MEETING THE NEEDS OF DIVERSE STUDENT POPULATIONS: FINDINGS FROM THE SCALING UP SIMCALC PROJECT

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While research has shown the effectiveness of representational technologies in mathematics education, barriers to broad use remain. The Scaling Up SimCalc project has begun to address these barriers by considering the role of technology within a wider "curricular activity system." In this paper we discuss how we leveraged the representational and communicative infrastructure of SimCalc to meet the needs of a diverse student population, while we also met the needs of key stakeholders in the wider education system. This resulted in increased learning for a diverse group of students. We also discuss possible improvements to our intervention.

Introduction

Research has shown the effectiveness of using representational technologies in mathematics to scaffold and support student learning (Mayer, 2005; Marzano, 1998). However, there have been barriers to broad use, such as the perception that technology is too difficult to implement in diverse classrooms (Becker, 2001), and inconsistent findings on the benefits of educational technology in mathematics (Dynarski et al., 2007; National Mathematics Advisory Panel, 2008).

In this paper we report on a study that leveraged the effective aspects of representational technology while overcoming existing barriers to broad use. The study evaluated a particular instantiation of the SimCalc approach, which integrates interactive representations with paper curriculum and teacher professional development to increase students' opportunity to learn advanced mathematics. In designing the Scaling Up SimCalc study, we incorporated the perspectives of different stakeholders –students, teachers, and school districts– to minimize barriers to implementation and increase the chance of having the intervention used. We addressed teacher and district concerns regarding current policy demands (e.g. NCLB and accountability testing) and the need to meet local standards. We considered multiple teaching styles and designed materials so teachers with a wide variety of mathematical and technological backgrounds could use them. And, through representational technologies and scaffolded curriculum we met the cognitive, linguistic, and social needs of a diverse student population. At the heart of this approach is a refinement of our conceptualization of the use of innovative technology in the classroom. Whereas earlier work focused primarily on the representational and communicative infrastructure of SimCalc, the concept of a "curricular activity system" has emerged as being vital to successful scale up (Roschelle et. al., in review).

Scaling Up SimCalc makes an important contribution to the literature by providing very strong evidence that embracing these diverse perspectives increased student learning of advanced mathematics with a diversity of teachers in a wide variety of settings.

Swars, S. L., Stinson, D. W., & Lemons-Smith, S. (Eds.). (2009). Proceedings of the 31st annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education. Atlanta, GA: Georgia State University.

Background

For over fifteen years the SimCalc project has had the goal of ensuring that all learners have access to complex and important mathematics, as expressed in the SimCalc mission statement "democratizing access to the mathematics of change and variation" (Kaput, 1994). The mathematics of change and variation emphasizes the concepts of rate and accumulation as thematic content that can be developed across many grade levels. A foundational belief of the SimCalc Project team is that reconceptualizing middle school and high school mathematics in light of the broader mathematics of change and variation developmental strand can yield a more coherent and fruitful mathematical experience for all learners, including those that have not traditionally been successful in mathematics (Kaput & Roschelle, 1997).

This view of how mathematics can be structured stands in contrast to the traditional mathematics curricula, which was laid out in the 17th and 18th centuries, and hasn't changed much since (Kaput & Roschelle, 1997). This is, in part, because the curriculum has "worked" to train a workforce where most jobs require little more than arithmetic, and few require deep understanding of advanced mathematical concepts. Today, the picture is different. Not only are there economic arguments for preparing more young people, of different races and backgrounds, to use complex mathematics on the job (National Advisory Mathematical Panel, 2008), but participation in society as an empowered citizen requires understanding the mathematics of change (Kaput & Roschelle, 1997), and increasing the number and diversity of those in the field of mathematics may even be vital in advancing the field itself (Gutierrez, 2007).

While the SimCalc research program has considered restructuring the mathematics curriculum as a way to achieve its goal of democratization, strict adherence to this goal in the short term may stand in the way of necessary reforms that can help many of the students who need this access the most—those in low-performing schools who are already likely to get worse instruction and less access to high-level content than their peers at high performing schools. In this study, guided by a curricular activity systems approach, we built upon the past successes of SimCalc, while taking an incremental approach to addressing what is taught.

In this paper, we will use *SimCalc* to refer to the Scaling Up SimCalc study (2005-2008) and the system of curriculum, software and professional development developed therein. The software, SimCalc MathWorlds® (hereon referred to as MathWorlds), is a simulation environment in which the user and the software co-construct mathematically meaningful objects and relationships. MathWorlds moves beyond simple interactivity and animations of math, and instead provides students with access to complex mathematics, and allows students to quickly conjecture, test, and iterate while preserving mathematical relationships and structures. This is very difficult to replicate in static media, where students may unintentionally violate mathematical principles in an investigation (Hegedus, 2005).

We next describe the results from the Scaling Up SimCalc study, and then report on those features of our intervention that most likely resulted in its success in helping a wide variety of students learn important mathematics.

Results from the Scaling Up SimCalc Study

The Scaling Up SimCalc study found the SimCalc approach to be successful in meeting the needs of a diverse set of students and teachers. Ninety-five seventh grade teachers and their students across varying regions in Texas participated in a randomized controlled experiment in which they implemented a SimCalc-based three-week replacement unit. An analysis of the results showed a large and significant main effect with an effect size of 0.8 (Roschelle et al., 2007; Roschelle et al., in review). 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,[1] teacher-rated prior achievement (we will discuss possible remedies for the trend of higher achievement students having slightly higher gain scores in the *Conclusion and Discussion*), and poverty level[2] (Figure 1). We provide a comparison of students in one particular region in Texas, Region 1, to other students in the study. Region 1 is in the Rio Grande Valley adjacent to the Mexican border, is predominantly Hispanic, and is one of the poorest areas in the United States. Consistent with our other data, we see that the students in Region 1 who used SimCalc had greater learning gains than students in the control condition.

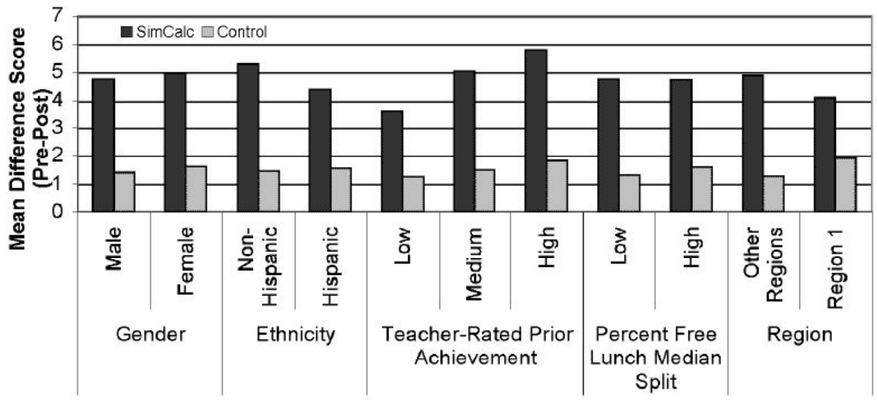

Figure 1. Mean student-learning gains by subpopulation group.

In the remainder of this paper we report on those aspects of the SimCalc curricular activity system that most likely led to these robust findings. In particular, we leveraged those features of the SimCalc environment that are consistent with the literature on under-achieving students (particularly those from non-mainstream backgrounds), while also meeting the needs of key stakeholders in the education system. We also discuss ways the integrated system could be improved to further close the gap for particular subpopulations.

Research Foundations

In this section we describe some of the key features of SimCalc as a representational and communicative infrastructure. These features of SimCalc relate directly to what we know about effective instruction for all student populations, including students from non-dominant cultural and language backgrounds and other students who traditionally underperform in mathematics (e.g. Moschovitch, 2007b; Kaput and Roschelle, 1998).

SimCalc builds on students' existing competencies and experiences. The SimCalc approach differs from the traditional pre-algebra approach in several ways. Perhaps the most important is that SimCalc places motion phenomena at the center of learning (see Figure 2), enabling students to build on their existing cognitive and social competencies. Research with urban students (Monk & Nemirovsky, 1994) has shown that students tend to engage in "interval analysis" of motion simulations and interpret motion in a piecewise manner (e.g. "First the boy was going slowly, then he was running really fast, and then he stopped"). Further, all students, including traditionally low-achieving students, are capable of constructing rich stories about motion over time and can use narratives as a resource for interpreting graphical and tabular representations of motion as they build a qualitative understanding of calculus (Stroup, 2002). SimCalc allows

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students to play and replay a simulation of motion as many times as they wish, allowing more students to access these fundamental resources than is possible using traditional static media.

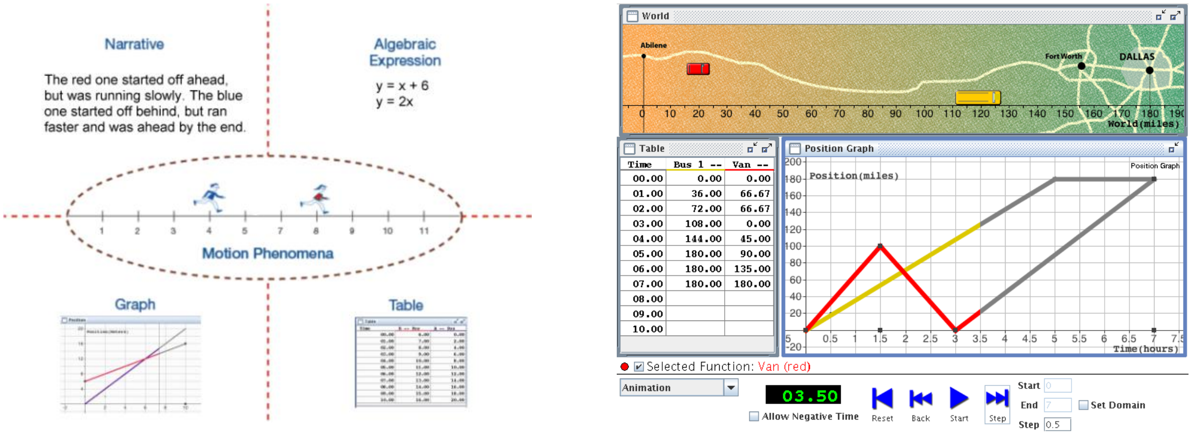

Figure 2. SimCalc linked representations (left); MathWorlds activity screenshot (right).

SimCalc supports multiple forms of representation and expression (see Figure 2). In SimCalc students study functions through linked motion, graphs, tables, and symbolic expressions. Research has found that complex mathematics is more learnable when students are not reliant on symbolic forms or dense textual descriptions, but can interact directly with a mathematical representation such as a graph, and immediately see the effects on other linked representations (Roschelle et. al., 2000). Moreover, providing access to multiple representations means that symbols can be introduced *after* students have experience with motion, narratives, tables, and graphs. In this way the symbols are *about* something, and can be understood as a compact and precise way of describing phenomena. By waiting to introduce the symbolic form, SimCalc is also not held hostage by what is symbolically or computationally simple. For instance, piecewise linear functions are quite complex to represent symbolically, and so are not introduced in most middle- and high-school curricula. However, interpretations of piecewise motions can help students understand the mathematics of change, and the narrative of an exciting race can provide exactly the context students can use to engage in deep mathematical thinking.

SimCalc supports communication and discourse. Making mathematical connections across different representations has social and communicative advantages. The four linked representations provide a shared set of referents for students and teachers to explore by replaying the motion or making changes in one representation to see the changes in the others. 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 the language of academic mathematics for a communicative goal (e.g., Does *going longer* refer to *time* or *distance*?). This goal- and meaning-oriented approach is consistent with best practices for learning language and with recommendations for supporting mathematical discourse (Moschkovich, 2007b; Swain, 2001) and is in contrast to traditional approaches to teaching academic language that rely on memorization of vocabulary lists.

Scaling-Up: Meeting the Needs of the Educational System

Taking these research findings to the classroom on a large scale was a new challenge for the SimCalc project. Previously, the SimCalc approach was taught directly by either researchers or teachers who had been involved in long-term professional development or collegial arrangements with the researchers. In order to reach a larger audience of teachers and students, we needed a robust combination of curriculum, technology, and minimal professional development to leverage the benefits and while minimizing the chances of lethal mutations (Brown, 1991). This resulted in the emergence of a curricular activity system approach (Roschelle et al., in review), which helped us to address teacher, district and state constraints and realities while extending the SimCalc mission.

We designed a curriculum sequenced in a way that would be comfortable to most American teachers: breaking complex concepts into small pieces, starting with the smallest piece, and culminating with complexity. This approach differs from the "historical" SimCalc approach, where students are presented with a fairly complex problem, are asked to generate solutions for it, and through this process, learn concepts of rate and function—and other calculus related ideas. What we retained from the SimCalc approach built up over the years was a reliance on motion as a context for understanding function, and function as a way to think about rate. This, fortunately, aligned with Texas state-advocated approach. And of course, the curriculum is tied to the MathWorlds software, in which students are able to control simulations of motion and representations of graphs, equations, tables and actions are related.

We also focused on a small number of important activity structures, and provided supports for these in the written curriculum materials. For example, we incorporated the SimCalc tradition of having students predicting a motion by interpreting a graph, running the simulation to check their predictions, and explaining verbally differences or coincidences between prediction and simulation. This "predict-check-explain" model was not only discussed in trainings, but also written into each lesson in the student workbook, as one way to ensure students were exposed to the SimCalc approach, regardless of the teachers' approach.

We used a fairly typical "week in the summer" model of professional development that met the time (and funding) constraints of a large number of districts and teachers. All teachers in the study received TEXTEAMS training, a two-day workshop on rate and proportionality developed by the Dana Center. SimCalc teachers received 3 additional days of professional development on the SimCalc curriculum. Over these three days, teachers became familiar with the SimCalc units and MathWorlds, and planned when they would teach the SimCalc units. The SimCalc pedagogy was modeled by the facilitator and included in the student workbook.

Deciding what mathematics to include in the units was a task of finding the intersections between the mathematics of change and existing national and state standards for 7th and 8th grades. The Texas Education Authority, through the Dana Center, was advocating an approach to teaching proportionality that was consistent with the SimCalc approach. Rather than presenting three numbers, and a procedure for finding the fourth, embedded in the equality among ratios (a/b = c/d), the advocated approach was to teach proportionality as a linear function of the form y = kx (Stanley et. al., 2003). This provided the SimCalc project with the opportunity to connect the multiplicative constant *k* in the algebraic expression y = kx, the slope of a graphed line, the constant ratio of differences in a table comparing y and x values, and the experience of rate as "speed' in a motion.

To ensure that students engaged with the mathematics in a variety of contexts, we grounded the unit in an overarching story framework–managing a soccer team. While use of real world contexts was consistent with prior SimCalc work (which has always been grounded in modeling the real world and students' own experience of motion), having a single story framework was a departure from past research. This decision enabled us to start the units with typical linear and piecewise linear motions, and extend into non-motion contexts, such as mileage and money (oft used contexts in traditional math curricula and standardized tests). Though the units had overarching contexts, they were "context-light" in that the problems and software presented a highly simplified model of the real world, and these simplifications were made apparent to students. Knowledge of soccer, for example, was neither an advantage nor a barrier to understanding the problems. All the clues and grounding experiences necessary for solving the problem were contained in the simulation, so that all students regardless of cultural or socioeconomic background have the same opportunities to engage with the materials. Because SimCalc provides the phenomena to be studied, we leverage student knowledge of the "real world," while avoiding inappropriate uses of their real world knowledge

Conclusion and Discussion

In this paper we have shown how the Scaling Up SimCalc project integrated multiple perspectives to meet the needs of diverse student and teacher populations. Our focus on the representational and communicative infrastructure of SimCalc allowed us to create materials that were effective for students who are considered among the most at-risk for academic failure. By also incorporating a focus on the larger educational system, we were able to create materials that were used by a wide variety of teachers in a wide variety of settings. We believe that, as more innovations attempt to make a difference on a large scale, this focus on the overall curricular activity system will become crucial to successful scale-up.

We also note that, while our instantiation of SimCalc was successful in its goal of helping a wide variety of students learn important and complex mathematics, we believe that more can be done to further meet the needs of a diverse student population. We recognize that the data shown in Figure 1 indicates that there may be some disparities in learning among sub-populations of students who used the SimCalc intervention. For instance, students who were rated by their teacher as having low prior achievement had smaller gains than those who were rated as having high prior achievement, and there is a non-significant trend that Hispanic students had smaller gains than non-Hispanic students.

Detailed analysis of classroom interactions of a subset of the SimCalc teachers shows the importance of specific teacher moves that were used to scaffold discourse. Teachers who incorporated student ideas into their explanations (called "responsiveness") and who engaged students in tasks that required cognitively complex intellectual work (similar to "cognitive demand", Stein et al., 2000) had greater student gains than those who did not use such moves (Pierson, 2008). Providing additional professional development and support to allow all teachers to engage in these high-impact moves is likely to increase student achievement for underperforming sub-populations, as students with low prior achievement and students from non-dominant cultures and languages are those most likely to have impoverished classroom discourse. An additional component of discourse support is aiding students in acquiring an appropriate vocabulary (Moschkovich, 2007a; Olivares, 1996) including highlighting those words that have register-dependent meanings (Halliday, 1978; Pimm, 1987). Future work will consider creating a visual glossary of mathematical terms as well as general academic words (e.g. "predict," "evidence") to support students in using academic language appropriately.

To further aid in supporting productive discourse for our target students, we will investigate strategies that allow a reduction of the language load while maintaining the rigor of mathematical discourse. A productive strategy has been that of making expectations explicit, and providing scaffolding that aids students in meeting these expectations (Lee, 2005). This strategy is based on the finding that much of academic discourse is based on implicit norms (Gee, 2001; Lee, 2005), and students who are not aware of, or have cultural norms that are in conflict with, academic discourse norms are at a disadvantage (Ladson-Billings, 1995). By making norms and expectations explicit, *all* students will be able to more fully participate in the classroom discourse, while also engaging in rigorous academic thinking.

Acknowledgements

This material is based on work supported by the National Science Foundation under Grant No. 0437861. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Endnotes

1. We focus on Hispanic students because they consisted of a majority of our student sample, there were negligible numbers of other minority groups in the study, and Hispanic students have traditionally underperformed in measures of mathematics achievement (Education Trust, 2003).
2. We take as our measure of poverty the percentage of the campus eligibility for the free and reduced price lunch program.

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