ESTABLISHING A LONGITUDINAL EFFICACY STUDY USING SIMCALC MATHWORLDS®

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We describe the construct of a 4-year longitudinal efficacy study implementing dynamic mathematics software and wireless networks in Algebra 1 and 2 classrooms. We focus on student learning and motivation over time, and issues of effective implementation in establishing a longitudinal study.

INTRODUCTION: BACKROUND TO DYNAMIC MATHEMATICS

New forms of mathematics technology (e.g., dynamic geometry) can provide *executable representations*—representations that transform the mathematics made by students into a more tangible and exciting phenomenon (Moreno-Armella, Hegedus & Kaput, 2008). In particular, we have designed and used SimCalc MathWorlds® to transform students' mathematical constructs into fascinating motion phenomena. Second, networks can intimately and rapidly *link private cognitive efforts to public social displays*. Consequently, students can each be assigned a specific mathematical goal (e.g., playing the part of a single moving character by making a graph with certain mathematical characteristics), which instantly links to public social display (e.g., the parade constituted by all characters moving simultaneously). This approach shifts the types of critical thinking that are possible in mathematics classrooms and transforms the role of instructional technology by integrating it into the social and cognitive dimensions of the classroom.

Our connected approach to classroom learning highlights the potential of classroom response systems to achieve a transformation of the classroom-learning environment. Similarly other investigators have expanded their approaches to include devices that allow aggregation of mathematical objects submitted by students. (Stroup, Ares & Humford, 2005).

SITUATED NEED

Our proposed work addresses three essential needs: (i) the Algebra Problem (RAND, 2002), (ii) the related problem of student motivation and alienation in the nation's schools, especially urban secondary schools (National Research Council, 2003), and (iii) the widely acknowledged unfulfilled promise of technology in education, especially mathematics education (e.g., Cuban, 2001).

An important analysis by the National Academies Institute of Medicine (National Research Council, 2003) of student motivation at the high school level reveals in painful detail what most high school teachers (and parents) know only too well: that student motivation in high schools, and even more acutely in urban high schools, is an urgent and complex national problem. The report also recommends that high school courses and instructional methods need to be redesigned in ways that will increase adolescent engagement and learning.

Ethnographical studies of high school students (Davidson & Phelan, 1999; Phelan, Davidson, & Yu, 1998) reveal a world of alienation with strongly negative responses to standard practices (Meece, 1991) and strong sensitivity to interactions with teachers and their strategies (Davidson, 1999; Johnson, Crosnoe & Elder, 2001; Skinner & Belmont, 1993; Turner, Thorpe, & Meyer, 1998). Negative responses, particularly as they are intimately connected with self image and sense of personal efficacy, can be deeply debilitating, both in terms of performance variables (Abu-Hilal, 2000) as well as in the ability to use help when it is available (Harter, 1992; Newman & Goldin, 1990; Ryan & Pintrich, 1997). See the comprehensive reviews by Brophy (1998), Newmann (1992), Pintrich & Schunk (1996), and Stipek (2002). On the other hand, students exhibit consistently positive responses to alternative modes of instruction and content (Ames, 1992; Boaler, 2002; Mitchell, 1993), particularly those that build upon intrinsic instead of external motivation (Linnenbrink & Pintrich, 2000).

The literature on motivation in education and social situations in general has focused on intrinsic and extrinsic motivation with a great deal of debate (Sansone & Harackiewicz, 2000). Intrinsic motivation reflects the propensity for humans to engage in activities that interest them. Extrinsic motivation, such as rewards, can have an undermining effect and decrease intrinsic motivation, i.e., the reason why the person chose to want to do the activity in the first place (Deci, 1971). Yet both intrinsic and extrinsic motivation, as a key feature of participation in mathematics classrooms, have appeared to be an orthogonal field of inquiry to the development and instruction of content, with motivation hesitantly intersecting with education in the form of "motivational strategies," incentivizing students to learn mathematics because it is "fun" or "applicable" to *their* life, through relevant contexts, e.g., sports or vocations.

Relevance, unfortunately, is a somewhat indirect means to link motivation and mathematics—the link between immediate cognitive effort and later applications that may seem improbable to students. There is a more direct alternative. Students can become motivated because they want to participate more fully in what their classroom is doing now. The alternative, thus, is to link motivation and mathematics through *participation*.

We advocate two radically new forms of participatory activity in technology-enhanced environments:

1. Mathematical Performances. These activities emphasize individual student creations, small group constructions, or constructions that involve coordinated

interactions across groups that are then uploaded and displayed, with some narration by the originator(s).

2. Participatory Aggregation to a Common Public Display. These activities involve systematic variation, either within small groups, across groups, or both, where students produce functions that are uploaded and then systematically displayed and discussed to reveal patterns, elicit generalizations, expose or contextualize special cases, and help raise student attention from individual objects to families of objects.

These activities aim at enhancing mathematical literacy, debate and coherent argumentation—all fundamental mathematical skills. The central point is that each requires and rewards students for cognitive engagement in producing tangible phenomena that are simultaneously phenomenologically exciting and mathematically enlightening. This happens not at some future time when mathematics can be applied to a career or personal goal; instead these activities draw students in and sustain their interest because they are exciting and enlightening in the moment, in the classroom. These activities create an intrinsic motivation context with a socio-cultural view to "motivation in context" (Hickey, 2003) that is also intrinsically mathematical, accomplishing a much more intimate intertwining of motivation and mathematics that can be typically accomplished in existing classrooms.

PRIOR WORK

SimCalc MathWorlds® creates an environment where students can be part of a *family of functions*, and their work contributes to the mathematical variation across this mathematical object. Consider this simple activity, which exemplifies a wider set of activity structures. Students are in numbered groups. Students must create a motion (algebraically or graphically) that goes at a speed equal to their group number for 6 seconds. So, Group 1 creates the same function, Y=(1)X, Group 2, Y=(2)X, etc. When the functions are aggregated across the network via our software, students' work becomes contextualized into a family of functions described algebraically by Y=MX (see Figure 1 below). Students are creating a variation of slope and in doing so this can help each student focus on their own personal contribution within a set of functions.

At the heart of SimCalc is a pedagogical tool to manage classroom flow. This tool allows teachers to control who is connected to the teacher computer using a simple user interface, and choose when to "freeze" the network and aggregate students' work or allow students to send a number of tries via the TI-Navigator™. In addition, teachers have control over which set of contributions (e.g., Group 1's functions) and which representational perspectives (e.g., tables, graphs, motions) to show or hide. Thus, the management tool encapsulates a significant set of pedagogical strategies supported by question types in existing curriculum materials to satisfy a variety of pedagogical needs, focus students' attention depending on their progress, and promote discussion, reasoning and generalization in a progressive way at the public level.

In our prior research, students build meaning about the overall shape of the graphs and have demonstrated gestures and metaphorical responses in front of the class when working on this activity. For example, in two entirely different schools, students have raised their hand with fingers stretched out (see Figure 1 below), and said it would look like a "fan." In this socially-rich context, students appear to develop meaning through verbal and physical expressions, which we observe as a highly powerful way of students engaging and developing mathematical understanding at a whole group level. Various forms of formative assessment can said to be evident as each student's work emerges in a public display, and representations can be "executed" (Moreno-Armella & Block, 2002) to test, confirm or refute ideas. These forms of reflection, enabled through particular question-types and classroom dialogue focused on the dynamic representations, can be attributed to students learning and resonate with established research on formative assessment (Black & William, 1998; Boston, 2002).

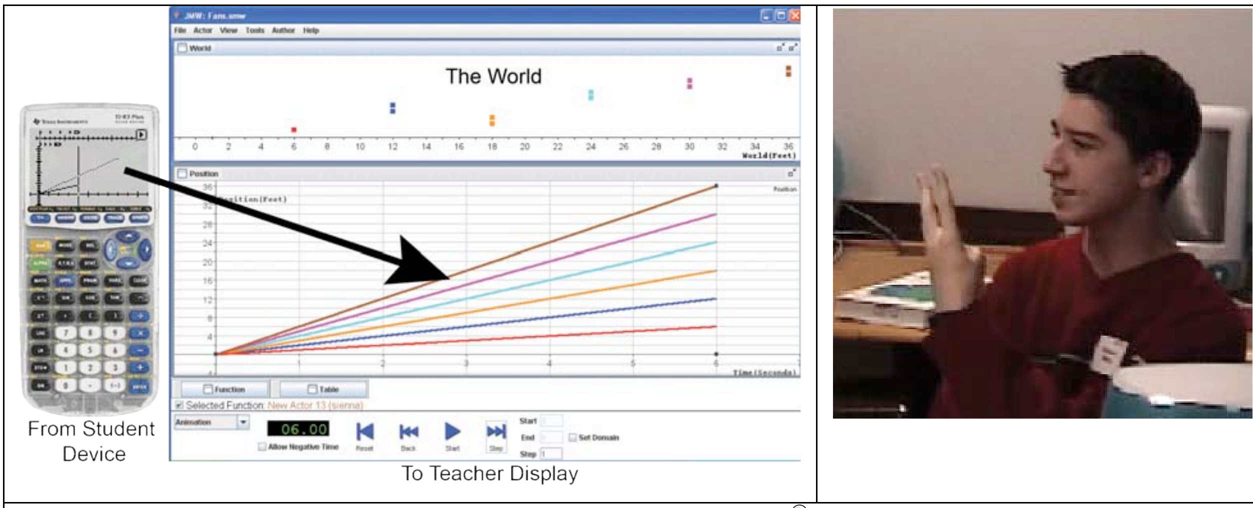

Figure 1. Sample Function in SimCalc MathWorlds®

Over the past ten years, over the course of three consecutive research and development projects (NSF ROLE: REC-0087771; REC-0337710; REC-9619102) and related projects at TERC (NSF REC-9353507), the SimCalc project has examined the integration of the Mathematics of Change and Variation (MCV) as a core approach to algebra-intensive learning. This work has led to a Goal 3 IERI-funded study (NSF REC-0437861), led by SRI International, focusing directly on large-scale implementability and teacher professional development in TX, and a recently funded IES Goal 2 project in the high school grades (IES Goal 2 # R305B070430) focusing on longitudinal impact of our curriculum and software products distributed by Texas Instruments on their popular graphing calculators in combination with a commercially available wireless network (TI-Navigator™ Learning system).

The Scale-Up pilot work employed a set of SimCalc resources in a delayed-treatment design. Teachers were initially randomly assigned to one of two groups. An ANOVA of difference scores (again teacher nested within condition) was significant [$F(1,282)=178.0$, $p<0.0001$]. The effect size for the gain in the group that used SimCalc is 1.08. In our main study, which is a randomized controlled trial in which 95 7th-grade mathematics teachers were randomly assigned to implement a 3-week SimCalc curriculum unit following training, our analyses show an effect size of 0.84 (Roschelle, Tatar, Shectman et al., 2007).

Prior work has documented statistically significant evidence for impact of SimCalc materials in connected "networked" environments with computers and calculators (Hegedus & Kaput, 2004) under multiple quasi-experimental interventions across grades 8-10 and college students demonstrating statistically significant increases ($p<0.001$) in student mean scores (effect=1.6) but with an even higher effect on the at-risk 9th grade population (effect=1.9). A major finding of our work was that critically important skills such as graphical interpretation were improved, i.e., cognitive transfer was evident. Recent studies show similar statistically significant results in terms of student learning and shifting attitudes towards learning mathematics in connected environments (Hegedus, Kaput, Dalton et al., 2007). We have also analyzed the changing participation structures using frameworks from linguistic anthropology (Duranti, 1997; Goffman, 1981). Our work has described new categories of participation in terms of gesture and language (Hegedus, Dalton, Cambridge et al., 2006) new forms of identity (Hegedus & Penuel, 2008), and theoretical advances in dynamic media and wireless networks (Hegedus & Moreno-Armella, 2008; Moreno-Armella et al., 2008).

DESIGN ASPECTS OF EFFICACY WORK

In this context, our research program (funded by the US Department of Education, IES Goal 2 # R305B070430) builds on prior work to examine this problem. It is focused on outcomes in terms of both grade-level learning gains and longitudinal measures that relate to students' progress and motivation in mathematics across the grades in Algebra 1 and 2 classrooms.

SimCalc combines two innovative technological ingredients to address core mathematical ideas: Software that addresses content issues through dynamic representations and, wireless networks that enhance student participation in the classroom. We have begun to develop materials that fuse these two important ingredients in mathematically meaningful ways and developed new curriculum materials to replace core mathematical units in Algebra 1 (8-12 weeks) and Algebra 2 (4-8 weeks) at high school. We are measuring the impact of implementing these materials on student learning (high-stakes State examinations in Massachusetts (MA), USA) and investigating whether one or multiple involvements in this type of learning environment over the course of their high school years affects their motivation to continue studying mathematics effectively and enter STEM-career trajectories.

Our work is conducted in eight school districts in MA offering a wide variety of settings in terms of performance on State exams and Socio-Economic Status (SES). Our treatment interventions are in 9th and 11th grade classrooms (Algebra 1 then 2) but we will also track some students when they are in 10th and 12th grade collecting simple questionnaire data. Our study is a small-scale cluster randomized experiment where we cluster at the classroom level, randomly assigning two classrooms in each school to treatment in our main studies (total of 28 classrooms and a. 500 students in each main study).

We are using two instruments comprised of standardized test items to measure student's mathematical ability and problem-solving skills before and after each intervention. We are also collecting survey data on student's attitude before during and after the intervention. We are administering these tests and surveys at similar times (with respect to curriculum topics covered) in treatment and control classrooms. Video data from periodic classroom visits are being analyzed using participation frameworks from prior work and triangulated with variations in student survey data on attitude.

We are using suitable statistical methods to assess gain relative to the control groups, and between-cluster variation using mixed-Hierarchical Linear Modeling. We are also collecting survey and classroom observation data to assess changes in attitudes and participation, and daily logs by teachers to monitor fidelity of implementation.

We have completed our first year of 4 years work with our first cohort of students that we will track for the duration of their high school career and will present initial findings from our pilot study and challenges we have addressed in sampling and establishing a longitudinal program of research. We focus on results from factor analyses of our survey instruments on student and teacher attitude and correlations with student learning. Following a minimal effect size in our pilot study, we aim to present findings for improving effective implementation from analyses of teacher daily logs and classroom video.

Such methodologies build a comprehensive program for evaluating how prior findings (briefly highlighted above) can scale to larger implementations whilst being cognizant of issues of fidelity. Our ongoing work and preliminary analyses report of the potential effect on outcome measures such as student learning and motivation.

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