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What Happens When the Research Ends? Factors Related to the Sustainability of a Technology-Infused Mathematics Curriculum

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This study examines factors related to the sustainability of SimCalc Mathworlds (SCMW), a technology-infused mathematics curriculum. We surveyed middle school teachers one year after their participation in a randomized trial where they were introduced to SCMW curriculum, to identify factors related to their continued use of the materials in ways congruent with the developers' intent. Fifty-two percent of teachers surveyed sustained their use of the SCMW curriculum. Factors related to sustained use included student SES, pre-intervention student mathematics ability, teachers' perceived coherence and perceived utility of the intervention, and the active nature of the SCMW professional development.

We explore the sustainability of a technology-infused mathematics curriculum intervention, where sustainability is defined as the continued use of the intervention in ways congruent with developers' intent. The data reported in this paper were collected one year after the completion of a multi-year experimental study of the impact on student learning from a replacement unit designed for middle-school mathematics. At that time, 52% of teachers who completed our survey were continuing to use the materials introduced as part of the experiment, while other respondents had chosen to abandon use of the intervention. This fact allowed us to investigate a key question in educational reform: What makes innovations sustainable?

The particular replacement unit in this study provides a useful context for investigating this question, since its designers considered its potential for sustainability from the start. The software that supported the unit, SimCalc Mathworlds®, was designed with the goal of democratizing access to concepts related to the mathematics of change that are normally reserved for students of advanced mathematics, but which can be grasped much earlier by students with proper scaffolding (Roschelle, Kaput, & Stroup, 2000). To accomplish this, SimCalc Mathworlds (SCMW) software uses innovative graphing technologies and dynamic, multiply-linked representations that students can interact with as part of a restructured curriculum. SCMW builds on extensive research in science and mathematics on the value of linked representations for student understanding (e.g., Goldenberg, 1995; Kaput, 1992; Kozma, Russell, Jones, Marx, & Davis, 1996). The curriculum units use the technology's linked representations (e.g. graphs, animations, tables, functions) to support students in developing a robust, integrated, multi-faceted understanding of core middle school concepts (such as rates, proportionality, and linear functions) in ways that foreshadow those concepts' further development in the sequence leading from Algebra to Calculus. For example, a key learning objective of one replacement unit was to enable students to understand how "rate" can be represented by slope in a graph, speed in an animated motion, a sequence of coordinated pairs of values in table, commonplace words like "fast" or "slow" in a story, and by m in the linear function $y = mx + b$.

SimCalc Mathworlds was developed over many years through cycles of design-based research (Hegedus & Moreno-Armella, 2008; Moreno-Armella, Hegedus & Kaput, 2008) that culminated in a recent experimental impact study that found that students in middle-grades classrooms using SimCalc made significantly greater gains in learning about rate and proportionality than did students in control classrooms (http://www.kaputcenter.umassd.edu/products/software; Roschelle, Shechtman, Tatar, Hegedus, Empson, Knudsen, et al., 2010). Importantly, the team that organized the treatment condition in the experiment focused on more than preparing teachers to use the technological infrastructure they had developed. Instead, they sought to develop a curricular unit in which technology use was integrated into a coherent sequence of rich mathematical tasks aimed at developing students' understanding of complex mathematics (Roschelle, Knudsen, & Hegedus, 2010). The unit included a student workbook, brief teacher notes, and software files, which were correlated to the workbook pages. The unit also sought to address state standards in such a way that teachers could replace activities they would normally use to teach selected topics in rate and proportionality; by doing so, the SimCalc research team sought to make the unit as scalable and as sustainable as possible within that state's policy environment.

The goal of the research presented in this paper is to identify features of the replacement unit and teachers' contexts that are related to its continued use after the conclusion of the experimental impact study. In this study, we define "sustainability" as continued use, and posit that factors related to the continued use of the intervention may speak to the larger question of what makes curricular innovations sustainable.

THEORETICAL FRAMEWORK

Researchers have made steady progress in developing educational interventions that combine curriculum materials in mathematics and science with integrated technological tools and teacher training to foster improved learning of standards-based content and to develop connections from grade level content to mathematics that will remain important throughout students' lives. These interventions have been called "coherent curricula" (Roseman, Linn, & Koppal, 2008) or curricular activity systems (Roschelle, Knudsen, & Hegedus, 2010), and they are the carefully designed products of collaborations between researchers and practitioners developed over multiple iterations of design, development, and evaluation (Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). In mathematics, materials that function as replacement units for topics reflected in standards have been tested in rigorous experimental studies and shown to be effective in supporting student learning of complex mathematical concepts (e.g., Saxe, Gearhart, & Nasir, 2001; Confrey, Castro-Filho, & Wilhelm, 2000).

An ongoing challenge to the success of replacement units such as the one that is the focus of this study is to create units whose impacts are sustainable, meaning that the teacher continues to employ the intervention in the manner intended by its designers and makes moves to "own" the intervention such that it becomes a regular part of the instructional repertoire and does not remain a "special" departure from normal practice (Coburn, 2003; Fishman, 2005; Hall & Hord, 1984). Part of the challenge is due to the diminished support associated with the completion of research: in "hothouse" research environments, support, funding, and encouragement is plentiful, but in everyday practice, teachers and schools have limited access to support for innovations and are subject to multiple competing demands (Fishman, Marx, Blumenfeld, Krajcik, & Soloway, 2004). In their planning and enactment, teachers must make choices about the continued use of innovative materials within their existing support structures and within the policy environment that includes pressures such as standardized high-stakes assessment. The development of educative curriculum materials (Davis & Krajcik, 2005; Ball & Cohen, 1999) represents one effort to embed the core ideas of curricular reform within curriculum materials, a potentially important move towards shaping teachers' practice away from the immediate influence of developers. But the field is still early in its understanding of how such materials should be designed, and the more complex the teaching (e.g., inquiry vs. direct instruction), the more difficult it appears to be to communicate those core ideas in printed materials (Crawford, 2000; Fishman & Krajcik, 2003).

Related work on curriculum adaptation begins to explore how and why teachers adapt curriculum materials to their local contexts and to provide tools to shape adaptation to maintain consistency with designers' intentions (Lin & Fishman, 2006). One key finding from this work is that without support, teachers often make decisions about how to adapt curriculum materials to fit with local constraints that are different than the choices curriculum developers might make given similar constraints, and these decisions result in adaptations that undercut the coherence of the curriculum. For example, many teachers, when faced with less time for enactment than called for in the materials, will omit activities such as a final capstone project in order to save time, even if that final project is considered crucial (by the curriculum designers) to students' overall understanding of the materials (Lin & Fishman, 2006).

When coherent curricula are implemented in ways that are at odds with their original design, the strength of the interventions as measured under more ideal conditions of support is diminished. An example is Carnegie Learning, Inc.'s Cognitive Tutor. The model for implementation of the Cognitive Tutor calls for a combination of cooperative, face-to-face learning and problem solving with an intelligent tutor. A number of small-scale experimental studies in which implementation was supported by researchers found positive impacts on students' explanations and transfer of knowledge (Aleven & Koedinger, 2002; Anderson, Corbett, Koedinger, & Pelletier, 1995). The magnitude of effects on student learning in one of these studies (Aleven & Koedinger) was over one standard deviation (+1.36). By contrast, a subsequent study conducted in the field with multiple classrooms still found the program to boost achievement relative to a control group, but the magnitude of effects was much smaller (+0.23) (Ritter, Kulikowich, Lei, McGuire, & Morgan, 2007). Most of the teachers in this second study of the Cognitive Tutor were new to the intervention and half reported that they did not feel comfortable implementing the Cognitive Tutor for the first half of the school year. A challenge for the field is to develop high-quality interventions that are able to maintain positive outcomes despite well-documented hurdles to successful implementation common in school settings (Penuel & Means, 2005).

The study of sustainability with respect to curriculum-based interventions is still evolving, and there are not yet widely accepted frameworks or approaches to study sustainability. Part of the challenge is that, by definition, sustainability is something that occurs *after* the work of design and implementation, and therefore at a point in time where research funding has concluded and researchers have moved on to a different set of problems (Fishman, et al., 2004). Even in the field of public health, where research on program implementation is much more mature than in education, researchers have commented that the study of "what happens after the research ends" (Scheirer, p. 323) is not well-conceptualized. By studying the continued use of SCMW materials after the formal research on implementing SCMW has ended, we hope to contribute to understanding in this crucial area for research on educational innovation.

Below, we review prior research with respect to implementation of curricular innovations. We organize our review into categories or factors that we explore in this study, namely teacher expectations for their own students, teachers' perceptions about the coherence of the innovation, and teachers' perceptions about the utility of the innovation.

TEACHER EXPECTATIONS AND MATH INSTRUCTION/ACHIEVEMENT

Apart from factors that are either intrinsic to an innovation or attributed to interventions by teachers, there is reason to believe that teachers' perceptions of their own students' mathematics ability shape the kinds of instruction they think appropriate and are willing to enact. There is evidence of a relationship between expectations and achievement, as was found in the 1988 National Education Longitudinal Study (Rowan, Chiang, & Miller, 1997). Analyses of survey data collected through the Third International Mathematics and Science Study (TIMSS) indicate a distinguishing feature of U.S. teachers is their belief that conceptual teaching strategies in mathematics are more appropriate for high-achieving students than for low-achieving students (Desimone, Smith, Baker, & Ueno, 2005).

This aspect of teacher belief may lead to a situation where "haves" get more and newer learning opportunities while "have nots" either stand still or lose what little they have to begin with. Such an effect has been documented in various areas of education (Walberg & Tsai, 1983; Stanovich, 1986), including mathematics (Young-Loveridge, 2005). If this were the case for SCMW implementation, its curriculum developers would be especially troubled, because they developed SCMW to enhance the accessibility of advanced mathematical concepts to *all* learners, and has been demonstrated to be effective at that goal across a range of studies (e.g., Stroup, 2005). These and other developers of curricular innovations would want to be especially attuned to perceptions that lower-achieving students are not capable of learning advanced concepts, because it could explain a component of teacher decision making about whether materials are a good "fit" for their students, and thus whether they would choose to sustain the use of a particular innovation. It may also explain whether or not a teacher is likely to make adaptations in the implementation of an innovation that significantly alter the nature of the teaching strategies. For an innovation such as SCMW, which is designed to foster greater access to important and readily-applicable mathematical ideas among students, this is an important concern (Kaput & Schorr, 2007; Kaput, 1994).

Studies have also found a strong relationship between teachers' beliefs about who should be in control of decision-making about mathematics activity in the classroom, the nature of mathematics ability, and mathematics instruction (Stipek, Givvin, Salmon, & MacGyvers, 2001; Wilkins, 2008). Even when teachers do believe in the potential value of conceptual teaching in mathematics, teachers often perceive that standards and accountability pressures make it difficult for them to implement these strategies with students (Bolden & Newton, 2008), a phenomenon that we discuss further below as contributing to the construct we refer to as perceived coherence.

PERCEIVED COHERENCE

One way to describe teachers' perceptions of an innovation is in terms of the innovation's coherence. The first two authors explored coherence in relation to teachers' perceptions of professional development for a K-12 science education reform curriculum called Global Learning and Observations to Benefit the Environment (GLOBE; Penuel, et al., 2007). Our first explorations of coherence were inspired by the Garet, et al. (2001) study of Eisenhower Math and Science professional development, in which it was found that professional development programs were more effective when viewed as part of a "coherent program" (p. 927). Garet et al. (2001) constructed their model of coherence based on connections between the professional development and other activities teachers were engaged in, alignment with state and district standards, and the extent to which teachers participated in professional development either by themselves or as part of a group. In the GLOBE study, we examined a confluence of factors that we hypothesized would be related to how teachers perceived the coherence of the professional development, based on findings from literatures related to policy and practice in teacher learning and reform. This included evidence that teachers use their own interpretative frames when making sense of how the messages in an intervention relate to the policy demands (state and local standards) placed upon them (Coburn, 2004; Cuban, 1986; Cuban, Kirkpatrick, & Peck, 2001). Research on the implementation of particular curricular materials provided evidence that school context plays a key role in how teachers decide either to enact or reject particular innovations (Rivet, 2006). If teachers perceive the innovation to be coherent or congruent with their own or their school's goals for reform, this should lead to an increased commitment to enact the innovation.

In the Penuel, et al. (2007), study of GLOBE, we found that perceived coherence was related to observed levels of implementation of the curriculum. Note that in the GLOBE research we were not studying sustainability, but rather initial levels of implementation following professional development. It is logical, however, that implementation is a necessary precursor of sustainability and that the same issues related to coherence would be at play. In this study we turn our attention to coherence as expressed by teachers *after* the curriculum was initially implemented and ask them to reflect on how the features of the entire intervention (curriculum *and* professional development *and* subsequent support are related to their perceptions of coherence with respect to the same factors we explored for GLOBE professional development). We hypothesize that higher levels of perceived coherence for the SimCalc Mathworlds intervention should be associated with sustainability in the current study.

ACTIVE LEARNING IN PROFESSIONAL DEVELOPMENT

The overall design of professional development activities has been shown to be important in both how teachers' beliefs are affected by professional development (Garet, et al., 2001) and as predictive of the adoption of an innovation by teachers (Penuel, et al., 2007). In science education, there has long been a belief that teachers need firsthand experiences within professional development with the style of teaching called for in materials, if they are to successfully enact that teaching in the classroom (Gess-Newsome, 1999), and the same is likely to be the case for teachers of mathematics. The developers of the SCMW curriculum materials intend for teachers to enact an interactive approach to mathematics learning that employs computer simulation to support student understanding. The professional development associated with the SCMW curriculum employs an active, hands-on approach that models the teaching called for in the materials so that teachers can experience and practice that kind of teaching. We hypothesize that the extent to which teachers engage with these kinds of activities will be related to continued use of the materials.

PERCEIVED UTILITY

Teachers' perceptions of the usefulness, or utility of an innovation as it relates to student learning, instructional practice, and their own professional learning may also influence their decisions to use an instructional innovation. We operationalize utility as a set of personal perceptions about the likely benefit of an innovation in terms of their value for teachers in the context of their practice. Just as Lave (1988) has characterized curricular experiences of students in terms of the degree to which they have clear "use-value" for students in their everyday lives, so, too, can we characterize curricular materials in terms of their use-value in supporting them in the everyday work of teaching. For instance, in mathematics education proportional reasoning is an important learning outcome featured in standards, so curriculum materials that teachers perceive as helping their students better develop proportional reasoning abilities may be viewed as useful in achieving that goal and therefore worthwhile to employ. The SCMW materials feature graphs and simulations as representations that support the development of proportional reasoning. What distinguishes learning about graphs as a component of utility as opposed to a component of coherence is the worth a teacher places upon it. Learning how to read graphs might be specified in standards (we described alignment with standards as a component of coherence above), but if a teacher feels that she or he is already meeting that standard in another way, and does not value the way in which graphing can support the development of proportional reasoning, the perceived usefulness of the new curriculum innovation in comparison to other options available to the teacher might be low.

Other factors can contribute to a teachers' perception of the utility of curriculum materials. A social norm emphasizing a particular approach to teaching (Judson & Lawson, 2007) or the use of technology (Frank, Zhao, & Borman, 2004) might drive perceptions of utility, such that an innovation that employs that approach or that embeds technology use in curricular activities will be viewed as providing a valued outcome beyond "regular" content learning. Teachers might also perceive as useful innovations that make their professional lives easier. Innovations that are highly specified (Cohen & Ball, 1999) help reduce the amount of decision-making by teachers. Some teachers who appreciate the ready-made character of curriculum materials may perceive such innovations as useful, but other teachers may see these innovations as providing less utility, because they reduce their autonomy and ability to adapt materials to students' diverse needs. Providing lesson plans or support for lesson planning could also appeal to teachers as being useful, as many teachers are required to provide lesson plans as part of administrative oversight: in fact, one reason why the "replacement unit" strategy for scaling has become so popular may be because in part it adds value in this respect. Replacement units support targeted curriculum improvements aligned to standards, but do not require teachers to create their own instructional materials from scratch.

Utility is also likely to have both general and specific dimensions. For instance, there are some elements that support planning that help teachers no matter what the curriculum materials are, such as information about how lessons help students meet standards, guides for organizing student activities, provision of worksheets, readers, or other materials. These are general features of curriculum materials that teachers could see as useful. Specific innovations, such as SimCalc, may have unique features for which specific support is required. For example, few replacement units in mathematics require the extensive use of technology. The fact that SimCalc does require the use of technology for a successful implementation may mean that teachers will value SimCalc more only if the professional development or other support materials provide them with sufficient support for technology or other specialized aspects of the SimCalc innovation.

METHODS

This study explores the extent to which each of the above factors—teacher expectations, perceived coherence, and utility—are related to continued use of the SimCalc Mathworlds middle school mathematics curriculum, one year after completion of a large scale randomized trial of the efficacy of the curricular activity system conducted with middle school teachers across Texas. This mixed-method study focused on the 7th and 8th grade teachers who participated in the "Scaling Up SimCalc" study (hereafter referred to as the "Scaling" study). The present study is correlational in nature; it focuses on identifying associations between school- and teacher-level variables and persistence (or *sustained use*) with the SCMW curriculum. In the Scaling experimental study, teachers were recruited by local education service centers, were provided with all necessary materials including computer software, and were paid a stipend for their participation. Results from the Scaling study indicated that students of teachers who implemented the 2-to-3-week replacement unit on rate and proportionality performed as well on basic-level test items as students in control classrooms, and much better on challenge items, indicating a deeper understanding of the math concepts (Roschelle, et al., 2010). The full intervention consisted of a professional development workshop, and a follow-on planning meeting during the school year, printed curriculum guides with student and teacher materials, and software to help students visualize concepts such as rate vs. time and proportionality. This paper does not focus on results of the Scaling study (see Roschelle et al., 2010), but instead uses that study and its participants as a context to understand what happened *next*, after the Scaling study was concluded (i.e., what happens "after the research ends").

DATA SOURCES

Data for this study come from two sources: (1) an online survey administered to teachers in 2008, approximately one year *after* the conclusion of the Scaling experiment, and (2) pre- and posttest data on student learning from the Scaling study described above from 2005-2007. The survey consisted of 15 items, focused on teacher perceptions of professional development, support for implementation, barriers to implementation, continuing use of the intervention materials, and communication with peers relating to the intervention materials. Many of these items were validated in prior studies of teacher professional development (Garet, Porter, Desimone, Birman,

& Yoon, 2001), implementation, and the scaling up of innovations (Fishman, Penuel, & Yamaguchi, 2006; Penuel, et al., 2007). Prior uses of the survey items were for generic professional development contexts in math and science (Eisenhower-funded math and science programs) and for a specific, but different set of curriculum materials (GLOBE). Consequently, we adapted the items slightly to address the specific context of the SCMW Scaling study. In addition, some new SimCalc-specific items were created for this study. The survey was piloted over the telephone with teachers who were users of SimCalc Mathworlds in order to determine that the items were comprehensible and being interpreted in the manner we intended.

SAMPLE

The sample population for this study was the 189 teachers who participated in the original SCMW Scaling studies. Sixty-seven teachers from the larger population responded and completed an online survey, for a response rate of 35%. Seventy-seven percent of survey responders were female (n=51), 23% male (n=16), ranged in age from 27 to 59 (M=43.47, SD=9.073), and represented between 1 and 27 years of teaching (M=10.87, SD=7.413) and 1 and 27 years of teaching mathematics (M=9.64, SD=6.867).

Because of concerns about the response rate, we conducted a non-response analysis in order to determine whether the teachers who responded to our survey differed in any meaningful way from teachers who did not respond, using data on teacher and student demographics from the Scaling study. Using independent-samples t-tests, we compared initial student mathematics scores ($t = -1.647$, $df = 145$, $p > .05$), gain scores from pre-post testing ($t = -.772$, $df = 146$, $p > .05$), the geographic distribution of teachers (data from the original experiment) ($t = 1.516$, $df = 178$, $p > .05$), and campus-level SES ($t = -.371$, $df = 146$, $p > .05$). None of these comparisons indicated a significant difference between response and non-response groups, giving us confidence that the results of this study are not biased as a result of response patterns on any measured characteristics of teachers or students. Other studies have reported difficulties in response rates from mathematics teachers in particular, reporting that "while normal expectations of survey response rates [in education] were between 65% and 83%, secondary mathematics teachers… responded from a low of 31% to a high of 46%" (Coffland & Strickland, 2004, p. 353). We are unsure of why mathematics teachers would be less likely to participate in survey research, but note that our response rate is consistent with that of earlier studies.

Most importantly for purposes of our analysis, the sample of survey responders was divided roughly evenly between teachers who were continuing to use SCMW and those who had discontinued use. This variability enabled the analyses we present here, though an important caution is that the associations between continued use and the teacher and contextual variables do not provide a strong evidentiary basis for causal inference. Replication studies, as well as sustainability studies that begin before the research ends and continue well beyond it are needed to accumulate further evidence for the theoretical framework articulated here.

MEASURES

The following items and scales were developed in our analysis of the surveys.

Sustained Use

A single, binary (1 = yes, 0 = no) item on the survey served as our measure of sustained use of the SCMW materials after the end of the SimCalc Scaling Study: "Are you still using all or part of the SimCalc curriculum?" We recognize that a more nuanced approach to studying sustainability might investigate the "fidelity" of continued implementation of SCMW materials, but we were explicitly not interested in that issue in the present study, preferring to treat any continued use as a necessary first step to sustainability.

Student Socioeconomic Status

We used the percentage of students in the teacher's school that were eligible for free or reduced price lunches as a measure of students' socioeconomic status.

Prior Mathematics Achievement of Students

We used as a baseline the normalized pretest scores of students in the SimCalc Scaling study on the tests of mathematics achievement developed by the SCMW research team (see, Roschelle et al., 2010, for a more extended description of the measure and its development). This test was constructed to measure both the more formula-oriented and procedural aspects of proportionality and linear function, as conventionally measured on the Texas statewide assessment as well as a function-oriented and conceptual orientation to these topics. For example the test asks students to consider the mapping between a domain and range and to connect such concepts as rate across multiple representations (e.g., k, in $y = kx$ and the slope in a graph of $y = kx$). The student scores used were those of students from teachers' classes that had participated in the SimCalc scaling study (in a prior year) and were not scores of teachers' students at the time we conducted the survey (after the experiment had concluded). To the extent that students across years have similar levels of ability, however, the pretest scores do offer a proxy measure of prior achievement levels of students, particularly with respect to conceptually rich mathematics.

Perceived Coherence

We incorporated into our questionnaire a six-item scale ($\alpha = .93$) used in three earlier studies of professional development (Garet, Porter, Desimone, Birman, & Yoon, 2001; Penuel, Fishman, Gallagher, Korbak, & Lopez-Prado, 2009; Penuel, Fishman, Yamaguchi, & Gallagher, 2007), which measures how well the professional development matched the teacher's goals for professional development, the existing reform ideas within the school, and whether the professional development was followed up with activities that built upon what was already learned. In this study, we used perceived coherence as a teacher-level predictor of sustained use of SCMW.

Perceived Utility (General)

The perceived utility scale is a 3-item scale ($\alpha = 0.84$) that measures teachers' perceptions of the use-value or usefulness of SCMW materials. We refer to it as a "general" scale because it encompasses items that teachers are likely to consider in assigning value to curriculum materials, regardless of the particular materials: the usefulness of the print materials, the timetable for enactment, and support for teaching required standards. For each of these items, teachers indicated whether they found SCMW materials very valuable, valuable, not so valuable, or detrimental for their teaching. The scale created represents the sum of the three items.

Perceived Utility (SimCalc Mathworlds Key Features)

The perceived utility scale for key features of SCMW is a 3-item scale ($\alpha = 0.94$) that measures teachers' perceptions of the usefulness of features judged by program developers to be "key features" of the software. These key features are: simulations, interactive graphs, and the tight integration of curriculum and technology. As with the other utility items, for each item teachers indicated whether they found these key features very valuable, valuable, not so valuable, or detrimental for their teaching. The scale created represents the sum of the three items.

Active Learning in Professional Development (General*SCMW)

The active learning in professional development scale is a three-item scale ($\alpha = 0.94$) that asks teachers to report how much interaction took place as part of their professional development to learn to use SCMW materials. The SCMW research team identified these items as key features of SCMW and active learning in professional development activities has been linked in other studies to reported changes in teacher outcomes (Garet et al., 2001; Penuel et al., 2007). We thus refer to this scale as a "general*SCMW" scale, since it might be expected to be generally related to curriculum implementation but is also a scale SCMW developers believe is particularly important for implementing their curricular activity system. For these items, teachers rated items on a 6-point scale from "did not participate" to "found essential" in preparing to teach the SCMW unit.

APPROACH TO ANALYSIS

Our primary interest was in analyzing what factors are associated with teachers' sustained use of SCMW after the study ended. Because of the small sample size, and also because our predictors were highly correlated with one another (see Table 1 below), we examined the contribution of each potential factor separately. The advantage of our approach is that it allowed us to consider how each of our theorized mechanisms may have contributed to teachers' decisions related to sustained use. At the same time, the strong, significant correlations suggest that there may be an underlying mechanism that explains the patterns of survey responses we see more adequately than do the scales we used in analysis. We return to this potential limitation of our analysis in the discussion and conclusion section.

Table 1
Correlation matrix of teacher-level predictor variables

	(1)	(2)	(3)	(4)	(5)
(**1**) Students' Mean Achievement on the M2 Scale (Pretest Prior to SCMW)	1.00	0.28*	0.18	0.21	0.30*
(**2**) Perceived Coherence Scale		1.00	0.43**	0.37**	0.96**
(**3**) Perceived Utility Scale (General)			1.00	0.72*	0.38**
(**4**) Perceived Utility Scale (SCMW)				1.00	0.35**
(**5**) Active Learning in Professional Development Scale (General*SCMW)					1.00

DESCRIPTIVE STATISTICS

Approximately half (n=35, 52%) of the teachers who completed our survey (n=67) reported continued use of the SCMW curriculum materials, what we refer to as "sustained use," one year after the conclusion of the "Scaling Up SimCalc" research study. Descriptive statistics for all other measures are reported below in Table 2.

Table 2
Descriptive statistics

	n	**M**	**SD**
School-Level Predictors			
Percent free and reduced price lunch	67	50.42	27.16
Teacher-level Predictors			
Students' Mean Achievement on the Complex Mathematics (M2) Scale (Pretest Prior to SCMW)	67	5.29	2.41
Perceived Coherence Scale	66	22.02	4.27
Perceived Utility Scale (General)	65	9.11	2.20
Perceived Utility Scale (SCMW)	65	10.03	2.61
Active Learning in Professional Development Scale (General*SCMW)	66	6.42	1.90

FINDINGS

Table 3 reports the significance of the factors explored in this study with respect to sustained use of the SCMW curriculum materials. The strongest correlate of sustained use was found in relation to students' SES (d = -0.93, $p < .001$), and students' prior achievement in conceptually-rich mathematics (d = 0.81, $p < .05$). The higher the SES and the greater students' pre-SCMW performance in conceptually-rich mathematics, the more likely the teacher was to continue using the SCMW materials. A relationship was also found between sticking and teachers' perceived coherence of the SCMW materials (d = 0.56, $p < .01$). A slightly weaker relationship was found for perceived value, both in terms of general value (d = 0.40, $p < .05$) and for the value of specific characteristics of the SCMW materials (d = 0.37, $p < .10$), and also for the active nature of the professional development (d = 0.26, $p < .05$).

Table 3

Factors related to sustained use of SCMW (t-tests)

	Sustained Users	**Non-Sustainers**	***t* (df)**	**d**
Percent Free and Reduced Price Lunch in School (SES)	*M* = 40.90 *SD* = (25.90)	*M* = 63.51 *SD* = (24.44)	-3.55*** (61)	-0.93
Prior Achievement in Conceptually- Rich Mathematics	5.96 (2.67)	4.47 (1.86)	2.53* (61)	+0.81
Perceived Coherence	23.37 (3.04)	20.93 (4.35)	2.65** (63)	+0.56
Perceived Utility (General)	9.60 (1.56)	8.53 (2.69)	1.99* (63)	+0.40
Perceived Utility (SCMW)	10.63 (1.33)	9.33 (3.47)	1.93+ (44.9)	+0.37
Active Learning in Professional Development (General*SCMW)	6.94 (1.41)	6.03 (3.47)	2.17* (63)	+0.26

+ $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$

REASONS GIVEN FOR *NOT* SUSTAINING THE USE OF SCMW

Finally, for those teachers (n=32) who indicated that they did not continue to use the SCMW materials) we asked them to identify reasons that might explain their decision. These reasons are presented in Table 4. Teachers were able to indicate as many reasons as they felt were relevant, though they were selecting from a list of items presented in the survey.

The top three reasons teachers gave for not continuing to use the SCMW materials were related to time (time to prepare for state tests, time to enact the activities, and time to prepare to use the activities). The second most common explanations were related to access to technology (if the school had computers, the SCMW teacher felt they did not have adequate access to them) or lack of computers overall in the school. We also note that very few teachers reported technical difficulties or administrative support as their reasons for not continuing with SCMW.

Table 4

Percentage of teachers indicating various reasons for no longer using SCMW materials (respondents could select multiple responses; *n*=32).

Reason for not continuing to use SCMW materials	Percent
Material took too long, interfered with preparation for state tests	30%
Difficulty completing activities in suggested time	27%
Lack of time to prepare	23%
Lack of technology access	20%
Lack of computers in school	13%
Interest level of my students	13%
Lack of alignment to state test	10%
Math knowledge level of my students	10%
Difficulty with software	7%
Unsupportive district administrators	3%
Lack of technology support	3%
Unsupportive building administrators	0%
Lack of understanding of how to implement units	0%

DISCUSSION

What can we learn from the findings presented above, and how do they help us further refine our understanding of findings from prior research on factors related to the sustainability of curriculum materials?

Our findings with respect to coherence are consistent with previous research and help us to continue to refine our understanding of how perceived coherence relates to teachers' decisions about the continued use of materials. In prior research (Garet et al., 2000; Penuel et al., 2009; Penuel, et al. 2007), we examined how teachers' perceptions of coherence are related to their implementation of materials. This construct looks across teachers' judgments of how well the professional development matches teachers' own goals for professional learning, how well the professional development (and perhaps by extension the innovation) matches existing reform ideas or approaches within their schools, and how well the professional development is followed up upon with activities that build on what was learned in the professional development. Our prior studies were focused on initial implementation levels. In the present study we focused on subsequent continued or sustained use of materials and found that coherence is also related to sustained use. The continued significance of this factor across multiple studies and in different contexts is encouraging, and provides further evidence for the importance of constructing professional development activities with teachers' perspectives about coherence firmly in mind.

This study represents the first time we have examined the perceived utility of curriculum materials directly. We were interested to see that both scales related to teachers' continued use of the SCMW materials, and further interested to see that the more general notion of utility was more strongly related to sticking than curriculum-specific notions of utility. This may be an indication that teachers are weighing the usefulness of any particular curricular innovation against an ongoing set of daily challenges, including planning, time to teach, and the demands of standards. The specific qualities of the SCMW materials, namely tight integration with technology and a focus on interactive graphs and simulations, may be viewed by teachers as important, but only within the context of the larger demands of teaching. This contrast deserves further exploration in future studies. We continue to examine data on how teachers who sustain the use of SCMW vary in their choices of *how* to implement the curricular intervention. In our theoretical framework, we introduced the example of the Cognitive Tutor, a high-quality and well-studied intervention. There was substantial variation in effect sizes between early experimental studies of Cognitive Tutor and later field trials at greater scale (e.g., Aleven & Koedinger, 2002; Ritter, et al., 2007). Positive effects are often attenuated as interventions move from conditions of high support to more widespread use, where implementation can introduce many adaptations not envisioned by designers (Fishman, et al., 2004). It is possible, of course, that implementations at great variance with the original design can lead to impacts as large as are estimated under conditions of high support, such as when teachers fully “own” an innovation to the extent that they can reinvent its use to suit their own purposes (Hall & Hord, 1984). Our belief is that for materials that are of high initial quality, attention to teacher perceptions of coherence and utility may help support adaptations that are more in line with designers’ intentions, even in the face of a range of well-documented hurdles to implementation (Penuel & Means, 2004; Rogan, 2007; Rowan & Miller, 2007).

Sustainability was also related to teachers’ perceptions about “fit” with either their preferred style of teaching or the capabilities of their students. There was a relationship between continued use of the SCMW curriculum materials and teachers’ perceptions about how “cognitively complex” their math teaching was *prior* to using SCMW. This is also borne out by data gathered as part of the Scaling study (Roschelle, et al., 2010). Findings from that study could be interpreted to argue for wide adoption of technology-infused mathematics curricula like SCMW; the experiment indicated that students in a wide variety of settings and with widely varied SES and other factors all learned more when their teachers used SCMW. Thus, broadly implementing these materials could be a component of a policy approach to enrich mathematics for all students. However, the further addition of data on sustained use in the present study adds a caveat: over time, the lower SES settings may be more likely to stop using the newly recommended curriculum materials. This could result in the unanticipated consequence that a policy intended to give *all* students access to more challenging mathematics materials could result in continued use of those materials only with higher-pretest students. To counter this possibility, our data suggest that researchers and policymakers should investigate how to enhance professional development (e.g., implement designs to increase teachers’ perceptions of coherence in the curriculum) for low SES settings or in settings where student performance is lower on pre-tests in order to increase the likelihood that use of such materials is sustained across all settings.

In considering the data presented in Table 4, reasons given by teachers for *not* continuing to use the materials, we find it encouraging that no teacher felt they did not understand how to use the materials, which would be a failing of the professional development. At the same time, it is less encouraging that relatively large percentages of teachers indicated a lack of time to enact SCMW in relation to other priorities was a barrier to continued use. This may be an indication of the overall pressure teachers feel to “cover” content for high-stakes tests, a scenario in which the in-depth approach of SCMW may feel like a luxury. Given findings from the SCMW

Scaling study (Roschelle, et al., 2010) indicating that students learn both basic-level items from high-stakes testing as well as more challenging mathematics, this could be an area for future SCMW professional development to highlight in its communication with teachers about the intent and most productive ways to use SimCalc Mathworlds.

CONCLUSION

Working to develop innovations that are usable and, more importantly, continue to be used by teachers is a critical challenge for the educational research community (Fishman, et al., 2004). If research-based curricular innovations are not sustainable, what hope is there that our investment in these materials will have a deep or lasting effect on education? We find it useful to view curriculum materials as a specialized "technology" for education, in that curriculum is intended as a systematic solution to an instructional problem (Gomez, Fishman, & Pea, 1998). SCMW is a technology, curriculum, and teacher professional development intervention designed to enable teachers to instruct students about complex mathematical ideas using a combination of thoughtfully designed and empirically-design lessons supported by computational tools and activities tailored to support students' learning about the concepts within the lessons. The SCMW materials are highly specified in an attempt to reduce teacher uncertainty about how to teach (Cohen & Ball, 1999), but SCMW developers also understand that there will always be local adaptations made by teachers based both on their interpretation of the materials and also on the constraints and opportunities of their local context.

The challenge is to ensure that these adaptations do not lead to implementations that result in enactments that vary so greatly from the intended design as to lead to undesirable outcomes, or in effect be a different innovation altogether (Brown & Campione, 1996). To help prevent this, it is also important to recognize that SCMW is a full "curricular activity system" (Roschelle et al., 2010) that consists not only of the curriculum and technology, but also of professional development intended to guide teachers' interpretation and use the materials in the classroom. Thus, the study of adoption and sustainability needs to examine not only the qualities of the materials and the contexts where they are to be used, but the system(s) of support provided to teachers across all phases of an innovations introduction and use.

In this work, SimCalc Mathworlds' developers were both surprised and pleased that *so many* of the teachers (52%) who responded to our survey continued to use the software and materials after the conclusion of the research study. The results from this study, together with emerging evidence from related work (e.g., Penuel, et al., 2007), point to factors that should be attended to in further research on how best to support implementation of complex technology-supported interventions in mathematics and science. The finding that both coherence and utility are important to decisions to continue with implementation should inform the design of educational interventions, so that they that can be widely used to ensure that children have meaningful and deep interactions with important mathematics content.

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