Chapter 2
Curricular Activity Systems Supporting the Use of Dynamic Representations to Foster Students' Deep Understanding of Mathematics

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Julia and Paloma are in mathematics class, learning for the first time about the mathematical idea of slope. In stark contrast to many students' experiences, eyes glazing over as a teacher has them recite and memorize $(y_2 - y_1)/(x_2 - x_1)$, Julia and Paloma engage in a heated debate about how to make a character they see on screen run faster. Julia says that to make an onscreen runner move more quickly, they have to extend the line on a position graph (Fig. 2.1). Paloma says that extending the line will make the runner go longer but not faster. As the two students debate, they each manipulate the graph to explain their reasoning. Finally, they decide they should each try to make the runner move as fast as they can. Julia extends the current line as far as she can, and clicks the *Play* button. Although they are not sure whether the runner is going faster, they both agree that she is not going very fast. "Fine, you have a try," Julia says. Paloma moves the line so it is very steep, going off the top of the graph while still very close to the vertical axis. When Paloma clicks the *Play* button, both students are quiet for a second and then begin to laugh. "Did you see how fast she went?" Julia says through her laughter. "Wow" is all Paloma can say.

As Paloma tries to figure out what she did, she notices that not only was the run over very quickly but that the timer stopped at 2 s, with the endpoint of the graph aligned with 2 s along the horizontal axis. Also, the runner was stopped at 50 m, and the endpoint of the graph is aligned with 50 m along the vertical axis. "Hey," says Paloma, "look at this: My graph says the runner should go 50 m in 2 s. Nobody can really run that fast, can they?" "I don't think anybody can run that fast, but how does the graph say that?" asks Julia.

In the ensuing conversation Paloma and Julia begin to develop the intuitive idea that the steeper the graph, the faster the runner. Going even further, they see that this is because a steep graph "covers" a lot of distance in a very short time. In future

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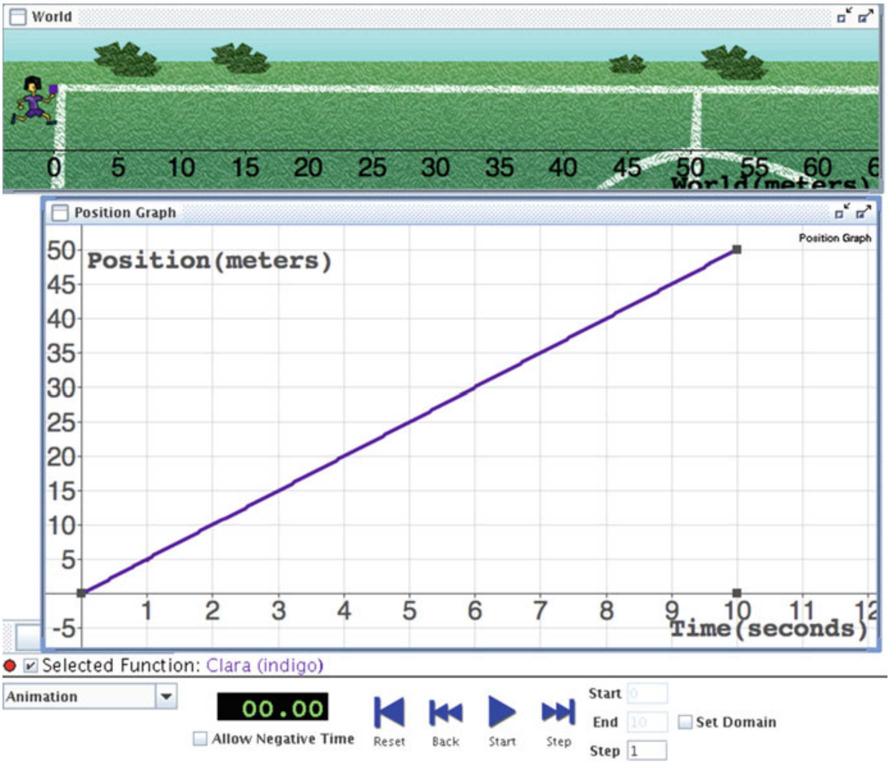

Fig. 2.1 A dynamic-representation environment, SimCalc Mathworlds®, with a "world" that shows a runner on a soccer field, a position graph, a timer, and a set of animation buttons

classes, this intuitive notion that a steeper graph represents covering more distance in less time will be used first to develop a formal measure of speed and then as the basis for the more general notion of slope. By the end of the unit, these students will know not only that the slope formula is $(y_2-y_1)/(x_2-x_1)$, but also *why* this is the formula and *how* to apply it in a variety of contexts.

While hypothetical, this account is based on experiences found in classrooms in which dynamic representations are being used to teach students about rate, proportionality, and slope. These experiences contrast markedly with what we call the *symbols first* approach that currently dominates current mathematics instruction. In the *symbols first* approach, students manipulate symbols as a way to engage in mathematics and presumably to learn the concepts underlying these manipulations. Decades of research have shown that the symbols first approach to teaching mathematics does not serve the majority of our students well (Healy & Hoyles, 2000; Stacey, Chick, & Kendal, 2004), as this approach leads students to view mathematics as an arbitrary set of rules to be memorized and regurgitated on command (Muis, 2004), instead of viewing mathematics as a system in which the manipulation of symbols represents an underlying logic that can be used to model phenomena in the world. Furthermore, the symbols first approach has resulted in great inequities in mathematics learning: Students from ethnic, cultural, and language minorities, as well as students who come from low socioeconomic status (SES) households, have been particularly underserved by traditional mathematics education (Education Trust, 2003a, 2003b).

Dynamic-representation environments provide a way to break free from the symbols first approach, fostering interactions such as those between Julia and Paloma. By leveraging now-common digital and computational technologies, we can engage more students in more meaningful mathematics, resulting in deeper learning and greater equity.

Background

The claim of increasing learning and equity is more than just a future promise. For approximately 20 years, the goal of research in dynamic representations in general and the SimCalc project in particular has been to ensure that all learners have the opportunity to learn complex and important mathematics. For SimCalc, this goal is expressed in the mission statement "democratizing access to the mathematics of change and variation" (Kaput, 1994). A series of studies have found SimCalc to be successful in meeting the needs of a diverse set of students and teachers. Ninety-five seventh-grade teachers and their students in varying regions in Texas participated in a randomized controlled experiment in which they implemented a SimCalc-based 3-week replacement unit. The results showed a large and significant main effect with an effect size of 0.8 (Roschelle et al., 2010). This effect was robust across a diverse set of student demographics. Students who used the SimCalc materials outperformed students in the control condition regardless of gender, ethnicity, teacher-rated prior achievement, and poverty level (Fig. 2.2). In addition, a study in Florida, the SunBay Digital Math project, used the same materials but with no control group. The SunBay project replicated the gains found in the Texas study (Fig. 2.3). In both Texas and Florida, on simple proportionality items, students using SimCalc materials gained about the same as students in the Texas control condition. These gains are shown in Fig. 2.3 as M1; these items were simple $a/b=c/d$, $y=kx$ problems, or questions calling for straightforward graph and table reading (often called "the basics"). However, on items that drew on more complex proportional reasoning, such as requiring a functions approach (e.g., in which students must map between a domain and range) or requiring reasoning across two or more representations, students who used SimCalc materials exhibited significantly stronger learning gains. These gains are shown in Fig. 2.3 as M2.

We attribute the success of these projects, which helped students to learn more complex mathematics while still learning "the basics," to two key features: the use of dynamic representations and the integration of the technology-based representations into an overarching *curricular activity system*. The curricular activity system includes professional development (PD), materials, and technology, all integrated to meet the needs of students, teachers, and schools.

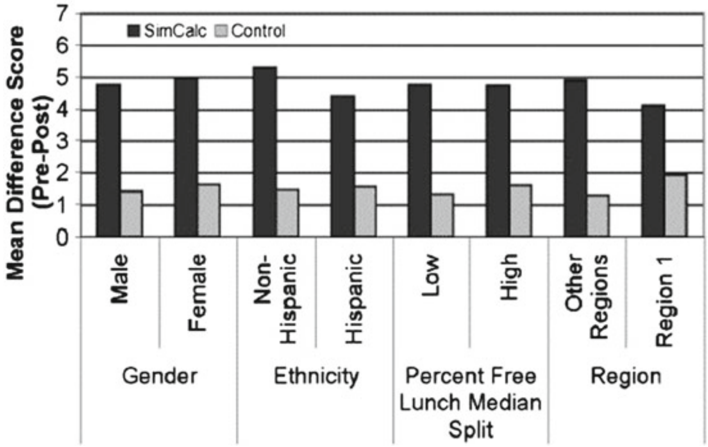

Fig. 2.2 Results from a randomized experiment showing SimCalc students outperformed control group students across a wide range of demographic factors

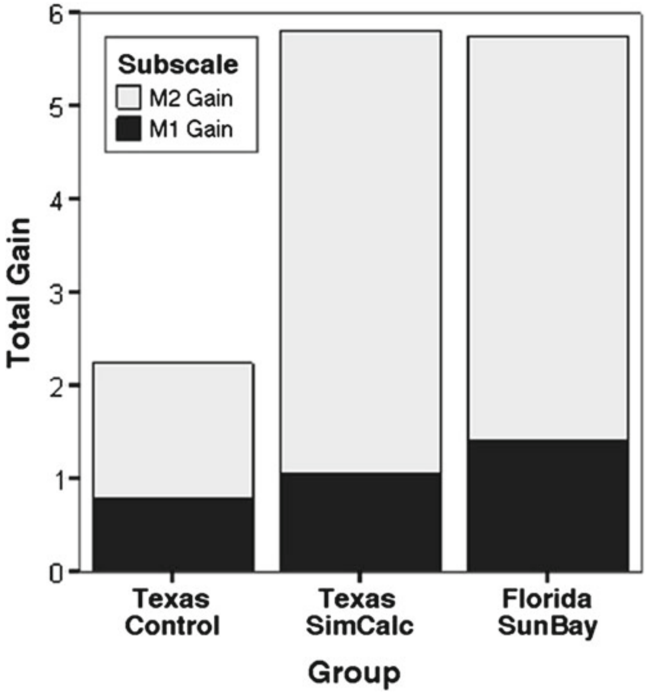

Fig. 2.3 A comparison of the SimCalc experiment and Florida SunBay implementation study showing similar learning gains

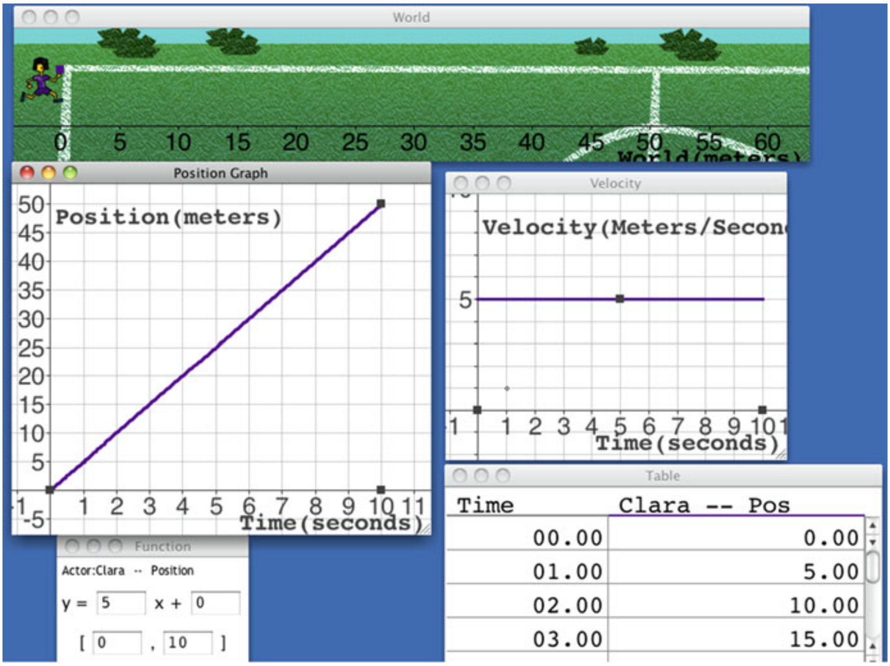

Fig. 2.4 A dynamic-representation environment, SimCalc Mathworlds®, with a "world," a position graph, a function window, a velocity graph, and a table

In the remainder of this chapter, we present how a curricular activity systems approach can be combined with the use of dynamical representation environments to help a wide variety of teachers increase student learning for diverse student populations. To do this, we describe what we mean by dynamic-representation environments, discuss the benefits of such environments, and present evidence that these benefits may be especially strong for students who traditionally underperform in mathematics. We describe what we mean by *curricular activity system* and follow this with exemplars that illustrate how a focus on curricular activity systems leads to the design of materials usable by a wide variety of teachers.

What Are Dynamic-Representation Environments?

Dynamic-representation environments embed mathematical relationships in (typically digital) objects that the student can manipulate. Consider a set of dynamic representations that may be available to understand the motion of a runner. Paloma and Julia were using a runner, timer, and position graph, but the environment could offer other representations as well (Fig. 2.4). For instance, increasing the slope of the line on a position vs. time graph could also (a) increase the height of the corresponding line on a velocity vs. time graph, (b) modify an algebraic expression of the motion, and (c) modify the entries in a table showing the position of the runner during the motion.

Enabling students to manipulate mathematical objects, and supporting them in predicting, evaluating, and understanding the corresponding changes in the environment, are at the heart of effective uses of dynamic representations. Although the algebraic symbol system is a key representation in this environment, it is not the primary focus, nor is it the starting point of the mathematical analysis. Instead, having students gain an understanding of the mathematics through an analysis of the behavior of a set of linked representations is the primary focus of a rich mathematical activity.

This manipulation typically is controlled via specific hot spots carefully chosen by designers of the environment (Moreno-Armella, Hegedus, & Kaput, 2008). Manipulating a single hot spot varies one specific mathematical relationship while other mathematical relationships remain invariant. These hot spots may be chosen in a way that is counter to design principles for productivity applications because efficiency of action may take a backseat to mathematical clarity. For instance, in the SimCalc examples displayed in Figs. 2.1 and 2.4, the student cannot simply select the end point of a segment and drag it to an arbitrary place on the graph. Instead, one hot spot is used to change the height of the segment, and another is used to change the length of the segment; these hot spots correspond to a change in range (position) and a change in domain (time), respectively. Similarly, in Geometer's Sketchpad (GSP), a dynamic-representation environment for interaction with Euclidean geometry, students do not have access to the set of drawing tools and manipulations found in traditional drawing or presentation software. Instead, the students (or the curriculum designers) construct the geometric figures and drag hot spots to manipulate these figures in a manner consistent with Euclidean geometry (insofar as consistency is possible; see Goldenberg, Scher, & Feurzeig, 2008).

As students manipulate the environment through the use of hotspots, the environment constrains the actions allowed while providing feedback as to the mathematical relationships embedded in the environment (Ares, Stroup, & Schademan, 2009; Moreno-Armella et al., 2008). One implication is that student actions are constrained to those that are mathematically possible: in SimCalc, the student cannot create a graph that is not a function (e.g., it is impossible to place the same runner in two places at one time). Another implication is that results of student actions are propagated throughout the rest of the environment: in SimCalc, moving the starting point of an actor in the simulation instantly changes the equation, position graph, and table. This interplay between user and environment, in which the logic of mathematics is simultaneously explored and enforced, can be used to create environments that have well-understood benefits for learning.

Benefits of Dynamic-Representation Environments in Mathematics Education

We leverage four key benefits of using dynamic-representation environments in mathematics classrooms: (a) providing multiple representations for student understanding, (b) providing a shared focus of attention, (c) supporting the use of narrative as a representation, and (d) engaging students in the mathematics. We first describe these benefits individually, and then discuss how the combination can lead to democratization in student learning of mathematics, as the use of dynamic-representations environments can be especially beneficial to students who are traditionally underserved in mathematics class.

A core benefit of dynamic representation environments is the use of *multiple representations* to instantiate mathematical concepts. Almost by definition, multiple representations provide students with multiple perspectives on the same mathematical phenomena. For example, to make sense of a scenario in which two runners race, students can draw on the perceived speed of each runner's motion, the initial and final location of each runner, the value of the timer, comparisons of the function lines on the graph, and on how changes in one representation affects the others. The aggregate effect is to embed computational rules in perceptual systems, which re-represent complex relationships in ways that can be more easily perceived (Ainsworth, 2006). Although it is possible for the presentation of so many resources to be confusing and overwhelming, the evidence on student learning shows that when these representations are properly designed and scaffolded, students can integrate the information from them to build a more complete mathematical understanding (e.g., Mayer, 2005).

By providing a *shared focus of attention*, dynamic representations can be particularly powerful tools for supporting effective mathematical discourse. They can allow gestural and physical communication to supplement verbal and written symbolic communication, and provide meaningful feedback that is consistent with the mathematical phenomena under investigation (Moschkovich, 2008; Roschelle, Kaput, & Stroup, 2000).

Dynamic-representation environments are also well suited to introducing meaningful *narrative* into the mathematical learning experience (Sinclair, Healy, & Sales, 2009). Through the introduction of narrative, the mathematics becomes "about something" (such as the running of a race or the speed at various times during a trip) and moves away from being solely a set of abstract rules that are disjoint from any experience. In addition, the use of narrative grounds investigations in familiar settings, which enables students to apply their intuitive knowledge of the real world, while also providing them with a means by which learners can translate between the different representations. Through the use of narrative as part of the mathematical activity, students are able to engage in creative and fanciful stories, which can then link back to the mathematics under investigation (see Chap. 15 for additional benefits). Students from backgrounds that are underserved by traditional mathematics instruction (such as students from low-SES and language minority communities) can engage in complex narrative creation and analysis as they successfully learn complex and important mathematics (Zahner, Velazquez, Moschkovich, Vahey, & Lara-Meloy, 2012).

Dynamic-representational environments have also been shown to increase *student engagement* in mathematics. Key features already discussed, such as allowing students to directly interact with and manipulate mathematical objects, influencing the behavior of the mathematical environment, and constructing and evaluating narratives, all help to lessen the distance between the student experience and the abstract mathematical concepts. Furthermore, when leveraged in productive learning activities, these features can lead to feelings of curiosity, excitement, and challenge, emotions that most students rarely feel in traditional mathematics classes (Schorr & Goldin, 2008). By actively participating in the mathematics, students may even project themselves into the mathematical system, imagining themselves as part of the mathematical environment (Hegedus & Penuel, 2008). Because of this increased engagement, even students with a history of disengagement in mathematics class can interact with deep and important mathematics more productively and for a longer time than they typically do when using a traditional symbols first approach.

These benefits can accrue to allow for a very different type of mathematics classroom, one in which engaged students use narrative and representations in conjecturing, justifying, and explaining. This type of classroom is beneficial across a wide range of students and demographics. For instance, there is consonance between the literature on improving instruction for low-income students from nondominant linguistic backgrounds and the literature on the use of representationally rich technologies in mathematics (Vahey, Lara-Meloy, & Knudsen, 2009). Both bodies of research highlight the use of multiple representations, point to supporting students as they make connections among these multiple representations, and point to the importance of language-rich practices. Linked representations can provide a shared set of referents for students and teachers to explore: They can replay a motion or make changes in one representation to see the changes in the others (as in Fig. 2.1). Students have opportunities to use a wider range of verbal and nonverbal communication acts, such as pointing: "See, right here, the boy starts running faster." Students also have opportunities to use academic mathematical language for a communicative goal (e.g., answering the question, Does "here" in the hypothetical example above refer to time or distance?). This multimodal and multisemiotic approach is consistent with recommendations for supporting mathematical discourse while developing vocabulary (Moschkovich, 2007; O'Halloran, 2003).

Although the benefits to using dynamic representations are well documented, the use of dynamic-representation environments is still rare in mathematics classrooms. While there are many economic and political reasons why schools may not have the technology infrastructure needed to effectively use these technologies, research shows that many mathematics teachers do not use computers in their teaching even in schools with available technology (Wachira & Keengwe, 2011). Many teachers are uncomfortable in using technology for teaching, are not sure of the most effective uses of technology, and feel constrained by accountability demands. In the next section, we discuss how an approach that goes beyond looking solely at the benefits of technology to consider the overarching *curricular activity system* can lead to an increased use of dynamic representations in the classroom.

Curricular Activity Systems

A *curricular activity system* approach (Roschelle, Knudsen, & Hegedus, 2010) deeply integrates learning progressions, PD, curriculum materials, and software, recognizing that these are all situated in a larger educational context that includes particular sets of people, conventions, and policy considerations. Our notion of a curricular activity system has its roots in Activity Theory (Engeström, 1987), which provides a framework for analyzing how cognition and learning are mediated by historically and culturally constituted tools.

Curricular activity systems help developers focus on activities. We think of an activity in terms of its objective for the participants, available materials, the intended use of tools, the roles of different participants, and the key things we want the participants to do and notice. But a focus on activities in this sense is not sufficient. While an activity may be well specified and be proven to have effective learning outcomes, it must fit into the wider context of the classrooms that are expected to engage in the activity. Considering the classroom context immediately leads to a cascade of questions: What do teachers need in order to realize these activities—what must the PD include? What are the material supports for the activities, including hardware and software that are available? Who are the students who will use the materials, and what are their special needs? A productive way to generate and think about such questions is through Cohen, Raudenbush, and Ball's (2003) framework in which the classroom learning environment consists of interactions between three primary resources: the content, the teacher, and the students. The scope of a curricular activity system can therefore be broadened to include how different aspects of a system can target each set of interactions.

Our introduction to this chapter illustrates an interaction between students and materials, showing how dynamic representations, embedded in learning activities, allow students to gather evidence for and then validate mathematical conjectures. To effectively support student–materials interactions, the materials must be carefully designed so as to be approachable by students with varying background in terms of prior achievement, past experiences, and reading levels, while also focusing students on the core mathematics to be learned.

We have found that teacher PD can play a key role in supporting the interaction between teachers and students, as well as between teachers and materials. A particularly effective way of supporting both sets of relationships simultaneously is by engaging the teachers with the materials in two phases. In the first phase, teachers approach the materials as though they are students. This allows them to experience the benefits of the dynamic representations in learning the mathematical content; otherwise, key aspects of the environment (such as analyzing the motion of a runner) may seem like an unnecessary waste of time. It also allows teachers to better understand and be prepared for the types of student reasoning they are likely to experience in the classroom. In the second phase, they approach the materials in their more familiar role of teacher. This allows them to explicitly link the materials to required standards and accountability measures, and provides time for them to consider how their own teaching practices can be leveraged to support student learning. Although using PD to address these aspects of the program may seem obvious, most traditional PD does not provide the time, activities, or content needed to help teachers use new materials and improve their classroom practice (Garet, Porter, Desimone, Birman, & Yoon, 2001).

The exemplars of curricular activity systems in the next section provide a sense of the specific design decisions that we have made in designing materials.

Exemplars

Exemplar 1: SimCalc

The SimCalc-based curriculum unit used in the Texas and the SunBay studies addressed core state standards as well as topics that were more challenging than those in the standards. The unit, *Managing the Soccer Team*, was originally developed to address Texas' seventh-grade standards on rate and proportionality and included multirate functions and the meaning of slope. It underwent minor revisions to meet the curriculum goals of teachers in Florida, but the core principles underlying the design remained the same. The 3-week unit was designed to replace the materials that teachers normally used to teach rate and proportional functions.

Beginning with simple analyses of motion at a constant speed, *Managing the Soccer Team* followed a learning progression that culminated in more complex topics. It addressed unit rate and proportional functions—topics from the seventh-grade Texas standards that are also core to Florida standards as well as the Common Core Mathematics Standards—and ended with multirate functions and an informal expression of the meaning of positive, negative, and zero slope.

By combining paper materials with guiding questions and SimCalc MathWorlds software files, the unit provided a structured exploration of algebraic representations through connections to real-world topics. Students had opportunities to use various motions and other "accumulation" contexts (distance was accumulated as a runner moved along; money was accumulated when increased at a given rate). *Managing the Soccer Team* presented soccer players running races and team buses traveling from one town to another, and students were to find speeds and write stories to explain patterns of motion. Nonmotion contexts included saving money when buying uniforms and predicting how much fuel vehicles would use, in miles per gallon.

Even with these decisions made, however, the curricular activity system approach highlighted significant decision points that still remained. We will address three key decisions that affected the ways in which teachers interacted with students: the form of the curriculum materials themselves, how teacher preferences for specific types of classroom interactions were scaffolded, and how the PD was used to prepare teachers for interacting with students during the unit.

Form of Materials

The actual curricular materials are typically the focal point of student–teacher interactions. Because of the centrality of these materials and because of the novelty of using dynamic representations in mathematics class, we decided that a traditional-looking set of paper materials would be the most productive form. The argument could be made that all materials should be embedded in technology, but we found that most mathematics classrooms do not have the infrastructure to provide all students with one-to-one computer access. Further, even if such access were available, at the time the authors wrote this chapter there were still benefits to using paper technology: students could take a workbook with them to complete homework in their afterschool program; teachers could move students around the classroom and to different groups on the fly without being concerned about moving technology; teachers were familiar with grading paper homework and assessments and would be more likely to take home paper workbooks to review student work; and many teachers in our studies had both an LCD projector and a document projector, enabling them to simultaneously display the dynamic representations and student work during class discussion. Although we expect that many of these constraints and benefits will soon change and that materials fully embedded in technology will soon be commonplace, we believe that changing the entire system at once, especially given the current state of technology in most schools, could delay the overall adoption of dynamic representations. Therefore, we introduced the key core innovation—dynamic representations—as the one novel approach in the materials and allowed teachers to use familiar paper workbooks in other aspects of the unit.

Teacher Preferences for Classroom Interactions

We have found that teachers are not likely to make significant changes to their general teaching style and routines to implement a short replacement unit with limited time for PD (see also Garet et al., 2001). Instead, they are more likely to shape their use of the materials to fit their styles and routines. We have also found, however, that engaging students in a routine of *predict*, *check*, and *explain* while using dynamic representations is very productive for learning. For example, students are asked to *predict* which of two runners will reach the finish line first. The students can run the simulation to *check* whether their predictions were correct. Students are then prompted to *explain* how their predictions matched or did not match what they observed in the simulation.

To meet teachers' need of maintaining much of their existing styles and routines while also introducing the routine of predict, check, and explain, we embedded all the important questions (including the predict, check, explain cycle) in the student materials. We have noticed that other materials often provide teacher guidance in the form of "lead a whole class discussion around the following questions." Instead, we embedded the questions in the student materials and provided the teacher with guidance on how to use the materials in leading a whole class discussion. Besides ensuring that all the important questions were in the student guide, this also gave teachers the ability to modify our suggested activity structure. Teachers could modify our suggestions (for instance, turning a whole-class activity into a small-group activity) while having the confidence that students would encounter all the important questions in the student materials. Instead of placing the burden on teachers to set up and carry out a sequence of questions that might be foreign to them, we made it possible for them to guide students through their workbooks in a way suited to their teaching style.

Professional Development

To meet district constraints on the amount of PD that could be offered, we administered a 3-day workshop. The workshop used a “teacher as learner” approach, providing teachers with the opportunity to experience our intended activities for themselves. The workshop leaders were able to point out the details of the learning progression and special features of the software and curriculum all along the way. During the unit run-through, the teachers were able to develop some comfort with the software and materials, and we provided technology advice to boost their confidence. More importantly, the teachers themselves and occasionally the workshop leaders would present the types of questions and reasoning that we would expect from students. By taking seriously these questions and lines of reasoning, teachers were able to become comfortable with the types of reasoning and questions they would be hearing from their own students.

Exemplar 2: Geometer’s Sketchpad

Our second exemplar involves the use of GSP in a curricular activity system focusing on students’ development of definitions for geometric similarity. The materials for the unit included premade GSP files and written materials that supported teachers in guiding students through making qualitative and quantitative definitions of the similarity of rectangles and parallelograms, contrasting, for example, the need for requiring only equivalent side-to-side ratios for rectangles with the need to have congruent corresponding angles for parallelograms. The GSP files enabled students to align geometric figures in ways that revealed their similarity or congruence and to collect data on changes in lengths of sides, as figures were scaled larger or smaller. In its first version, the unit did not use cross multiplication in finding missing sides in similar figures, reflecting the curriculum developers’ belief that this algorithm is often misunderstood and misused by students at the middle school level. Partly as a consequence of this decision and partly for internal consistency, the terms “similar,” “ratio,” and “equivalent ratios” were used instead of “proportion” and “proportional” in the written materials.

During the PD session, teachers and a PD leader from the development team went through the unit, with the teachers playing both the roles of learners and of teachers of the materials. In both roles, teachers found troubling the lack of both proportion language and the cross multiplication algorithm. Many said they had already taught both these concepts, so it did not make sense to exclude the terms and procedure in the similarity unit. Furthermore, the district pacing guide stated that students should connect similarity with prior learning on proportionality. Although the PD leader explained the developers’ position, the teachers believed that it was important to connect students’ prior learning on proportionality to their work on similarity, as well as to conform to the district expectations.

The PD leader brought these concerns to the development team as it prepared to make final changes to the materials for classroom use. After much deliberation, the team decided to include a lesson on the language of proportion and connect this language to the language of similarity in the remainder of the unit. We did not, however, include cross multiplication; to include this algorithm while staying true to our philosophy of teaching would have required additional activities to foster understanding of cross multiplication. Adding such activities to the unit would have been a significant conceptual detour and would have required too many lessons for a reasonably sized replacement unit.

A key lesson from this experience is that a focus on a curricular activity system produces a set of supports not only for an intended activity, but also for the *relationships* among teachers, students, and materials. This requires flexibility on the part of curriculum developers. If we had seen our job as solely to best support our own ideas and hypothesized learning progression for similarity, and viewed teachers as implementers of these materials, we would not have changed the materials. Instead, we considered the importance of preserving relationships already formed among teachers, students, and materials in addition to the learning progression we had designed.

Although the use of dynamic representations is a core aspect of our unit, our view of the curricular activity system in relation to the instructional relationships in the classroom led to serious consideration of curricular issues that were only peripherally related to how students use the dynamic representations. Such considerations are consistent with our position that the use of representations must be situated in a larger context. Only when teachers' concerns are addressed will they feel compelled to use the materials, thus allowing their students to benefit from the use of dynamic representations.

This case also highlights the importance of considering the existing curriculum sequence as part of a local policy context—the environment in which the classroom is situated—even when a supplementary curricular activity system is being designed. The curriculum sequence, which is often mandated by a pacing guide (particularly in urban districts) or structured by an adopted textbook, is an outside-the-classroom factor that affects what is taught and learned in the classroom. Not all developers, of course, have the luxury of rewriting materials before localized implementation. But all curriculum developers can investigate the policy context—be it local or national—in which their materials can be used and adjust them accordingly. How to accomplish this task without compromising core intentions and beliefs is a design tension that needs to be resolved on a case-by-case basis.

Next Steps

For teachers and administrators, curricular activity systems provide a way to consider practical problems of choosing and implementing the kinds of technologies discussed in this chapter. For example, administrators will want to consider teachers' prior experiences with technologies and paper-and-pencil environments when choosing a mix of these for classroom use. They will want to consider current practices and choose or adapt programs that enable teachers to keep many current teaching moves while changing some—as in the predict, check, explain routine. Teachers can advocate for materials that suit their practices yet still challenge students, and they can advocate for technologies, such as those described, with affordances for a wide variety of students.

There is more to understand about curricular activity systems and their relationship to dynamic representations. While the relationship between materials—particularly technology—and students is a traditional focus of learning scientists, the cases described here bring up the need for balance between the intentions of teachers and developers and the needs of students. As we broaden our perspective, new questions arise; for example, what is the existing set of relationships among teachers, students, and materials into which the new system must fit? And what aspects of the system can we reasonably expect to change, and what aspects must we work within?

Our perspective on a curricular activity system moves us away from the view that a single factor (e.g., a technology, curriculum, or PD plan) can result in meaningful and widespread educational change. Instead, each factor must be considered with respect to the others and situated in an overarching context. In this chapter, we provided examples of how these different factors can be considered as part of an overall system. As the field moves forward practitioners, developers, and researchers must advance this line of thinking and better understand how local constraints, the broader policy environment, specific learning goals, and available resources interact, with the aim of creating learning environments that are widely used and widely effective.

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