research that is potentially well suited to address the challenges of system transformation and promoting equity. The practice of infrastructuring aptly describes DBIR's emphasis on forming long-term partnerships between researchers and educators and its attention to components of infrastructure that shape teachers' decision making about what to implement, how, and for how long. Our own projects demonstrates the possibilities for making changes to infrastructures and designs that enable teachers to take risks to implement new materials that reflect bold new visions for science teaching and learning.

I would be remiss, though, if I were not to emphasize that DBIR is no magic bullet for achieving the elusive goals of system transformation and equity. Our partnership is small relative to the size and complexity of the infrastructures we seek to re-design or even modestly shape. We benefit from funding that pays our time and teachers' time to participate and that generates good will from the district toward our efforts. But the work is both taxing and requires expertise that is not common either among researchers or educators. Developing the field's capacity of DBIR is necessary, if the promise outlined here is to be realized in even a small way.

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