Scaling Up SimCalc Project

Can a Technology Enhanced Curriculum Improve Student Learning of Important Mathematics?

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This report is intended to serve as timely means to share findings with Texas teachers and educators, which is necessary for the diffusion phase of our research beginning in June 2007. The research team is simultaneously preparing detailed, scholarly articles for researchers and policy makers, to be submitted to peer-reviewed journals. We prefer that researchers and policy makers wait for and cite the forthcoming peer-reviewed articles. Contact Jeremy.Roschelle@sri.com for more details.

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Overview of Findings from the Seventh-Grade Year 1 Study

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Overview of Findings from the Seventh-Grade Year 1 Study

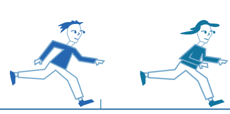
Findings from a large-scale experiment demonstrate the power of a technology enhanced curriculum to deepen middle school mathematics learning across diverse ethnic and economic settings.

Middle school is an important transition point for students' school trajectories[1] and middle school mathematics sets the stage for future careers in science.[2] Starting in middle school, mathematical concepts become increasingly crucial to understanding scientific concepts and are considerably more difficult than mathematical concepts in elementary school. International comparison research shows that although U.S. fourth-grade students compare favorably, eighth-grade students fall behind their foreign peers, particularly in their mastery of complex, conceptual mathematics[3], a cause for concern about the preparation of students for careers in science.

Among middle school mathematical concepts, proportionality ranks high in importance, centrality, and difficulty and is recognized as such in both mathematics standards and learning research.[4, 5, 6] Proportionality is at the core of the concepts of rate, linearity, slope, and covariation. Without understanding rate and proportionality, students cannot master key topics and representations in high school science, such as laws (e.g., $F = ma$, $F = -kx$), graphs (e.g., of linear and piecewise linear functions), and tables (e.g., interpolating between explicit values relating the width and length of maple leaves).

A Partnership to Enhance Mathematics Teaching

In 2002, SRI International began work with researchers from Charles A. Dana Center at the University of Texas at Austin and the University of Massachusetts, Dartmouth to address student learning of rate and proportionality in Texas middle schools. Texas already had an aligned system of standards, curriculum, assessment, and teacher professional development. Within this system, the Dana Center's highly regarded and well disseminated TEXTEAMS workshop emphasized proportionality not only as an equivalence of ratios ($a/b = c/d$) but also as a focal opportunity to develop students' concepts of function, rate, slope, linearity, and covariation. Adding to this foundation, the Massachusetts researchers brought their innovative integration of curriculum and computer software called "SimCalc Mathworlds™".[7] SimCalc Mathworlds™ software engages students in linking visual forms (graphs and simulated motions) to linguistic forms (algebraic symbols and narrative stories of motion) in a highly interactive, expressive context.[8] Confirmatory evidence from mathematics education research found that graphing calculators, which link graphing and algebraic symbols, enhanced algebra learning.[9] SimCalc software engages students in linking visual forms (graphs and simulated motions) to linguistic forms (algebraic symbols and narrative stories of motion) in a highly interactive, expressive context. SimCalc curriculum leverages the cognitive potential of the technology to develop multiple, interrelated mathematical fluencies, including both procedural skill and conceptual understanding, per National Research Council recommendations.[10] Prior classroom research in places like Fall River, Massachusetts, and Newark, New Jersey, suggested that disadvantaged students' engagement with SimCalc software and curriculum was the factor likely to have enabled students to learn difficult aspects of rate and proportionality in those classrooms.[11]



Hallmarks of the SimCalc approach are:

1. Anchoring students' efforts to make sense of complex mathematics in their experience of familiar motions, which are portrayed as computer animations.
2. Engaging students in activities in which they make and analyze graphs that control animations.
3. Introducing piecewise linear functions as models of everyday situations with changing rates.
4. Connecting students' mathematical understanding of rate and proportionality across key mathematical representations (algebraic expressions, tables, graphs) and familiar representations (narrative stories and animations of motion).
5. Structuring pedagogy around a cycle that asks students to make predictions, compare their predictions to mathematical reality, and explain any differences.
6. Integrating curriculum, software, and teacher professional development as mutually supporting elements of implementation.

The new partnership realized that extending the TEXTEAMS approach with SimCalc could further enhance learning of rate and proportionality throughout Texas. But the partners also articulated concerns: Could an ambitious integration of curriculum and technology work in a diverse range of Texas classrooms? Could it work given only the 1-week investment in teacher training that most schools can afford? Would the added complexity of using technology in the classroom negate any potential benefits?

Research Design

To address these questions, SRI International led a rigorously designed randomized controlled experiment that began in summer of 2005, with additional experimental support from Virginia Tech. In the summer, participants attended a 2-day TEXTEAMS workshop that established common learning objectives for seventh-grade rate and proportionality. The principal contrast was between (a) an integrated replacement unit incorporating SimCalc curriculum, software, and 3 additional days of teacher training and (b) the "best available alternative", in which teachers used their existing curriculum but had the benefit of TEXTEAMS training and materials on the topic of rate and proportionality.

In the discussion that follows, we refer to the group that received the integrated replacement unit as the "Treatment" group and the group that received the best available alternative as the "Control" group. We did not, however, use these terms with the teachers as we wished to avoid any suggestion as to which group might perform better. Teachers were invited to participate for 3 years; we report here on the findings of the first year only. To ensure fairness to all participating teachers, we used a "delayed treatment" design in which Control teachers would receive all SimCalc materials and training in their second year. We gave teachers in both groups an equal stipend for their participation.

The research team followed this design with great care in execution. Our scientific advisory board reviewed our plan for avoiding any suggestion of which condition was "better." We implemented this plan with great diligence. Every presentation to teachers was reviewed in detail by the PIs and co-PIs with this concern in mind. We even reviewed the presentations to all recruitment partners. We videotaped and reviewed for bias key presentations for the workshops in which teachers were informed about the research design and showed teachers the videos rather than making presentations in person so that we could be sure that both groups got exactly the same presentation (although a few details were systematically changed between the videos for the two groups that reflected slightly different research procedures).

In the Texas seventh-grade curriculum, rate and proportionality is typically covered in a 2- to 3-week unit. Teachers in the Treatment group were asked to replace this unit with a SimCalc unit and teachers in the Control group were asked to continue using their existing textbook for this unit. (We intend to report later on how Control group teachers used TEXTEAMS.) The main outcome variable was student learning of concepts of rate and proportionality, measured on identical tests administered before and after the 2- to 3-week rate and proportionality unit.

Participants

We selected teachers from a voluntary applicant pool open to teachers in eight regions of Texas. Through Texas's Educational Service Centers (regional teacher support centers), we recruited a pool reflecting Texas's regional, ethnic, and socioeconomic diversity. Teachers were randomly assigned by school to either the Treatment or Control group. After receiving invitations, 120 teachers from our applicant pool were able to attend a summer workshop, and eventually 95 teachers (and their 1621 students) returned complete data for the 2005-2006 school year. At intake, the Treatment group (48 teachers) and the Control group (47 teachers) did not differ in any important way. Our attrition rate is comparable to other large experiments with educational technology[12] and we have no evidence that would suggest differential attrition, which would be the principal threat to validity.

Development of the Student Assessment

With a panel of mathematicians and mathematics education experts, we developed an assessment blueprint encompassing both simple and more complex aspects of rate and proportionality.

The simpler items were based on items used on the Texas state test for seventh-grade; these typically ask students to calculate using a proportional relationship stated either as a word problem or more mathematically. For example, one question asks:

"If $\frac{2}{25} = \frac{n}{500}$, what is the value of n?"

Our expert panel also viewed proportionality as the basis of the first nontrivial function, $f(x) = kx$, that students learn in their multiyear journey through the mathematics of change and variation – the mathematical strand that continues through high school calculus. In preparation for future mathematics and science, they argued that students should learn to analyze this function across representations, including graphs, tables, and symbolic expressions. An item addressing this more complex approach asks students to complete several missing x and y values in a table describing a proportional function, then to write an algebraic expression for the function, and finally to sketch a graph of it.

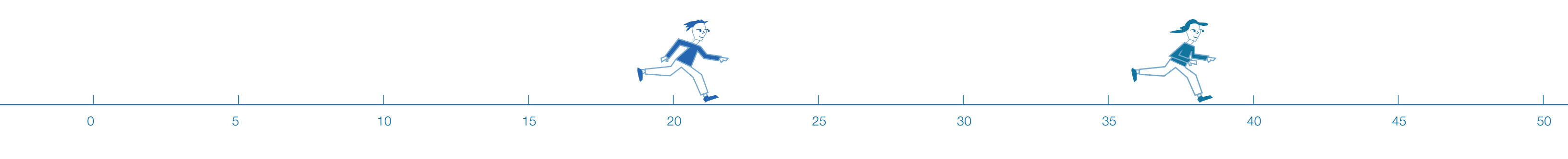
Our expert panel also asked us to be sure to address common mathematical misconceptions. Hence, one item targeted a common misconception about position graphs: that the intersection of two graphed lines on a position vs. time graph indicates when two objects are moving at the same speed.

Teachers who used SimCalc said:

"It is an excellent, excellent unit. It kept the students very involved. The use of computers was phenomenal. I'd give it a 10. My goals were met with this unit."

"This is the type of program that creates innovative and higher-thinking educators –which in turn produces that type of learner."

"I'm very excited about it. It's a program I'll keep using and being able to help other people as they try it!"



The correct concept is that slope indicates speed, so that two objects have the same speed when their graphed lines have parallel slopes. We included this complex item because interpreting slope as a rate and connecting this representation to a narrative description of change over time is an important skill in all sciences: analysis of motion in physics, and interpreting rates of reaction in chemistry and rates of growth in biology are some of the many topics for which this concept is used.

The overall 30-item test included 11 simple and 19 complex items. We carried out rigorous validation processes on the test, including cognitive interviews with students, item-response theory analyses on field test data collected from a large sample of students, and expert panel reviews.

Results and Discussion

Our main effect was statistically significant and showed that students in the Treatment group learned more (see Figure 1). The overall effect size was 0.84, considered large in education studies ($t(93) = 9.1$, $P < 0.0001$, using a two-level hierarchical linear model with students nested within teacher). The difference between the groups occurred mostly on the complex portion of the test. The effect size of treatment on this portion was 1.22 ($t(93) = 10.0$, $P < 0.0001$). The effect size of the treatment on the simple portion was 0.17 ($t(93) = 1.8$, $P < 0.072$, n.s.); many students had mastered these concepts before the unit began.

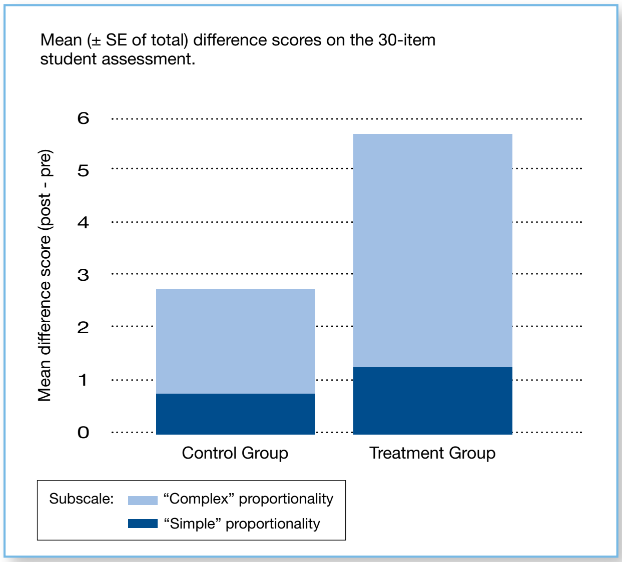


Figure 1. Student gain scores aggregated by teacher.

These results were robust across demographic groups and socioeconomic settings. Importantly, the pattern of results held for both boys and girls. Moreover, students whose teachers reported their

	Dallas / Fort Worth Region		Rio Grande Valley Region	
	(27 Teachers / 438 Students)		(19 Teachers / 370 Students)	
% Hispanic students in school	16		98	
% White students in school	75		2	
% Students in school in free/ reduced-price lunch program	33		89	
	Treatment	Control	Treatment	Control
	(14 Teachers)	(13 Teachers)	(8 Teachers)	(11 Teachers)
Pretest score	13	13.2	11.8	11.3
Posttest score	18.5	15	17	14.1
Gain score	5.5	1.8	5.2	2.8

Table 1. Strong gains in two contrasting regions. The source of the demographic data is the state of Texas's 2005 Public Education Information Management System (PEIMS). Percentage of students participating in the free/reduced-price lunch program is a strong indicator of socioeconomic status. A higher percentage indicates greater poverty in the school.

prior achievement as low, medium, or high all gained more in the SimCalc condition. The results also held across regions in Texas. Table 1 shows data from two contrasting regions. The Dallas/Fort Worth region is a major urban center with students from a mix of ethnic and economic backgrounds. In contrast, the Rio Grande Valley region is predominantly Hispanic and impoverished. The results show that although students in the Rio Grande Valley started with lower scores, students in both regions learned more with the SimCalc materials. Rio Grande Valley students who used SimCalc closed the gap with Fort Worth students who used their ordinary curriculum.

We found that the cognitive complexity of teaching was higher in the Treatment group and was related to student learning gains. We asked teachers to rate their degree of focus for each day's class on goals of low and high cognitive complexity on a 4-point Likert scale. For analyses, we averaged the daily ratings of lower-order goals (e.g, memorization and use of routine procedures) and the daily ratings of higher-order goals (communicating conceptual understanding; making mathematical connections and solving nonroutine problems; and conjecturing, generalizing, or proving). Treatment teachers reported a stronger daily focus on higher-order goals ($t(93) = 2.3$, $P < 0.05$); Control teachers reported a stronger daily focus on lower-order goals ($t(93) = 3.1$, $P < 0.01$). There was a positive statistical association between teachers' report of their use of higher-order goals and the mean student gain in their classes on the complex portion of the test (ß = 1.4, $P < 0.0001$). For lower-order goals, there was a negative statistical association (ß = -0.84, $P < 0.05$).

General Discussion

Randomized controlled trials of this scale support the strongest causal inferences, yet they are rarely conducted in education.[12] These results support claims (a) that the SimCalc approach was effective in a wide variety of Texas classrooms, (b) that teachers successfully used these materials with a modest investment in training, and (c) that student learning gains were robust despite variation in gender, ethnicity, poverty, and prior achievement. By way of contrast, it is worth noting that a recent randomized controlled trial examining 16 different educational technology products found no effects.[13] This contrast should be interpreted with caution because of striking differences in the nature of the "interventions," the research design, and the measures. Regardless of these differences, the contrast is helpful in discounting the possibility that the Hawthorne effect accounts for the findings in this study. Clearly, the mere availability of new technology and teacher training is not enough to produce test score gains in other well-designed randomized controlled trials. In her classic paper, Brown[14] provides an extensive discussion of the Hawthorne effect as it pertains to educational interventions. A major point is that the Hawthorne effect has non specific results. In Hawthorne's research, mak-

Students who used SimCalc said:

"The simulation thing and the stepper really helps [me learn] a lot on that thing because you can really see what you're doing instead of just like on a sheet of paper... And then on that you can actually see it moving and it's like you can experience it so it's easier to understand."

"[The SimCalc unit is about] figuring out how to figure it out."

ing the lights either brighter or darker increased worker productivity. Brown argues that if we are able to predict specific, cognitive dimensions of an improvement due to specific, cognitive features of an educational intervention, then the Hawthorne effect is not implicated. In our research, we predicted strong gains on complex proportionality test items because we have a cognitive theory that links the intervention to these outcomes. The results we found fit that prediction. In contrast, on simpler test items, both groups experienced similar gains.

It is particularly striking that SimCalc's integration of curriculum, representational software, and teacher training worked well in the Rio Grande Valley region, an especially impoverished region bordering Mexico. Although, on average, Treatment and Control group students progressed equally well on simple mathematics, the Treatment group gained more on complex mathematics. For example, at posttest, Treatment students were more likely to use the correct idea of "parallel slope as same speed," whereas Control students were more likely to have the misconception "intersection as same speed."

Generalizations from this research should be made with caution. We tested only a 2- to 3-week unit in one grade level (other grade levels are under study). Our sample lacked a majority African-American school (although prior SimCalc field trials were successful in Newark, New Jersey). We worked with volunteer teachers and do not know how well nonvolunteer teachers would fare. We required schools to have a computer lab (many but not all schools have a suitable facility). The curriculum and measures were tuned to Texas; results may not translate to other states.

These results show what can be accomplished through an artful integration of teacher professional development, curriculum, and software. Using established cognitive principles, software can be designed to provide interactive depictions of important mathematical concepts that help students understand connections across graphical and linguistic forms. Curriculum can focus teachers' and students' attention on more important and complex mathematics. Teachers can successfully implement innovative software and curriculum with a modest investment in training, although we suspect more teacher training would further increase student gains. Implementing this approach more widely and across grade levels could boost diverse students along the pathway leading to algebra and calculus, a pathway that is widely seen as critical to increasing the number of students prepared to excel in science.

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