Curriculum Co-Design as a Strategy for Supporting Equitable Implementation of Next Generation Science Standards

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Abstract

In this paper, we propose an approach to design research within the learning sciences that foregrounds the tensions between two objects of design: preparing all students to meet externally defined goals for disciplinary learning and expanding participants' possibilities for collective action in activity systems. Design-Based Implementation Research (DBIR; Penuel, Fishman, Cheng, & Sabelli, 2011) is a family of approaches that is organized principally to accomplish the first object, while intervention research informed by Cultural-Historical Activity Theory takes up the second object (Engeström & Sannino, this issue; Gutiérrez & Jurow, this issue). We describe how foregrounding both objects and the tensions that arise between them has informed the organization of our joint work with leaders and teachers in a school district. We highlight ways in which these objects have shaped the organization of participation in the co-design process, the selection and use of tools and routines for design, and the research evidence we are gathering as part of our research. We argue that our approach provides a way forward for design research in the learning sciences to grapple with concerns about equitable design and promoting agency in the context of external reforms.

Design research has played an integral role in the development of the learning sciences, contributing to our understanding of the means of supporting ambitious goals for disciplinary learning. Historically, learning scientists have taken as their point of departure an analysis of goals “from a disciplinary point of view” (Gravemeijer & Cobb, 2006, p. 20), rather than the goals currently pursued by schools, local educational agencies, and policymakers. Over the past two decades, design research has produced rich descriptions of specific interventions and how they can support student learning, difficulties and challenges with implementing those challenges, and the processes used to design, test, and iteratively refine interventions (Anderson & Shattuck, 2012).

Critics have pointed out that researchers have given too little attention to the larger activity systems in which design studies are embedded and the agency of participants within those systems. Engeström (2011), for example, has argued that learning scientists are concerned more with control of the learning environments they engineer than with developing tools and resources that participants can use to expand their collective agency, that is, their ability to imagine and pursue expanded possibilities for action. He argues that formative intervention research, informed by cultural-historical activity theory, provides a better way forward for learning sciences, because it foregrounds *transformative agency* as an object of design, that is, joint enterprises focused on breaking away from given frames of action, imagining new possibilities for action, and taking steps toward developing new activities that realize those new possibilities (Haapasaari, Engeström, & Kerosuo, 2014; Virkkunen, 2006).

In this paper, we outline an approach we have employed that holds explicitly two objects in tension—the promotion of more equitable opportunities for students to accomplish externally defined disciplinary learning goals and transformative agency for teachers and students. We illustrate our approach by describing a project in which we are collaboratively designing curriculum materials as a strategy for helping students meet ambitious new learning goals embodied in the *Framework for K-12 Science Education* that can also expand the agency of teachers by disrupting the historical relations among curriculum developers, researchers, district leaders, and teachers and expand student agency by developing materials that provide students with the opportunity to develop their own agency by allowing more meaningful science learning that breaks the "encapsulation of schooling" (Engeström, 1991) where students typically experience inauthentic learning within the four walls of a classroom.

Externally Defined Object: New Disciplinary Aims for Learning

The research and development project that we describe in this paper is organized in part to help implement a new vision for science education presented in *A Framework for K-12 Science Education* (National Research Council, 2012). This consensus report laid out a set of principles for re-organizing science education and new vision of science education that was deeply informed by findings and principles developed in the learning sciences over the past two decades. The key principles emphasize that children are born investigators, that science is both a body of knowledge and set of practices for generating knowledge, that student understanding develops over time, and that science education should build on students' interests and experience. It developed a "three-dimensional" view of science proficiency, in which developing understanding of a few disciplinary core ideas goes hand in hand with students' engagement in science and engineering practices and their making connections to crosscutting concepts in science.

The vision of the *Framework* included a strong focus on equity and the sources of inequity in American schooling. A key source of inequity, the report argues, is "differences in opportunities to learn because of inequities across schools, districts, and communities" (National Research Council, 2012, p. 279). Despite evidence that all students are capable of learning science, schools and districts have created different tracks and reduced instructional time in science that have limited opportunities for students of color and low-income students to participate in science and engineering practices. A second source of inequity—inattention to what motivates and fails to motivate students from different backgrounds—leads the authors of the *Framework* to call on educators to employ a wider range of strategies for "build[ing] on students' interests and backgrounds so as to engage them more meaningfully and support them in sustained learning" (National Research Council, 2012, p. 283).

Changes to Curriculum Materials Called For in the *Framework*

Helping all students reach proficiency as defined in the *Framework* will require *significant* changes to existing curriculum materials, and the authors call out some specific changes that are needed. Specifically, they call for curriculum materials that are organized around a few disciplinary core ideas, that present multiple opportunities for students to participate in science and engineering practices, and that help students make connections to crosscutting concepts in science. Such materials, they argue, must also be organized to help develop student understanding in science over multiple years.

If followed, these recommendations would yield science curriculum materials that are very different from those available today to most students. Most commercial textbooks today provide students with a view of science as a body of facts or “rhetoric of conclusions” (Schwab, 1982), rather than as a set of practices for building knowledge. Inquiry-based materials, which are often organized around student-led investigations, provide for more opportunities for students to engage in science and engineering practices. But these are not widely available (Banilower et al., 2013), and many do not provide adequate opportunities for eliciting student ideas and interests or for connecting investigations to disciplinary core ideas (Kesidou & Roseman, 2002).

New materials aligned with the vision presented in the *Framework* may be especially important to teachers within states that have adopted the Next Generation Science Standards (NGSS; NGSS Lead States, 2013). The *Framework* was the foundational document for developing the NGSS. The NGSS reflect the vision of the *Framework* in student performance expectations that embody “three-dimensional science learning” through their purposeful integration of disciplinary core ideas, science and engineering practices, and crosscutting concepts. The standards have been adopted by 14 states (including the District of Columbia), and many more states are developing standards based on either the NGSS or the *Framework.*

Local Implementation of NGSS as Opportunity for Studying the Potential of Collaborative Design for Accomplishing Externally Defined Goals and Expanding Agency

The challenge of promoting equitable implementation of the Next Generation Science Standards presents an ideal context for organizing research according to the key features of Design-Based Implementation Research (DBIR; Penuel et al., 2011). DBIR represents a significant expansion of design research beyond a focus on individual classrooms to encompass educational systems, including schools and districts; it focuses more sharply, though, on how to support broad and effective implementation of principles, materials, and practices intended to support disciplinary learning. Equity is a central concern within DBIR in two key respects: (1) in calling for the collaborative design of interventions that includes implementers as co-designers, and (2) in calling for attention to promoting equitable opportunities to learn throughout an educational system (Penuel & Fishman, 2012).

In our view, supporting local implementation of the NGSS also presents an ideal opportunity for exploring whether and how collaborative design of curriculum materials can expand teacher agency and support equitable implementation of the standards. On the surface, such a claim might seem puzzling, because for most teachers, NGSS presents yet another example of externally imposed reform goals teachers have been asked to implement. But the lack of available curriculum materials fully aligned to the *Framework* and NGSS, coupled with limited federal and foundation investments in new materials, has led many leaders and teachers in school districts to take their own initiative to adapt existing materials or develop new materials that align to the NGSS and that embody the vision of the *Framework*.

Furthermore, there is significant room for teacher agency in the design of new materials that embody the vision of the *Framework.* Though the *Framework* outlines some key characteristics of the materials that are needed, the authors do not fully specify what these new curriculum materials should look like. Instead, the authors name a number of important design decisions that will face design teams (National Research Council, 2012, pp. 246-249). For one, teams will need to decide what practices and crosscutting concepts to emphasize in lessons and units organized around a particular disciplinary core idea. Another key consideration is how to present historical, social, cultural, and ethical aspects of science and its applications to students, so that they come to appreciate science as a cultural endeavor of human beings. A third key decision outlined in the *Framework* is how best to address particular disciplinary core ideas in ways that help students identify with the enterprise of science and participate fully in classroom activities.

Teams' design decisions are likely to be consequential for *equitable implementation* of the NGSS. For example, the phenomena in which teams choose to anchor curriculum experiences can effectively build on students' diverse interests and experiences, if the phenomenon chosen is relevant to students' everyday lives (e.g., Tzou & Bell, 2010). In addition, curriculum can present opportunities for students to identify with the scientific enterprise by contributing directly to developing scientific knowledge or to engineering design solutions (e.g., Bang & Medin, 2010; Trumbull, Bonney, Bascom, & Cabral, 2000; Penuel, 2014). Given that two key principles of the *Framework* are that science curriculum and instruction should build from students' interest and experience and that all students should be provided with opportunities to learn science, helping teams select phenomena of likely relevance to students and designing experiences where students can engage in contributing to either scientific discovery or the design of engineering solutions to community problems are of great importance for promoting equity of implementation.

Local implementation of curricula co-designed following the above specifications also provides opportunities to expand student agency. The sort of meaningful science learning called for in the *Framework* requires students to authentically engage in the use of science and engineering practices (National Research Council, 2012). The practices have replaced the static and outdated notion of a sequential scientific method as how scientists go about their work (Bell & Horne, 2014; National Research Council, 2012). Instead, the practices serve as tools that students can draw upon in order to build their knowledge of disciplinary core ideas and crosscutting concepts. In order for students to "develop both the facility and the inclination to call on these practices, separately or in combination, as needed" (National Research Council, 2012, p. 49), students must exercise their own agency and volition in determining when and how to make use of certain science and engineering practices. A curriculum that embodies the *Framework* will purposefully leverage both student agency in the integration of authentic opportunities to utilize the practices and students' existing interests and experiences to promote equitable access and identification with science as a human enterprise. Such an approach addresses the widespread contradiction commonly found in traditional science instruction of an artificial "encapsulation of schooling" (Engeström, 1991), where the science learning experienced by students lacks authentic connections to beyond the classroom.

Articulating a Hybrid Approach: Holding Two Objects in Tension

In this paper, we develop an approach supported by an argumentative grammar for studying how co-design can support equitable implementation of NGSS by holding two objects in the foreground of our work and attending to how these objects exist in tension within the organization of our work. The two objects are (1) to provide all students with opportunities to engage in meaningful and personally relevant science learning that reflects the vision of *A Framework for K-12 Science Education* (National Research Council, 2012), and (2) to expand the agency of participants implementing this vision, especially teacher and student participants.

In describing our approach, we address three key questions that reflect the dual objects of our work in partnership with a major urban district in the United States:

1. How is our design process organized to surface and address dilemmas and contradictions within and across activity systems?
2. How does the design process stimulate the imagining of new possibilities for action?
3. How will we know if our design process has to expanded opportunities to meet ambitious new disciplinary goals for learning and to transformative agency?

The Importance of Surfacing Dilemmas and Contradictions in Co-Design

In CHAT, contradictions refer to historically accumulating structural tensions present within and across activity systems (Engeström, 2011). Within a particular activity system, such tensions may arise from the different roles and authority given to different actors in that system. For example, historically teachers have limited authority to set policies regarding curriculum and instruction, relative to school and district administrators (Black & Wiliam, 2009; Ingersoll, 2003). These give rise to and exacerbate tensions between administrators and teachers whenever new reforms are introduced. Educational reforms often entail interactions of actors from multiple activity systems, not just schools (Spillane & Burch, 2006). These different activity systems are organized according to sometimes competing motives or incentives, often leading to miscommunication and conflict when actors join together in reform efforts (Meyer, 2006).

From a CHAT perspective, a primary contradiction in today's system of schooling that must be addressed is its "encapsulation" from everyday life (Engeström, 1991). That is, though school activities are intended to prepare students with knowledge and skills needed to participate in mature practices of different communities, in fact they are separated from them. Young people do not participate directly in those practices, either as apprentices within them or by observing or listening-in (Rogoff et al., 2007). As a consequence, students' encounters with curriculum provides them with few opportunities to develop a sense of how the practices in which they are engaged in schools are relevant either now or in the future to their lives and their communities.

Addressing this basic contradiction, as well as the historically accumulating tensions that arise from the division of labor in which classroom outsiders design curriculum materials while teachers implement them, are critical in our collaborative design. From a CHAT perspective, those contradictions are a critical impetus or starting point for design.

Designers must “face the current contradictions” and “draw strength from their joint analysis” of those contradictions (Engeström, 1991, p. 257). Moreover, they must work their own way out of the current situation, inventing strategies to address these contradictions and learning something that is not fully determined ahead of time (Engeström, 1987). This is no small task, and so collaborative design must incorporate specific tools and routines for helping participants work through these contradictions.

Tools and Routines for Stimulating the Imagining of New Possibilities for Action

A key strategy for surfacing contradictions and helping participants work their way into new forms of activity in CHAT is the functional method of double stimulation, an idea developed by the Soviet psychologist Lev Vygotsky (1978). In his research on child development, Vygotsky would present a child with a task or first stimulus to complete. This task, however, “is beyond the actor’s present capabilities” (Vygotsky, 1978, p.74). When a second, “neutral” stimulus (Vygotsky, 1978, p.74) or artifact is placed near the child, the child often chooses to employ the object as a mediational means with which to resolve the task. In such a scenario, the researcher does not usurp the agency of the child. Instead, by supplying a “neutral” object, the child must decide how to imbue that object with meaning in order to resolve the task at hand. This is equally true in interventions involving researchers and adults engaged in workplace transformation efforts (e.g., Engeström, Engeström, & Kerosuo, 2003; Ritela & Hakkarainen, 2012) This use of a mediating tool to address a task reflects the transformative potential of such interventions in that application of the new mediating object “re-creates and reorganizes the whole structure of behavior just as a technical tool re-creates the whole structure of labor operations” (Vygotsky, 1981, p. 140).

In contemporary CHAT intervention research, there are multiple "second stimuli" that facilitators of collaborative design can present to participants to surface contradictions and facilitate participants' imagining of new possibilities for action. In an intervention called the "Change Laboratory," the intervention itself is treated as a high-level "tool" to be taken up by participants (Cole & Engeström, 2007; Engeström, Virkkunen, Helle, Pihlaja, & Poikela, 1996). The specific components within a Change Laboratory provide more concrete mediational means with which participants can exercise their own agency to address the problem they face. In a Change Laboratory setup, the researchers use a set of writing surfaces referred to as the "model/vision" (Cole & Engeström, 2007, p. 494) space to serve as the second stimulus. On these writing surfaces are "conceptual models," such as Engeström's representations of activity systems, for three time categories: the past, present, and future (Cole & Engeström, 2007; Engeström, 2011). Participants complete these diagrams and use them to analyze their own activity and to surface contradictions present in the group's activity system (Cole & Engeström, 2007). In this manner, the participants can trace the genetic history of their current problematic situation as well as mediate through prolepsis with some desirable future form of their activity (Cole, 1996).

Notably, the tools and routines of CHAT intervention research are intended to be *ambiguous* and not overly specified. Rather than supplying a tool in "ready-made form" (Engeström, 2011, p. 604), the second stimulus is introduced as "an ambiguous and often quite skeletal or sketchy artifact" (Engeström, 2011, p. 621) that participants collectively fill in with significance to address the design task at hand. This approach purposefully sets agency as a layer of causality—the researchers actually intends for participants' agency to influences outcomes (Engeström, 2011). In addition, it sets as an aim to avoid the "hyper-mediation" (Gutierrez & Stone, 2002) of learning by participants, that is, over-scaffolding of participation such that it limits creativity and innovation.

In the learning sciences, second stimuli are critical tools for supporting the accomplishment of disciplinary learning goals in classrooms. Although they may be designed to be "ambiguous" in that learners are expected to decide when and how to take them up, tools' functionalities are deeply informed by what is known about how to advance students' understanding of core ideas of a discipline (Cobb, 2002; Lehrer, 2009; Rubin, Hammerman, & Konold, 2006). In addition, when "practices" are introduced to students, their purposes, contours, and organization are each intended to work together to support particular disciplinary learning goals (e.g., Forman & Ford, 2014; Lehrer & Schauble, 2012).

These differences in second stimuli relate specifically to the different objects of CHAT research and design-based research, which we elaborate next. For now, it is important to note that might be seen as an "ambiguous" stimulus from the standpoint of design-based research might be viewed as over-specified from a CHAT perspective, because the object of activity has been defined ahead of time without reference to participants' goals. At the same time, from the perspective of a learning scientist, a tool that helps participants reflect on contradictions and dilemmas of practice might be insufficient as a resource for supporting learning in a particular context. Thus, perceptions of ambiguity are an important focal point for researchers' attention if we are to hold different objects in tension: we must attend to ways participants experience tools and practices for facilitating design as striking a balance between being under- and over-specified.

Holding Two Objects in Tension And Evaluating their Accomplishment

A key reason why educational leaders participate in DBIR is that design researchers organize their efforts to address persistent problems of practice that are defined in relation to more institutionalized learning goals (Donovan, Snow, & Daro, 2013; Penuel, Coburn, & Gallagher, 2013). In some instances—as in the case of implementation of the vision of the *Framework*—leaders are concerned with accomplishing new aims for learning, but even in these situations, the object of design activity is externally rather than internally defined. A key task in such situations is to develop buy-in or a sense of "ownership" over the external goals for learning among a group of stakeholders who are brought together to collaboratively design tools and practices intended to accomplish those aims.

This object contrasts most sharply with the object of CHAT intervention research, which is *transformative agency* (Engeström, 2011; Engeström & Sannino, 2010; Engeström, Sannino, & Virkkunen, 2014; Haapasaari, Engeström, & Kerosuo, 2014; Virkkunen, 2006). Transformative agency entails "breaking away from the given frame of action and taking the initiative to transform it" (Virkkunen, 2006, p. 49). Employing the notion of a group's activity system (Engeström, 1987), Virkkunen (2006) notes that the "transformation of an activity system into qualitatively new concepts of activity requires the coordinated actions of the actors involved in the activity, in other words the community of the activity system" (p.45). Successful transformative change in an activity system thus requires a shared collective agency (Haapasaari et al., 2014; Virkkunen, 2006).

Determining the presence and form of transformative agency requires attending to equity of participation in an intervention. Top-down efforts at change often fail, Virkkunen (2006) argues, by not addressing the “basic dilemma” (p. 47) of coordinating stakeholders to successfully achieve a new concept of activity, a dilemma brought on by disparities in agency within an organization (e.g. management vs. workers). Focusing on how participants negotiate the object or motive for activity, whether the object is truly “shared,” and how a group goes about the division of labor to achieve the object and transform it into a lasting outcome can provide insights into the nature of transformative agency in a group and if it exists to the degree necessary for achieving a new concept of activity (Virkkunen, 2006). Developing new forms of activity inherently serve as the object of this collective effort (Engeström & Sannino, 2010; Haapasaari et al., 2014).

Voogt and colleagues (Voogt et al., in press) have proposed that co-design can productively be understood as work that both requires and brings about transformative agency on the part of teachers. They write,

> When designing collaboratively, teachers are enacting their capacity to initiate educational change….By engaging teachers over an extended period in the collaborative design of curriculum materials, chances are increased that they will assume individual and collective responsibility, leading to intentional and transformative action and learning from the process. (Voogt et al., in press, p. 262).

In other words, teachers that assume a sustained collective and collaborative stance, increase their potential for wielding transformative agency. Intentionally attending to and fostering transformative agency in a design process can also potentially mitigate the historically accumulating tensions in how standards are implemented. Specifically, a CHAT intervention approach that seeks to promote transformative agency in the design of curricular materials requires the amalgamation of a new collective where discourses of stakeholder groups overlap, resulting in a transformative space where the expertise of one group is not privileged over another and the opportunity to surface potentially fruitful contradictions increases (Gutiérrez, Rymes, & Larson, 1995; Severance, Leary, & Johnson, 2014). In such an arrangement, traditionally marginalized groups will have the chance to coordinate with other stakeholder groups more effectively and purposefully, to achieve a division of labor necessary to achieve a shared object and a lasting desired outcome (Virkkunen, 2006).

To address the primary contradictions of schooling, it is not enough to expand teachers' agency; curriculum co-design must also expand students' agency as well. Ideally, students' experience would include opportunities to contribute directly to developing science knowledge or to design engineering solutions relevant to problems in their communities. In addition, curriculum materials should provide students with opportunities to identify with the endeavors and practices of scientists and engineers.

If students are not directly involved in designing materials, a study of the design process itself is not sufficient to determine whether or not collaborative design results in transformed agency for students. As such, collaborative design must include mechanisms for learning from implementation about how students experience curriculum materials as teachers use them to organize learning activities in the classroom.

Applying our Framework: Analyzing Co-Design in the iHub Project

We are engaged at present in a collaborative design project called the *Inquiry Hub* (iHub) with XXXX Public Schools (XPS) that includes teachers and leaders from the school district, curriculum developers from the Biological Studies Curriculum Study (BSCS), researchers from the University of XXXX, and software developers from the University Corporation for Atmospheric Research (UCAR). This project takes place within the larger frame of a longstanding research-practice partnership (Coburn, Penuel, & Geil, 2013), which aims to support teachers in meeting the demands of new standards like the NGSS. The focus of our particular co-design project is on developing and testing a new unit on ecosystems that addresses NGSS performance expectations in high school life science, chiefly those associated with the disciplinary core idea HS-LS2 (NGSS Lead States, 2013). The development process is organized both as an opportunity to produce usable, engaging materials for the classroom and as an opportunity for teachers to learn through developing those materials. The equity strategy is two-tiered in the project: (1) teachers are co-designers of curriculum materials, so the project builds agency over materials used in contrast to a traditional adoption model, and (2) the design process builds in routines for considering how emerging activities build from diverse student interests and experiences.

Below, we apply the framework outline above for analyzing co-design by describing:

- how we surfaced contradictions in the design process

- what tools and routines we used as "second stimuli" in collaborative design, and
- how we collected and are analyzing evidence related to transformative agency among teachers and students.

How We Surfaced Contradictions Within and Across Activity Systems

Within our research-practice partnership, dilemmas, contradictions, and tensions can arise at intersections of multiple activity systems. We have designed participatory processes to surface these at two key points in our project: (1) in specifying our design process, and (2) during our design conference with teachers.

Surfacing contradictions across activity systems in specifying our design process. In early spring, a team of district leaders, software developers, researchers, and curriculum developers met to outline a design process and timeline for developing an eight-week unit. We (the researchers) knew going into the meeting from a set of email exchanges that the curriculum developers from BSCS on the team had a different vision of both the scope and timeline of the project from district leaders. The curriculum developers had a small budget for their part, and they initially had proposed a brief two-week unit. By contrast, district leaders wanted to have a new full-year curriculum as quickly as possible. They hoped to have a first unit complete and ready to field test in spring 2015, with revisions and large-scale rollout the following year. In that year, they also hoped that we could help them develop three other units of study. Some members of the software development and research team had experience with rapid teacher-led design of two-week units in Earth science using digital library researchers from an earlier project (Khan, 2007; Khan, Maull, & Sumner, 2008). Their image of the design process mirrored their approach on that project. The main agenda item for the meeting among the district leaders, software developers, researchers, and curriculum team was to surface these competing visions for the design process and come to agreement on a single process, timeline, and target for the unit.

In preparation for the meeting, the Principal Investigators constructed an agenda in which representatives from each of these groups presented its model for a proposed design process and timeline. We provided a template for each presentation, so as to surface similarities and differences in approaches. We asked each presenter to specify in their process how they would represent the learning goals for the unit (e.g., as a list of standards to be met or in a concept map), how they would identify, create, or adapt activities, needed expertise at the table for their process, timelines for development, and their proposal for the length of the unit.

A key tension surfaced through this process was between meeting the district's timeline and ensuring quality in the unit through iterative design and testing of the units. A typical curriculum development project at BSCS might take several years, because the process involves not only extensive up front design, but also review by outside experts and classroom testing. Units might undergo several revisions before they are considered ready to be published. The district faced a dilemma, though, if it were to replace only one-quarter of its biology curriculum. The adopted textbook was another BSCS product, *Biology: A Human Approach.* A new unit developed to align to the Next Generation Science Standards might not easily replace a unit in that approach, so the district wanted an accelerated time frame for development. Ultimately, the meeting ended with the team agreeing to develop an 8-week unit of study that would cover a "bundle" of performance expectations related to one of the four disciplinary core ideas in biology, *Ecosystems: Ecosystems: Interactions, Energy, and Dynamics* (National Research Council, 2012, pp. 150-157).

Surfacing contradictions faced by teachers within the school system during our design conference with teachers. Teachers in every district face multiple and often conflicting demands that affect what and how they teach (Hatch, 2002; Knapp, Bamburg, Ferguson, & Hill, 1998). In deciding which demands command their attention, teachers engage in discussions with colleagues and local leaders to help them manage those external demands (Coburn, 2001). Today, district and school leaders often provide extensive guidance to teachers about instruction in the form of curriculum frameworks, pacing guides, and assessment blueprints (Spillane & Hopkins, 2013). In addition, some districts administer their own interim assessments of student learning, which are intended to signal what is most important to teach (Davidson & Frohbieter, 2011). There is strong evidence that science teachers orient to these forms of guidance from leaders in their schools and districts (Allen & Penuel, in press; Furtak & Heredia, in press).

We anticipated the need—and potential—for coordinating key elements of guidance from the district as part of our design process. We knew that pacing guides would need to be changed to allow for the full eight weeks allotted for a new ecosystems unit at the end of the school year. We also understood that for teachers to devote this amount of time to the unit, they would need some assurance that the unit's topics would align with what appeared on mandatory district interim assessments. Because the district secondary science coordinator was part of the project and responsible for organizing pacing guides and the process for designing interim assessments, we saw potential for surfacing perceived issues related to coordination with teachers and for addressing them through our collaborative design activities.

To surface issues from teachers, we relied on two different formal processes within our design conference. The first was the use of a public “parking lot” chart where any issue that a teacher raised was recorded, including those related to district guidance. Each day, we reviewed the parking lot as a formal agenda item, and we also devoted time at the end of the conference to review all of the issues raised in the parking lot. We continued this process throughout the school year with teachers in a digital format, as our designs for the units evolved. The second mechanism for surfacing these dilemmas was a lengthy planned discussion about the district guidance regarding pacing and how it would need to be adjusted to accommodate the unit that the team was developing. This discussion included a formal review and discussion of the district calendar, in which teachers identified weeks when they might teach the unit. As part of this discussion, district leaders also highlighted windows for interim testing.

Both processes surfaced a number of concerns from teachers. In the parking lot, teachers raised issues about whether they were still accountable to the XXXXX Academic Standards (they were), and they asked whether the state would be assessing the Next Generation Science Standards (there were no plans for this). Later in the year, teachers also raised concerns about the structure of individual lessons, because some principals required students to have a “Do Now” at the beginning of every lesson that related to the previous day’s lesson. We incorporated these into each lesson plan, to accommodate this requirement. The review of the existing pacing guides first with the district secondary science coordinator and subsequently with the teacher revealed a much bigger problem: the time devoted to ecosystems in the current pacing guide was just six days before interim tests were to be administered. Together, the team negotiated a shift in the start date of the unit, so that teachers could start in late March and work through the end of the school year on the unit. Subsequent to the design conference, the research team also worked closely with the district secondary science coordinator to develop two multi-component assessment tasks for interim assessments that were reviewed and accepted by teams of teachers in the district for inclusion on the ecosystems assessment. The tasks focused on two performance expectations highlighted in the unit and that were aligned to XXXXX Academic Standards.

Though the compromise on the pacing guide pleased teachers, the calendaring activity surfaced a different tension between the teachers present and the rest of the design team. Not all the teachers selected by the design team planned to teach the pilot unit in spring 2015 as intended. Some were not planning to do so because they were not assigned to teach biology. In their evaluations of the design conference, two teachers said that the district needed to do a better job of recruiting teachers from each of its high schools to participate in the project. As one teacher put it, “The district really needs to put pressure on the principals to have a science rep from each school here. I feel like we’re doing a lot of great work, and the people missing are at a disadvantage.”

Some teachers remained concerned about alignment as well. One of the teachers who had not yet committed to piloting the new unit commented,

> There are so many different moving pieces crashing into each other at the same time; the NGSS, XAS [XXXXX Academic Standards], XMAS [XXXXX Measures of Academic Success], BSCS, district assessments, LEAP [Leading

> Effective Academic Practice; pertaining to teacher evaluation], SPF [School Performance Framework; pertaining to accountability], etc. It's going to take time to come out with a product that works for everyone…. Will someone help me talk to my administration?

Another teacher raised a substantive concern related to the placement of the ecosystems unit within the year, a concern that echoed earlier concerns of district leaders about developing a single unit of study. She asked,

> If we are able to move this unit around like this - then have we really done our job? Will it be aligned to the other units that we will eventually (theoretically) plan? Will it be standalone? Is that meaningful? These are all questions that I still have about the implementation of this curriculum and the eventual continuation of the project.

Tools and Routines for Stimulating Imagining of New Possibilities for Action

We employed three different sets of tools intended to serve as a "second stimulus" for collaborative design, which we describe below: (1) a jigsaw process for identifying a phenomenon that could connect student interests and experiences to learning goals; (2) a storyline tool for developing a coherent unit; and (3) a student "workflow" tool to facilitate their engagement in a cascade of science practices.

Jigsaw process for identifying a phenomenon that could connect student interests and experiences to learning goals. There are multiple references within the *Framework for K-12 Science Education* (National Research Council, 2012) to anchoring curriculum in the study of natural phenomena and to connecting curriculum to student interests. A key goal of science, the committee asserts, is "to develop a set of coherent and mutually consistent theoretical descriptions of the world that can provide explanations over a wide range of phenomena" (National Research Council, 2012, p. 48). To that end, curriculum that provides students with opportunity to engage in practice that allow them to develop and use models to explain phenomena are key, a theme that is also highlighted in an earlier consensus report on science education (National Research Council, 2007). But the *Framework* also acknowledges that children grow up in environments where they may be exposed to widely differing activities and phenomena that relate to different science domains (National Research Council, 2012, pp. 283-284). Moreover, the report concludes, "[i]nstruction that builds on prior interest and identity is likely to be as important as instruction that builds on knowledge alone (National Research Council, p. 287). This conclusion similarly echoes an earlier consensus report on the importance of developing interest in science and identification with the scientific enterprise as integral components of science learning (National Research Council, 2009). Connecting to student experiences and contexts outside the four walls of the classroom provides for more authentic applications of knowledge and has the potential to transform school learning (Engeström, 1991).

To help our design team devise a unit that was both anchored in a phenomenon and connected to student interests, we devised a jigsaw activity (Aronson & Patnoe, 1997) for the first day of our design conference. In this activity, one group brainstormed a list of potential ecosystems-related phenomena that they believed would be of interest to students. This group was not tasked with examining specific performance expectations of the NGSS, only phenomena to which their urban students might relate based on their experiences. A second group focused on analyzing the disciplinary core ideas related to ecosystems as outlined in the *Framework* and on identifying key connections among the performance expectations of the NGSS, a process sometimes known as "unpacking" (Krajcik, Codere, Dahsah, Bayer, & Mun, 2014). A third group focused on analyzing research related to one dimension of the crosscutting concept "Systems and System Models" emphasized in the *Framework.* The research passages they analyzed identified student strengths and difficulties that learning scientists had discovered when students learn about complex ecological systems (e.g., Hmelo-Silver & Azevedo, 2006; Hmelo-Silver, Marathe, & Liu, 2007; Wilensky & Resnick, 1999). Then, small groups re-configured such that a team member from each initial group joined together to share what they discussed. Together, new groups were tasked with proposed anchoring phenomena that could (1) build upon student interests and experiences, (2) address multiple dimensions of disciplinary core ideas highlighted in the *Framework,* and (3) help students develop a strong understanding of systems and system models of complex ecological systems.

Through this process, two potential anchors for our curriculum unit emerged: one focused on the growth of coyote habitats within cities and a second focused on efforts across the globe to plant trees to benefit the environment (e.g., to reduce air pollution). After much deliberation, the group settled on the latter phenomenon, because teachers believed it would most captivate student interests. Of note is that this particular phenomenon is driven by human activity, and so it provides an opportunity to present human beings as integral to ecosystems functioning and resilience (cf., Medin & Bang, 2014).

In their evaluations of the workshops, some teachers mentioned this jigsaw activity by name as a particularly important moment in the process. At the same time, one teacher expressed worry that we had chosen a focus that might not appeal to all students. In fact—and in contrast to some other approaches to building connections between science curriculum and student interests (e.g., Tzou & Bell, 2010; Vye, Bell, Tzou, & Bransford, 2010)—we did not involve students in this initial process, so this teacher was right not to assume that in fact would do so. This teacher also noted that he preferred "more flexible approaches to curriculum that can easily substitute in student choice from time to time" than seemed to be afforded by the evolving unit.

The choice of this phenomenon also created a new dilemma for the team: participants immediately recognized the need for expertise on the team that was not in the room. Though there were both researchers and teachers with backgrounds in biology on the design team, none had specialized expertise needed to help figure out what kinds of learning experiences might be needed to help students understand this phenomenon. Teachers called on researchers to identify forest ecologists to join the team, to provide the necessary subject matter expertise. We on the research team set out to identify people suitable for that role, though we knew we would not be able to devote significant funding resources to pay a scientist to be anything other than a reviewer. We successfully identified forestry experts within the XXXXX Parks and Recreation Department and another city agency who agreed to volunteer their time to the design process, and they joined the project in early fall.

Promoting coherence with a storyline tool. Another key idea in the *Framework for K-12 Science Education* (National Research Council, 2012) is the importance of coherence in curriculum. There are multiple dimensions of coherence, but with respect to curriculum, the committee emphasized that curriculum should be “logically organized, integrated, and harmonious in its internal structure” (National Research Council, 2012, p. 245). This notion of coherence is echoed in earlier rubrics for analyzing curriculum, such as those developed through Project 2061 (Roseman, Linn, & Koppal, 2008). Some involved in the development of the Next Generation Science Standards go further in their claims, asserting that no lesson or activity can be designed that by itself can lead to mastery of a single performance expectation in the NGSS; rather, the ideas expressed in a “bundle” of related performance expectations need to be developed over time, across multiple lessons (Krajcik et al., 2014).

From the start, researchers on the team knew that developing coherent materials through a collaborative design process could prove challenging. We believed we needed some structure or process for developing and reviewing materials as a team that foregrounded coherence. In spring 2014, researchers on the team presented a Storyline tool developed by Reiser (2014) for developing NGSS-aligned units oriented to answering driving questions anchored in natural phenomenon. The Storyline tool built from an earlier collaborative curriculum development effort to develop project-based units in science in which Reiser had been a leader (Shwartz, Weizman, Fortus, Krajcik, & Reiser, 2008). The key elements (depicted in Figure 1 below) are a set of connected boxes ordered in rows that design teams are to complete prior to developing individual lessons. The tool is intended not just to help organize the flow of activities into a coherent whole, but to ensure that students are engaged in science practices to “figure out” things that can help them answer the unit’s driving question.

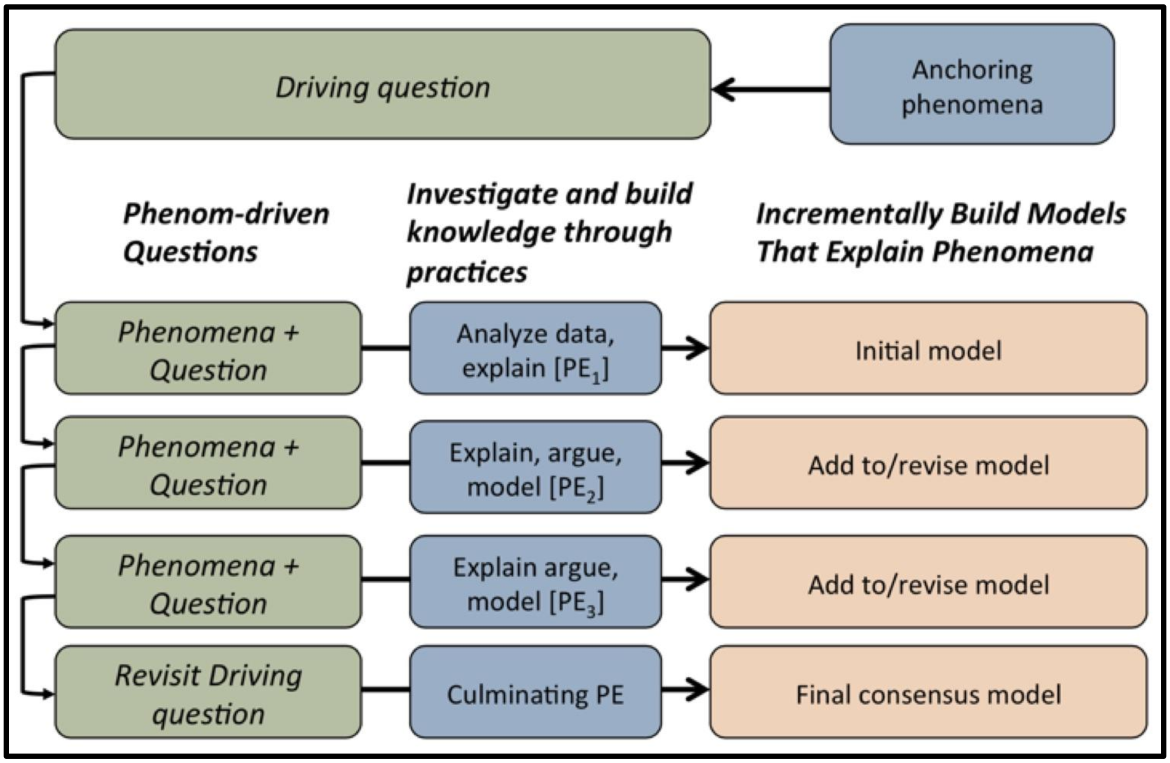

Figure 1. Blank Storyline Tool (from Reiser, 2014)

In our design workshop, we introduced this tool early in the process as a resource we planned to use. We proposed using it to promote coherence for the unit overall, as well as for sub-parts of the unit. We proposed using it for sub-parts, because we believed our team was too large to develop lessons as a "committee of the whole," and yet we were concerned that each part should have a logical flow and connect with the overall storyline for the unit. Each day of the conference and also in subsequent design meetings in the fall, we updated the overall storyline and the four component storylines regularly, using it as an anchor not only for small group work but also for whole group discussions of the unit as we developed it.

Several teachers' evaluations of the workshop and subsequent design process pointed to the value of the storyline tool as a resource for unit development. One teacher pointed specifically to the dual function of the storyline as a resource for design and for providing feedback to peers to improve coherence:

> Providing feedback to other groups: working in small groups was so valuable for me, because I function better in small groups, but it was crucial to hear the feedback of my peers, especially as they were concurrently writing other pieces of the unit. It also helped keep us focused on the overarching goals of this unit. (Sometimes it's easy to forget when you get caught up in your own design!)

At the same time, teachers and others on the team noted a tension between the desire to break the design effort into sub-teams and the goal of coherence. The tensions named by this teacher continued throughout the year:

> I think a problem that inevitably came up (and I don't have an answer for) is how you align each of the groups together to make sure that everyone is on the same page, that the flow is right and that we come up with a product that truly everyone can and will want to use.

Student "workflow" tool for organizing engagement in practice. Embodying "three-dimensional science learning" (National Research Council, 2014, p. 1)--the integration of disciplinary core ideas, science and engineering practices, and crosscutting concepts--in a coherent manner that results in "meaningful learning" (National Research Council, 2012, p. 2) remains challenge for those developing curricular materials aligned to the *Framework* and NGSS. One potential avenue for developing a coherent sequence of lessons that reflects three-dimensional learning involves foregrounding the interconnected nature of science and engineering practices. Past modes of science instruction, made the mistake of presenting an idea or practice in isolation (Berland & Reiser, 2009; National Research Council, 2012). To provide students with a more authentic and coherent experience that aligns to the inquiry-oriented approach at the heart of the framework, a sequence of interconnected practices can provide a framework for building pieces of disciplinary core ideas and exploring crosscutting concepts with the final aim of meeting potential performance expectations.

The authors of the *Framework* intended for the practices to be used “iteratively and in combination” (National Research Council, 2012, p. 49) to reflect more authentically the actual experiences of scientists and engineers. For example, the science and engineering practice of “engaging in argument from evidence” may often authentically occur in tandem with the practice of “constructing explanations” (Reiser, Berland, & Kenyon, 2012). Although the *Framework* does not endorse one set “linear sequence” (National Research Council, 2012, p. 49) of practices reminiscent of the troublesome notion of the scientific method (Bell & Horne, 2014), having students engage in investigations using a sequence of practices can provide a powerful coherence for students’ learning. Such a “cascade of practices” has students engage in inquiry investigations and “experience firsthand the interrelatedness of [the] practices—as an unfolding and often overlapping sequence, or a cascade” (Bell, Bricker, Tzou, Lee, & Horne, 2012, p. 18).

In our design work, we developed a tool to facilitate student engagement in practices once we discovered a gap in the storyline tool, in terms of how it supported the organization of student engagement in science practices. Teachers noted in a mid-process survey the need to develop a means to ensure a more fine-grained coherence from the student point of view, in terms of how activities built toward the key challenge outlined in the unit. For example, one teacher remarked in a mid-process survey, “A strategy needs to be implemented to tie it all together as we move toward the culminating decisions and activity.”

The surfacing of this tension in the mid-process survey cohered with internal conversations within the district admin and researcher tier. This prompted an attempt by the authors’ of the final section of the unit to develop a coherent workflow that purposefully sequenced the practices necessary to meet our unit’s culminating activity. This group developed a cascade of practices organized around specific investigations related to the overall challenge and phenomenon, beginning with the practice of planning and carrying out investigations, followed by analyzing and interpreting data, developing and using models, and concluding with engaging in argument from evidence. In each case, students must present and defend arguments related to how the investigation helped them address some aspect of the challenge.

The development of a cascade of practices for each section of the unit led to a greater sense of coherence at the lesson level of the unit. District administrators and researchers who used the filled in cascades as planning tools and to help organize activity with their groups in particular found the student workflows or cascades helpful in developing the unit in concert with the storyline diagrams. One participant remarked, “The storyline tool to organize coherence of unit and workflows to make integration of practices meaningful have also proved useful.” Another participant also noted the value of the “[i]ntegration of the “student view” and practices to help ensure meaningful cascades of practice." Notably, a software engineer who had fewer interactions with the larger team had a positive view of the workflows' contribution to the design process:

> My involvement in this project is probably somewhat different from others. I regard the "design sprint," in which we first tried to design for a student experience to be helpful, as well as the early meetings with each group (Q1-4) to understand the workflows (commonalities and differences).

Having come into the project midway to help develop the technological infrastructure for the unit, the software designer shows how the workflows served to mediate the design of the unit and organize the division of labor. Still, some felt that the workflows in tandem with the storyline diagrams had not been utilized enough. One researcher commented, "I think we need to consider how to use the student workflow and storyline diagram together for more student-centered development. I think we could explore the theoretical umbrella this work falls under."

Analyzing Transformative Agency Among Teacher and Student Participants

The above excerpts in relation to the jigsaw activity, storyline diagram, and student cascade of practices, came from a set of interim surveys conducted periodically with the aim of capturing reflections on the design process from teachers and other participants. In our ongoing design research, we have had the meaningful participation of sixteen secondary school science teachers of which seven are pilot teachers of the curriculum. Of these sixteen secondary school science teachers, we had attrition of four teachers. In addition to the focal teacher group, the project also had meaningful participation from five district level administrators from the XPS's curriculum office, six members from community stakeholders such as XXXXX Parks and Recreation and the

US Forest Service, two curriculum writers from BSCS, six university researchers, and two members from UCAR, a large research non-profit.

Developing Evidence of Transformative Agency among Teachers

Teachers, administrators, researchers, community partners, computer scientists—the participants in the joint co-design tier—share, at least partially (Engeström, 2011), a common object. The variety of the participants in this tier of activity has no doubt led to a "*multiperspectival*" (Spinuzzi, 2014, p. 4) notion of the object of activity, however, the collective work that the participants engage in together bounds the shared object (Spinuzzi, 2014): designing new high school biology curriculum materials that lead to new meaningful forms of activity for students, ones that extend beyond the encapsulation of the classroom (Engeström, 1991). Examining how participants go about approaching the shared object, particularly the internal tensions which surface within the co-design process around how to go about achieving the object, serves to further focus our analysis within the activity system of the joint design space.

Although at the design tier, participants have oriented around the object of their collective work within that space, i.e. the design of new curriculum materials, other objects *not* shared by all participants shaped the design of the co-design space. The co-design process in which teachers take part serves as a deliberate intervention. Recall in this design-based research experiment, multiple tiers of design occur simultaneously. The tier in which the co-design of the curriculum occurs, itself served as the object of design for an organizing tier of participants. The organizing tier purposefully sought to create an "incomplete" space in which teacher participants could cultivate their agency in the design process and steer the process and direction of the design. Specifically, we sought to create a hybrid shared “third space” (Gutiérrez, Rymes, & Larson, 1995), an emergent activity system where the expertise and voices of traditionally separate groups of participants mingle to create a new multi-voiced space or heteroglossia (Rosebery, Ogonowski, DiSchino, & Warren, 2010). Structuring the co-design process in this manner, seeks to directly address the historically accumulating tension of a lack of teacher agency in curricular development and implementation.

To determine whether shifts occurred in the collective agency of teachers within the co-design space, we will apply an analytic frame specific to agency to a variety of data sources collected throughout the first year of the co-design process. The main sources of data that will undergo analysis for evidence of transformative agency include transcripts and fieldnotes of eight face-to-face design sessions totaling approximately fifty hours, transcripts and fieldnotes of twelve one-hour meetings which occurred via videoconferencing software, mid-process surveys on the co-design process completed by teacher design participants, interviews with teachers piloting the curriculum materials in their classrooms, fieldnotes of observations of classroom enactments of the curriculum, and shared artifacts such as an ongoing “Parking Lot” where teachers logged their concerns and questions during the co-design process for further discussion.

We will focus on identifying forms of transformative agency in discourse—from transcripts, fieldnotes, interviews, and survey responses—and characterizing when and how they arise within the design and implementation process. Our initial coding scheme will draw from recent conceptualizations of the key forms of transformative agency in CHAT intervention research (Engeström, Sannino, & Virkkunen, 2014, p. 125):

1. Resisting the proposed change, or suggestions or initiatives associated with it.

2. Criticizing the current activity and organization.

3. Explicating new possibilities or potentials in the activity, often relating to past positive experiences.

4. Envisioning new patterns or models for the activity.

5. Committing to taking concrete actions to change the activity, often formulated as commissive speech acts tied to specific time and place.

6. Taking consequential actions or reporting having taken consequential actions to change the activity.

Engeström et al. (2014) argue that the above list is a continuum, moving from individually-oriented forms of agency at the top to more collective forms of agency reflective of more transformative forms of agency at the bottom. The movement is developmental, in that "agency [is theorized] as something that can be purposefully cultivated" (Engeström & Sannino, 2010, p. 20). As such, we also plan to focus some of our analytic efforts on transitions from individual actions to collective activity over multiple timescales that address participants' shared problems (Scollon & Scollon, 2004). In addition, our analysis will also look for evidence of the development of a collective identity within the co-design activity system geared towards group action. Such identifications may index a collective will for achieving a shared object or a tension shared amongst group members impeding movement towards an object. The emergence of "we, "us," and "our," for example may embody expanded identification with a collective effort (see also Kerosuo, 2004).

In addition to identifying evidence that may support claims for the sort of explanations sought, we also intend to develop a body of potentially disconfirming evidence or evidence that would lead us to qualify our claims that we seek. Using the data sources named above, we will search for discursive moves that may indicate a lack of agency within the co-design process such as silence, expressing powerlessness in the process, acceding decisions to others traditionally positioned as having more authority and say, or talk around leaving the co-design effort altogether. Other sources of potentially disconfirming evidence, such as teachers' attendance records for design sessions and the frequency and quality of their within meeting participation as derived from analysis of transcripts and fieldnotes of design sessions, may also indicate negative shifts away from a sense of collective agency. These shifts in participation may occur due to external constraints from a teachers' broader activity system encroaching within the co-design space, yet it would still signal an inability to take up the opportunity for agency in curriculum development and implementation. Teachers' production of design artifacts will also serve as another source for disconfirming evidence of agency. A lack of production on the part of a teacher may indicate their continued participation and presence in the co-design process does not cohere with the shared object of the larger group. Lastly, examining the uptake of topics posted by teachers in the "Parking Lot" may also provide disconfirming evidence of expanded agency. Intersecting the two tiers of design, the organizing tier attended to topics provided by teachers in the "Parking Lot" and could either support further discussion of the topics raised or not.

Developing Evidence of Transformative Agency among Students

Students do not encounter the curriculum materials we have developed as a resource to support new forms of teaching but as something else entirely. Our hope (meaning that of teacher and researcher members of the design team) is that the object of activity for students is to solve an engineering design challenge that is relevant to their everyday lives. At the same time, students in our field trial are encountering the materials at school, with all the meanings that "school science" has for them. As such, as a design team we need to attend carefully to what students think they are up to, as they engage with tasks from the curriculum led by teachers in their classrooms, and expect that students' experience will at best be mixed. Sometimes, they will make use of science and engineering practices to address a challenge that they find compelling and relevant in their lives, but sometimes, students will be engaged in the activity of "doing school science" in ways that do not engage students' interests and life experiences (Basu & Calabrese Barton, 2007).

Engaging in a design challenge they see as relevant to their lives is only one dimension of transformative agency. We also need evidence that students have opportunities to shape the flow of activity itself, bending it to their own purposes as a class and deciding upon how to address the challenge. Moreover, our goal cannot simply be to apprentice students to science and engineering practices as conceived in the *Framework,* but rather to provide them with tools they can appropriate to address human needs in their communities (Penuel, 2014). We hope that they can see themselves in the enterprise of science, without having to give up other ways of knowing, being, and relating to peers, family, and community (Bang & Medin, 2010). At the same time, as a design team, we need to be attendant to ways that enactment limits students' possibilities to shape the flow of activity or identify the enterprise of science.

We are relying on three sources of evidence that can help us understand if, how, and when students' encounters with the curriculum materials result in expanded possibilities for action. One source is a brief survey of student experience that teachers are administering to students on a weekly basis. The survey is intended to be a *practical measure* (Bryk, Gomez, Grunow, & LeMahieu, 2015) of implementation. Practical measurement is a strategy to learn in and through practice quickly as to whether a particular design is accomplishing its key aims (Yeager, Bryk, Muhich, Hausman, & Morales, 2013). Our practical measure asks questions of students as to whether what they did in the class that day helped them solve the overall design challenge and engaged them in different science and engineering practices. In addition, it asks them to report on affective dimensions of their experience, including whether they were excited by the day's activities and whether during the course of it, they "felt like a scientist." These questions were adapted from another research team's effort to document students' experience of agency in encounters with curricula (Morozov et al., 2014). The more that students endorse these items would indicate to us that students are doing more than just "doing school science": it would indicate that the tasks interest them, are linked to the overall object of solving a design challenge, and engage them in science and engineering practices.

Students' solutions to the design challenge are a second important source of evidence related to transformative agency. Within these solutions, we will be looking for the unexpected: for evidence that students' models and proposals foreground criteria developed within the class and that take into consideration the diverse concerns of their classmates. We hope to see solutions to the challenge that indicate their appropriation (Rogoff, 1995; Wertsch, 1991) of science and engineering practices for purposes of developing solutions that are localized to their schools and communities.

Last, we are developing field notes from classroom observations as a source of evidence for transformative agency. We are attending in these notes to the ways the materials help teachers cultivate student interest in ecosystems and elicit and make use of relevant student interests and experiences from outside of school. In addition, we will pay close attention to teachers' adaptations of materials, both those that expand students' opportunities to shape the flow of activity and those that appear to limit it.

We do not anticipate that the evidence will support in a uniform or consistent way the claim that either our designs or teachers' enactment of the materials promote transformative agency. Rather, we expect a pattern of evidence that some curricular tasks and ways teachers enact those tasks serve as productive stimuli for expansive learning, while other tasks and forms of enactment limit the scope of student action that help reproduce, rather than transform, common experiences of school science. At the same time, holding up transformative agency as an object of activity does provide us with a benchmark for judging the success of our larger project and for helping guide ongoing improvements to the materials and supports for teacher enactment of the materials.

Developing Evidence of Science and Engineering Learning

To assess whether our collaborative design yielded materials capable of developing student understanding in science, we developed a set of assessment tasks that reflect the "three-dimensional" vision of science proficiency described in the *Framework for K-12 Science Education.* A subsequent consensus volume (National Research Council, 2014) provided guidance for the development of multi-component assessment tasks that we followed in developing our tasks. We focused on specific performance expectations in the NGSS related to carrying capacity and transformations of matter and energy in ecosystems, because these learning goals were closely aligned with the XXXXX Academic Standards to which all students were held accountable for learning. We did so, because not all teachers in the district were to be part of our initial pilot test, and we wanted to integrate assessments into the existing district interim assessments in biology so as not to add any additional time for student testing.

We are planning analyses of evidence of student learning from these tasks that focus on answers to two questions: (1) Do the materials represent an improvement over current materials teachers use to teach science, as measured by differences in performance on the interim assessments? (2) Which students benefit most and least from engagement from the materials? Answering the first question requires us to compare performance of students on our tasks with performance of students in classrooms where teachers are not piloting the materials. Answering the second question requires us to attend carefully to variation within and across classrooms. The second question addresses an important aspect of equity, as a key aim of DBIR is to reduce variation in outcomes, while still supporting productive adaptation of materials at the teacher level (Bryk et al., 2015).

Another dimension of equity entails studying variations in student opportunities to learn. We recognize that some adaptations teachers make to materials may reduce opportunities for students to engage meaningfully with science and engineering practices and with the engineering design challenge presented to them. In addition, teachers will experience varied levels of success in connecting science activities to students' interests and experiences. Classroom observations in our design research are a key means for developing descriptions of how and when students engage, as well as which students engage. We are using a mixture of field notes and structured observations (Forbes, Sangori, & Biggers, 2013) to develop evidence related to opportunity to learn through observations.

Analysis of Tensions Among Objects: Emergence of New Dilemmas and Contradictions

In CHAT, participants within an activity system orient their activity towards pursuing shared objects, often partially shared (Engeström & Sannino, 2010; Engeström, 2011). In moving towards an object—itself always internally contradictory (Engeström & Sannino, 2010)—participants must attend to contradictions within their existing activity system in order to achieve the object of activity. Specifically, in seeking to resolve existing contradictions, participants must learn new forms of activity that provide solutions to existing contradictions; in turn, these new forms of activity result in a transformative expansion to a qualitatively new activity system (Engeström & Sannino, 2010; Engeström, 1987). The introduction of new elements within an activity system, however, inevitably leads to the creation of new, secondary contradictions within the activity system (Engeström & Sannino, 2010; Engeström, 2001). These new contradictions, as with past contradictions, can spur expansive activity if attempts to resolve them meaningfully relate to the object of activity shared by participants (Engeström & Sannino, 2010).

In our design-based research study, preparing all students to meet externally defined goals for disciplinary learning and expanding participants' possibilities for collective action in activity systems serve as the primary objects of design for two activity systems. Within the hybrid space of co-design, itself the result of design by organizers focused on promoting teacher agency, teachers and other experts engaged in the development of new curricular materials aligned to the Framework and NGSS. This common work served to bound the activity of the participants to the two primary objects of design, themselves held in tension within our process of design. External reforms, in this case the prescribing of disciplinary learning goals, circumscribe the agency of both teachers and students. In specifying standards, teachers and students have less of a say in what to teach and learn and, to a certain degree, how to teach and learn. For example, developing curriculum materials around the disciplinary core idea of Ecosystems found in the NGSS (NGSS Lead States, 2013), required the specification of pacing guides for lessons addressing sub-ideas within Ecosystems, which pre-shaped to a large degree the temporal and structural form of the curricular materials.

Our analysis will focus in part on how tensions between the two primary objects of design shape the co-design of new curricular materials and how teachers navigate these tensions in their adaptation and implementation of the curricular materials. As stated previously, attending to contradictions inevitably introduces new contradictions into an activity system. Efforts to reconcile the primary two objects of design within both the co-design and implementation spaces created new, secondary contradictions. How these new contradictions emerged and how participants attended to them will likely provide insights into overcoming the larger tension between our two primary objects of design. Specifically, we will examine the enactment of curricular materials for evidence of teachers making trade-offs between goals, selecting one over another, or finding ways to "satisfice" (satisfy and sacrifice) for both objects.

Discussion and Conclusion: the Utility of a Hybrid Approach

Our development and implementation of curricular materials served to bring multiple activity systems of research and practice and hybrid spaces—the co-design space and implementation space—into interaction with one another in addressing longstanding contradictions around teacher agency, student agency, and the development of disciplinary subject matter expertise. Within the hybrid space of co-design, teams of researchers, teachers, and district leaders wrestled directly with contradictions about the role of teaching and teachers in the implementations of reform, namely that those who are expected to implement changes to address problems of teaching are the very targets of reform by policymakers external too classrooms (Cohen, Moffitt, & Goldin, 2007) by positioning teachers as co-designers of curriculum materials. In the implementation space, we confronted with the primary contradiction of schooling, namely that schools position students not as subjects but as objects or "products" of the educational process (Lave & McDermott, 2002) by developing materials that could help expand student agency and connect school science experiences to students' everyday lives.

We also held two contradictory objects for teachers simultaneously and in tension within our research: transformative agency and promoting equitable implementation of new standards. Reflecting the intersecting nature of the activity systems under study, addressing contradictions in one activity system offered opportunities to address contradictions in the other. Expanding teacher agency became an object of design for the organizers of the co-design space where, subsequently, the development of innovative curriculum provided design participants with the bounds for a partially shared object. At the same time, we also framed this activity as oriented toward developing materials that embodied the three-dimensional science learning called for in the *Framework*. The resulting curricular materials, where students have ample opportunities to meaningfully engage with science and engineering practices in the pursuit of topics designed to leverage existing student interest and experience, were intended to provide meaningful opportunities for students to both cultivate their own agency and identify with science as a human enterprise. In our research, we are developing evidence that examines both implementation and transformative agency among teachers and are attending to ways that accomplishing both objects might require tradeoffs and "satisficing" on the part of teachers, students, and the participants in the design space.

Simultaneously, as called for in three-dimensional learning (National Research Council, 2012), the curriculum materials also were intended to help students develop mastery of disciplinary subject matter, according to an ambitious new set of goals for student learning outlined in the *Framework for K-12 Science Education* (National Research Council, 2012). The curricular materials developed here through the co-design process purposefully allow students to meaningfully exercise their volition in applying their budding knowledge in tandem with science and engineering practices, further supporting the development of student agency. At the same time, it is important to underscore that the vision presented and taken up in our co-design process and within classrooms is one that was externally rather than internally defined. Thus, student agency is bounded by the vision of the Framework, in terms of what the scope of possible actions might be for pursuing the challenges presented in the materials.

The challenges we have faced as a team and the contradictions that served as the focus of this study reflect the hybrid nature of the approach we have taken, drawing on traditions from design-based research and CHAT. The concern for increasing student understanding of subject matter coheres with the aims of design-based research. Design-based implementation research (DBIR), in particular, seeks to help prepare all students to meet externally defined goals for disciplinary learning (Fishman, Penuel, Allen, Haugan Cheng, & Sabelli, 2013). How this study attends to contradictions around equity and agency, chiefly the issue of "transformative agency" (Haapasaari et al., 2014; Virkkunen, 2006), draws almost exclusively on ideas from CHAT.

In terms of teacher agency, CHAT provided a conceptualization of how to support and expand teacher agency, particularly around the design and use of second stimuli during the development of curricular materials. CHAT also provided a means to conceptualize how to support student agency, namely how students' volition in relation to when and how they use their subject matter knowledge in tandem with practices can engender agency. In other design-based research, learning scientists often do not consider teachers' agency in the design and enactment of materials and see teachers as simply the means to enact an already completed design (Engeström, 2011; Ormel, Pareja Roblin, McKenney, Voogt, & Pieters, 2012). Researchers also often fail to consider students' agency, perceiving students as only a recipient of a linear intervention (Engeström, 2011). CHAT has much to offer learning scientists engaged in design-based research around such issues of agency, however, the learning sciences has much to offer in return in other areas.

Since the publication of seminal works on design research by Brown (1992) and Collins (1992), the abundance of design-based research has steadily increased resulting in a variety of tools for supporting more thoughtful and impactful design-based research. Key to our work, recent curricular design tools provide a means to coherently structure the design of complex design objects like curricular materials. Artifacts such as the storyline tool (Reiser, 2014) and student workflow (i.e. cascade of practices; Bell et al., 2012), in particular, proved integral in our design of curricular materials aligned to the *Framework* and NGSS. These tools—from a CHAT frame—functioned as effective second stimuli. Both artifacts have an "ambiguous" (Engeström, 2011, p. 621) incomplete nature, which allows for participants to exercise their own agency and imbue the artifacts with meaning. In our study, the use of these tools streamlined the often-burdensome task of meaningfully sequencing curricular materials. The introduction of such design tools effectively "re-creates and reorganizes the whole structure of behavior" (Vygotsky, 1981, p.140) of design work.

Other recent work in the learning sciences, such as that found in DBIR, offers conceptualizations for how to support the implementation of educational interventions on a large scale. DBIR—a collaborative approach to research and design with education practitioners that focuses on bringing effective, scalable, and sustainable educational interventions to all students—purposefully problematizes issues of implementation (Fishman, Penuel, Allen, Haugan Cheng, et al., 2013; Penuel, Fishman, Haugan Cheng, & Sabelli, 2011; Penuel & Fishman, 2012). As such, researchers can better understand what conditions of implementation support bringing innovations to scale (Penuel et al., 2011; Penuel & Fishman, 2012). Importantly, DBIR attends to issues of agency and equity in the design and implementation of interventions. Within the context of this study, DBIR provided a framework for how researchers and their education partners could equitably engage in co-design and implementation work by, in part, attending to "persistent problems of practice from multiple stakeholders' perspectives" (Fishman, Penuel, Allen, & Cheng, 2013, p. 142).

CHAT and the learning sciences both have much to offer design-based researchers. In this study, a hybrid approach using CHAT and ideas and tools from the learning sciences provided an effective means to conceptualize how to organize an equitable co-design space for the development of curriculum materials focused on achieving the two objects held in tension in our design work: preparing all students to meet externally defined goals for disciplinary learning and expanding participants' possibilities for collective action in activity systems. Notably, our hybrid approach also has led to the beginning of an "argumentative grammar" (Kelly, 2004) for our analysis of data from the multiple activity systems under study, including the specific forms of evidence sought related to our objects of design. Such work, when completed, will ideally provide a tool design researchers can use to further engage with issues of equity and agency in co-design.

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