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Editorial

Building and Structuring Knowledge That Could Actually Improve Instructional Practice

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In our March editorial (Cai et al., 2018), we considered the problem of isolation in the work of teachers and researchers. In particular, we proposed ways to take advantage of emerging technological resources, such as online archives of student data linked to instructional activities and indexed by learning goals, to produce a professional knowledge base (Cai et al., 2017b, 2018). This proposal would refashion our conceptions of the nature and collection of data so that teachers, researchers, and teacher–researcher partnerships could benefit from the accumulated learning of ordinarily isolated groups. Although we have discussed the general parameters for such a system in previous editorials, in this editorial, we present a potential mechanism for accumulating learning into a professional knowledge base, a mechanism that involves collaboration between multiple teacher–researcher partnerships. To illustrate our ideas, we return once again to the collaboration between fourth-grade teacher Mr. Lovemath and mathematics education researcher Ms. Research, who are mentioned in our previous editorials (Cai et al., 2017a, 2017b).

Connecting Partnerships to Create Richer Learning Opportunities for More Students

In Cai et al. (2017a, 2017b), we described ways in which Mr. Lovemath's partnership with Ms. Research made use of the professional knowledge base to address students' difficulties with a fraction-ordering task.[1] Here, we explore the details of how the knowledge base about this topic could develop and the kinds of data it could contain (Cai et al., 2018) by considering what might have happened had Mr. Lovemath and Ms. Research confronted this problem of practice—that is, an ineffective lesson on ordering fractions and the number line—before the topic and its associated learning goals had been addressed in detail in the knowledge base. We can imagine that, as in Cai et al. (2017a), Ms. Research could have analyzed the fraction-ordering task to identify potential learning subgoals needed to support students' engagement with the lesson in ways that foster deeper understanding. Additionally, Ms. Research would have had access, as a mathematics education researcher, to a wealth of prior research on students' understanding of fractions.

[1] Order the fractions 7/9, 2/4, 9/10, 6/13, 1/2, 9/5, and 3/7 from smallest to largest, and place them on the number line.

However, having access to this knowledge does not necessarily mean that it could be directly applied to Mr. Lovemath's instructional problem. There remains a critical implementation gap between research-based knowledge of student learning and a set of learning opportunities that could effectively address the instructional problem in Mr. Lovemath's class.

It is likely that many teachers have encountered difficulties similar to those of Mr. Lovemath in helping their students achieve the learning goals of the fraction-ordering task. Therefore, in a world in which many active teacher–researcher partnerships are operating, there should be multiple partnerships interested in finding a solution to this shared problem. We have argued that implementation should be a continual focus of research that aims to have an impact on practice and that it involves "an ongoing cycle of defining learning goals, creating learning opportunities, and improving them by monitoring their effectiveness in real classrooms" (Cai et al., 2017c, p. 346). This is where our vision for a continuously evolving professional knowledge base becomes relevant. We envision Mr. Lovemath and Ms. Research participating in a multiphase, cyclic collaboration with other teacher–researcher partnerships across multiple sites to generate usable professional knowledge about their shared problem.

Initiating a Collaboration Among Partnerships

Initiating such collaborations requires that teacher–researcher partnerships find other partnerships who share their problem of practice. Let us imagine that in addition to working with Mr. Lovemath, Ms. Research is partnering with another teacher whose students also encountered difficulty with fraction ordering. Moreover, imagine another mathematics education researcher, Mr. Inquiry, who is working with a group of three teachers who are all similarly frustrated with their students' difficulties with fraction ordering. One way for these partnerships to connect would be for the two researchers to search a knowledge base designed to keep track of queries and connect users who submit similar queries.[2] Thus, when Ms. Research and Mr. Inquiry search for information related to fraction-ordering learning goals, they are notified that their partnerships could collaborate to address the gap.

At the beginning stage of collaboration, it is important that collaborations include enough participants to benefit from their shared work but not so many that the process becomes overwhelming. Moreover, it is imperative that collaborators are interested in working on the same specific problem of practice. Ms. Research and Mr. Inquiry, therefore, begin by assessing the potential compatibility of their respective partnerships. Through their initial conversations, Ms. Research and Mr. Inquiry determine that their partnerships can indeed coalesce around this particular problem of practice. Based on their analysis of the learning goal and

[2] This is only one example of a mechanism for connecting teacher–researcher partnerships across school sites to collaborate on solving common instructional problems. There are certainly many other ways that such connections could be initiated, including postings to online forums or social networks and informal conversations at professional meetings.

subgoals and their individual discussions about these goals with their teacher partners, they determine that all of the partnerships are focused on addressing the same learning goals. In addition, their students have reasonably similar prior knowledge and are ready to tackle these learning goals. Thus, the two researchers and their five teacher partners decide to pool their resources and experience to tackle this shared problem of practice.

In the following sections, we discuss three phases of the collaboration, each of which may involve a number of cycles of implementation and refinement, involving the following components: (1) teaching toward the same learning goals, (2) studying implementations of the instructional tasks, and (3) aligning instructional implementations with contextual conditions. Table 1 summarizes the key features and work of each phase, including factors at each site that will be held constant or allowed to vary. We pose this process as a mechanism for how teacher–researcher partnerships might work together to amplify the benefits gained compared with each partnership working alone. Other arrangements are likely to emerge as this imagined world becomes a reality. Indeed, some of the processes we describe below are similar to those involved in design research, specifically classroom design studies (Cobb, Jackson, & Dunlap, 2017; Collins & Bielaczyc, 2004; Lamberg & Middleton, 2009).

Phase 1: Teaching Toward the Same Learning Goals

During the first phase, a set of common learning goals and subgoals is fully elaborated and agreed upon, and common assessments are developed. Because the five teachers are likely located in different schools and districts, they might begin Phase 1 using different curriculum materials and instructional approaches. For a variety of reasons (e.g., student characteristics, differences in how the respective curricula introduce fraction concepts, differing implementation approaches), the student learning outcomes at the five sites are also likely to be different. Thus, during Phase 1, the group's first step is to develop greater specificity and agreement about the learning goals and subgoals that they want their students to achieve and to develop common assessments so they can compare their students' learning.

By sharing their experiences and consulting research and standards documents, the collaborators begin to develop a shared understanding about the appropriate learning goals for this topic. For example, Mr. Lovemath shares that his students did not achieve his learning goal of being able to use multiple strategies and reason about fraction size to complete the task. Rather than trying different strategies, 70% of the students were able to order the fractions, but only 10% used any strategy other than common denominators. In turn, the other teachers share how their students struggled with fraction comparison on similar tasks, and they work with Ms. Research and Mr. Inquiry to specify a shared set of learning goals and subgoals that reflects the learning trajectory along which they want their students to progress. This shared set of goals, as well as initial information from the teachers' experiences, would comprise the first product of Phase 1—the beginning

Table 1
Features of Each Phase of the Teacher–Researcher Partnership Development Cycle

Feature	Phase 1	Phase 2	Phase 3
Variables held constant across sites	Learning goals Assessments	Learning goals Assessments Instructional tasks	Learning goals Assessments Instructional tasks Implementation approach
Variables allowed to vary across sites	Instructional tasks Implementation approach Contextual variables	Implementation approach Contextual variables	Contextual variables
Desired outcomes	Shared learning goals and assessments	Shared instructional task	Shared implementation approach refined over time based on contextual variables
Contributions to the knowledge base	Shared set of precisely stated learning goals Common assessment items Assessment results (e.g., similarities and differences among students' responses, strategies, understandings, difficulties, and errors)	Information about the implementation of the tasks (e.g., videos) Shared set of highly refined instructional tasks Hypothesized relationships between the assessment data and implementation of the tasks Updated learning goals, instructional activity plans, rationales for the instructional activities, common assessment data including prototypical student responses, and recommendations for a shared implementation approach	Shared implementation plan(s) Information about the conditions under which the implementation approach works well for most students Hypotheses about the conditions that would benefit students for whom the approach is not working as well

of a *knowledge package* stored in the knowledge base and indexed by the relevant learning goals.

The second key product of Phase 1 is a set of common assessments for each teacher to use to collect relevant data on students' responses and learning outcomes at each site. Together with Ms. Research and Mr. Inquiry, the teachers generate assessments that are aligned with the learning goals and subgoals that they identified. The common assessments, which allow collaborators to compare students' learning across sites, are also stored in the knowledge base.

Given the different contexts at each site during Phase 1, it is likely that the instructional approach at each site will differ. For example, one teacher may plan a very guided and structured lesson in which she asks key questions to prompt students to think about the different strategies they could use to compare fractions. Another teacher, whose students have done well with open explorations in the past, may plan a less structured approach similar to what Mr. Lovemath initially tried. Yet another teacher might choose to do a number of worked examples of different strategies before giving his students the fraction-comparison task. Some of the teachers may teach a lesson with small-group activities, whereas others may focus their lesson on individual activities. The specific tasks that the teachers use with students bear some similarity (i.e., all of them ask the students to place some set of fractions in order on the number line), but they are not yet common to all the classrooms. However, each teacher implements his or her lesson and collects data using the common assessments.

After implementation, the group collectively analyzes the assessment data and builds a shared understanding about what the results mean. The assessment data, combined with the teachers' observations and experience, allow the group to develop a profile of the students' responses, strategies, difficulties, understanding, and errors. Ms. Research and Mr. Inquiry help connect the group's discussions with what is known from the research literature. By comparing students' responses across sites, the collaborators develop hypotheses about instructional tasks and activities that appear to be especially effective. The results of the assessments are stored in the knowledge base as part of the knowledge package being developed by the collaboration.

Phase 2: Studying Implementations of the Instructional Tasks

The second phase of the collaboration focuses on the development of a common instructional task (or set of instructional tasks) that each teacher will use. To develop the tasks, the group begins by reviewing the shared learning goal and subgoals in light of the assessment results from Phase 1. In doing so, they identify tasks used in Phase 1 that seem to hold promise for helping students achieve the learning goals. The partners discuss what completing a task entails, different approaches to the task (e.g., common denominators, decimal conversion, comparison using a number line), and ways in which they would like students to respond (e.g., developing the inclination to use multiple strategies). As part of this process, they might reference standards documents that are relevant to their districts' guidelines (e.g., *Common Core State Standards for Mathematics*; National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010), information from their textbooks and curricula, research on fraction-learning trajectories, the teachers' own experiences, and the researchers' mathematical expertise. The group also reviews and potentially updates the shared assessments so that they align with the learning goals and subgoals as they are instantiated in the tasks.

Each of the five teachers then implements the instructional tasks in his or her classroom. Even though the tasks and learning goals are the same, because the contexts are different and the details of implementation may diverge, student responses and learning outcomes are likely to differ from site to site. Because the details of implementation are the key focus of this phase of development, various technologies are used to gather comprehensive data on the task's implementation at each site (e.g., video, records of student and teacher discourse and student engagement with the task, teacher reflections) and on students' learning (e.g., the common assessments). These technologies would need to be developed in such a way that they could either automatically transfer data to the knowledge base for further analysis or allow the teacher–researcher partnerships to review and work with the data quickly and easily before the data are incorporated into the knowledge base. Either way, these data are added in some form to the growing knowledge package in the knowledge base so that differences in implementation approaches can be connected to differences in learning at each site.

Following the lesson, the teachers and researchers study the implementations and the assessment data. Once again, the group works to develop a shared understanding and recommendations based on the data and on the teachers' experiences and observations. They identify features of the implementation approaches that were potentially associated with better student learning outcomes. To test their hypotheses about which features of instruction are effective at helping students achieve the learning goals, the teachers and researchers develop a common lesson plan around the fraction-comparison task with the goal of implementing it in the same way at all sites in the subsequent year. The data collected in this phase are again stored in the knowledge base and include the updated learning goals, instructional plans, rationales for the instructional activities, common assessment data including prototypical student responses, and recommendations for implementation.

Phase 3: Aligning Instructional Implementations with Contextual Conditions

During the third phase, all sites share the same task implementation approach in addition to the same learning goals, instructional task, and assessments. The goal of this phase is to carefully observe small variations in implementation and to "tinker" with the lesson through multiple cycles of development in order to improve the lesson's effectiveness at providing students with the desired learning opportunities. This process harnesses the natural small variations in instruction that arise as teachers make moment-to-moment adaptations in the classroom, and it allows the teacher–researcher partnerships to begin to determine under what conditions the implementation approach increases student learning.

After the lesson is taught and data on implementation and student outcomes have once again been gathered, the teacher–researcher partnerships focus on whether students at all of the sites exhibit similar learning outcomes. They again study the collected implementation and assessment data to determine further contextual factors that could affect student learning—for example, students' entry skills and the range of performance levels within a classroom. They might also examine smaller variations in the implementation strategy, observed through a careful analysis of the implementation data stored in the knowledge base, to connect these variations with differences in student learning outcomes. A refined lesson plan is developed for use in the subsequent year, and the cycle repeats itself. During each subsequent cycle, the knowledge package in the knowledge base is updated with new data, analyses, and revised lesson plans. Perhaps several versions of the lesson plans are developed to offer choices that are suitable for a range of conditions or contexts. Thus, the implementation strategy is fine-tuned over time to converge on instruction that provides effective learning opportunities for all students to achieve the desired learning goals.

Ultimately, the products generated by these cycles are detailed and tested lesson plans along with assessments that help partners interpret the effects of particular instructional approaches under particular conditions. The lesson plans gradually add detail to the following elements: specific learning goal statements, instructional activities with time allotments and rationales, likely student responses to each instructional activity, suggested teacher use of these responses, and teacher explanations and questions that have been shown to be most effective. In addition, the knowledge base preserves a history of the lesson that describes previous versions and reasons for the changes (thus saving other teacher–researcher clusters from testing already-tried versions or providing them with a record of alternative approaches that might be better suited to their contexts). The technology allows for each refinement to be stored in the knowledge base, indexed by learning goals and contextual information, and made accessible to other teacher–researcher partnerships that search for information about fraction-comparison learning goals.

Although the initial development process carried out by the teacher–researcher partnerships involving Ms. Research and Mr. Inquiry has produced one or more lesson plans that are likely to be effective with students in instructional contexts similar to those of the five original teachers, there is no guarantee that the plans will be equally effective in other contexts. At this point, other teachers and teacher–researcher partnerships may become involved in the development process by implementing a lesson that is stored in the knowledge base in their own classrooms. By examining the results of their implementations of the lesson using the same assessments, they may generate new modifications to adapt the plans to work more effectively with their students. These modifications would then also be stored in the knowledge base, along with contextual information to guide future users. As for the teachers working with Ms. Research and Mr. Inquiry who have now developed an effective lesson for their students and are done tinkering with this lesson, they might take on the role of mentors or lead teachers to help others work in ways similar to their collaboration, and they might identify new shared problems of practice that they want to pursue.

Expanding the Reach of the Development Cycle

In this editorial, we have described only three main phases of a possible knowledge-building process that connects research and practice in a meaningful way. In reality, there could be more than three phases, and within each phase, there could even be a number of improvement cycles. A key to making this process beneficial for the participating teacher–researcher partnerships, as well as other partnerships and researchers, is that the development and refinement processes are documented and saved using technologies that make sharing easy. The type of "historical data" generated by these collaborations will provide information both to support teacher–researcher partnerships in making data-based instructional decisions and to help teachers and researchers understand more generally what works for students' learning.

Wouldn't the process we have described take a long time to improve instruction in each teacher's classroom? Yes. However, we are betting that incremental, lasting improvement will have a deeper impact on practice than the common reforms that depend on quick fixes. Furthermore, by establishing multiple teacher–researcher partnership collaborations across sites, many educators would be working in concert to more quickly accumulate knowledge through these incremental efforts.

Shifting the Focus from the Class or Lesson Level to the Individual Student Level

We have described a process by which collaborations of teacher–researcher partnerships could improve lessons to solve problems of practice and help students achieve learning goals. Another question is whether, and how, a professional knowledge base could help teachers follow individual students' progress along a learning trajectory. Could there be a dimension of the knowledge base that extends deeply into individual students' mathematical thinking? How would that interact with the aspects of the knowledge base that we have already described, and how might it help (or possibly hinder) teachers and researchers? In our next editorial, we will explore these questions in detail as we envision how various technologies could make our rhetoric reality.

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