

RELATIONSHIPS BETWEEN MOTIVATION AND STUDENT PERFORMANCE IN A TECHNOLOGY-RICH CLASSROOM ENVIRONMENT

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We report results from a larger study using a mixed-methods approach to examine the relationship between changes in attitude and achievement using the connected SimCalc MathWorlds® environment. Aspects of students' anxiety linked to sharing work publicly declined during our curriculum intervention. This was significantly correlated with increases in student knowledge and interpretation of multiple representations of functions. Similarly, positive change in student attitude towards technology was related to increases in knowledge of algebra concepts related to linear functions. After analyzing video data, we believe positive student outcomes result from increased motivation through active and mathematically-meaningful participation in the classroom.

Background

SimCalc MathWorlds® software (herein referred to as SimCalc) allows students to create mathematical objects on graphing calculators and see dynamic representations of these functions through the animations of characters whose motion is driven by the defined functions. Students are then able to send their work to a teacher's computer. Calculators are connected to hubs that wirelessly communicate to the teacher's computer via a local access point. The flow of data around a classroom can be very fast allowing large iterations of activities to be executed during one class.

In our intervention, we included activities that allow students to create functions in SimCalc on the TI-83 Plus or TI-84 Plus graphing calculator which can then be collected (or "aggregated") by a teacher into the SimCalc software running in parallel on a computer using TI's Navigator Wireless network. The activities are part of a curriculum, developed and refined over many years, that focuses on core high school Algebra ideas such as linear functions, simultaneity, covariation, and slope-as-rate — rather than slope as m in the equations, $y=mx+b$. The activities utilize Classroom Connectivity (CC) in new ways to supplement or replace existing traditional algebra curriculum (Hegedus & Kaput, 2004).

We report some specific findings from a larger quasi-experimental study where we investigated the implementation of SimCalc—a dynamic software and curriculum package—in regular U.S. high school classrooms. In particular, we focus on the impact of our resources on student motivation and attitude, and its correlation with mathematical performance. Significant learning gains by high school Algebra 1 students were measured across a 3-6 week quasi-experimental intervention conducted in several ninth grade Algebra 1 classrooms across two medium- to low-achieving districts in Massachusetts, U.S., with teachers of varying experience 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.

$(t(322)=2.711, p=0.007)$.

Theoretical Perspectives

Our connected approach to classroom learning is reiterated in seminal works that highlight the potential of classroom response systems to achieve a transformation of the classroom-learning environment (Bransford, Brown & Cocking, 1999). Similarly other investigators have expanded their approaches to include devices that allow aggregation of mathematical objects submitted by students (Wilensky & Stroup, 2000). Linking private work in a mathematically meaningful way through networks, and displaying the aggregations of whole class work, potentially enhances students' metacognitive ability to reflect upon their own work in reference to others (Huffaker & Calvert, 2003). 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.

Research Questions

In this paper, we focus on one particular SimCalc class, taught by an experienced SimCalc teacher, with respect to changes in attitude and learning gain. We explore the following questions:

- What relationship(s) exists between student gains in performance on pre- and post content tests and measures of attitude?
- In what ways might attitude influence performance gains?
 - Which classroom behaviors and/or interactions suggest an attitude–performance connection?
- How might the SimCalc environment impact relationships between student performance gains and attitude?

Methodology

Sample

Five teachers in a total of eight classes in two school districts participated in the larger SimCalc study. The remaining Algebra 1 classes in each district, eight in total, were used as comparison classes. Algebra 1 is typically taught in ninth grade where students are 14-15 years old. The teachers involved in the study were not randomly chosen; rather they agreed to be a part of the project for various reasons. We chose the single SimCalc classroom on which to focus our paper based upon the robustness of the relationship between the variables we wished to investigate, i.e., performance gain and attitude.

Data Collection

Motivation was measured using pre- and post-intervention attitude surveys. The student survey used to measure attitudes and beliefs about mathematics, school, and technology was comprised of 27 items that participants responded to on a Likert-type scale ranging from "0 – Strongly Disagree" to "4 – Strongly Agree." An example item was, "I think mathematics is important in life."

Video data was collected for each class in the SimCalc group and one class in the comparison group during the intervention. Each class was recorded with two digital cameras. One of the cameras was focused on the teacher and the whiteboard space where connected SimCalc was

projected. The other was positioned at the front of the class and was focused on the students using a wide-angled lens to pan out and observe whole class dynamics and small group interactions. Both cameras were used as roaming cameras when the class was involved in small group work. Video data was collected for twenty-six classes, each class lasting approximately fifty-five minutes for the SimCalc class in this case study. A second researcher took detailed field notes of the classes. Selected students were interviewed at the end of the intervention. Classroom video episodes were used as a qualitative component that re-enforced our quantitative findings because surveys and/or structured interview analyses do not always accurately reflect the attitude/affect of a student (Goldin, 2008; Ma & Kishor, 1997; Schorr & Goldin, 2008).

The instrument used to measure learning gains was a mathematics content test compiled from various state high-stakes state tests used to determine school success for No Child Left Behind (NCLB) accountability. The 22 item pre- and post-test included twenty multiple choice items worth 1 point, one short answer question worth a maximum of two points, and one long answer question worth a maximum of four points.

Results

Quantitative

Our initial analysis focused on student gain in specific content areas and on changes in attitude. Our goal was to identify patterns of change and potential relationships between various dimensions of the data.

The content test was broken down into concept categories: graphical interpretation items (41% of the test), proportion and rate items (23%), recognizing and determining a pattern items (9%), and multiple representation items (27%). These groups did not include the long answer open response item, which was omitted due to a low response rate by both treatment and comparison groups. The SimCalc group showed gains on each category of the content test. In particular, the SimCalc students had a significantly greater gain than the comparison group on multiple representation items $t(322)=3.069, p<0.01$. These items dealt with generalizing relationships across representations. Conceptual transfer across multiple representations of a mathematical concept or object is an important theme in mathematics education and one of the National Council of Teachers of Mathematics process standards (NCTM, 2000).

We conducted a principle components analysis on items from the student attitude survey, which produced a four-component model that accounted for 48% of the total variance. We categorized these into four broad components that coincided with our theoretical model of attitude: *Deep Affect/Beliefs not subject to casual change* (20.8%), *Anxiety* (11.4%), *Preference to work alone* (8.5%), and the *Perception and Use of Technology* (7.3%). Based on this analysis we computed weighted composite scores for each dimension on the survey to allow us to measure change in attitude over time. Table 1 below displays descriptive statistics for each subscale used in the analysis from our sample population.

The SimCalc case study class. The case study class demonstrated gains in both performance and attitude when compared with the aggregated treatment and comparison groups. This class had a lower score mean score on the pre-content test than the aggregated treatment or comparison groups. However, the case study class demonstrated greater content gains (2.42) from pre to posttest than either the treatment (1.99) or comparison (.96) groups. They also had higher mean scores on the pre-survey for the *Deep Affect* subscale (11.3, compared to 10.6 for treatment and 10.4 for control), and the *Anxiety* subscale (9.0, compared to 8.4 for treatment and 8.3 for control), and recorded a greater gain (.40 and -1.2 respectively) than the other two groups 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.

(-.19 and -.27 for treatment and -.48 and -.07 for control).

Table 1

Descriptive Statistics for Attitude and Content Test Sub-scales on the Pre Survey and Pre Content Test for all Classrooms in the Study

		N	Mean	SD	Min	Max
		Initial Score				
Content Test	Content Test Score (0-26)*	396	10.2	3.6	1	19
	Graphical Interpretation (0-9)*	396	5.1	1.6	1	9
	Proportion and Rate (0-6)*	380	2.9	1.8	0	6
	Recognizing and Determining a Pattern (0-2)*	396	.36	.48	0	1
	Multiple Representations (0-6)*	396	1.8	1.4	0	6
Student Survey	Deep Affect	301	10.5	3.6	0	18.2
	Anxiety	296	8.3	3.4	1.1	18.7
	Preference to Work Alone	304	3.2	2.5	0	9.3
	Perception and Use of Technology	301	5.7	2.1	0	10.9

*The range of scores for the subscale

A larger positive gain on the *Deep Affect* subscale implied that students chose higher agreement responses on items describing math as interesting and important. This gain also suggested a more positive overall attitude toward school at the end of the intervention than at the beginning. Similarly, the case study class had a larger negative gain for the *Anxiety* subscale, which suggests students were less anxious at the end of the intervention than they were at the beginning. The case study class had a lower mean for the *Perception and Use of Technology* subscale on the pre-survey (5.3) but had the highest positive gain among classes (.36). The gain for the aggregated treatment group was negative (-.20) indicating that they enjoyed technology slightly less than they had at the beginning of the intervention.

We explored the relationships between changes in attitude and gain in content knowledge by analyzing a correlation matrix of these dimensions (Table 2). Most notably, changes in anxiety and preference to work alone were correlated to gain on the multiple representations subscale. A regression analysis confirmed that *Anxiety* significantly predicted gain on this subscale, $\beta = -.39$, $t(16) = -2.82$, $p = .012$. *Anxiety* also explained a significant portion of variance in gain scores on this factor, $R^2 = .33$, $F(1, 16) = 7.96$, $p = .012$.

Table 2
Correlations between Gain on the Content Test Subscales and Changes in Attitude Subscales for the Specific SimCalc Class

	Mult. Rep. Gain	Gain in Graph Int.	Change in Deep Affect	Change in Anxiety	Change in Work Preferences	Change in Perception and Use of Technology
Total Gain	.711**	.764**	.327	-.422 [†]	.370	.460 [†]
Mult. Rep. Gain		.261	.214	-.576*	.515*	-.047
Gain in Graph Int.			.336	.004	.350	.535*
Change in Deep Affect				-.389	-.007	.633**
Change in Anxiety					.065	-.016
Change in Work Preferences						-.004

*p<.05, **p<.01, [†]p<.1

Qualitative

In the video data collected in our comparison classrooms, and at the beginning of the SimCalc intervention for this particular class, students were seated in rows, answered teacher questions when called upon, and the Initiation-Reply-Evaluation sequence was the primary discourse method of the class (Wertsch & Toma, 1995).

Towards the end of the SimCalc intervention, the classroom discourse in this specific SimCalc class was quite different. Dialogic function was evident as students actively questioned, reacted to, and transformed the ideas and utterances of their peers, their peers' work and their own work (Wertsch & Toma, 1995). We propose that these illustrate the significant learning and, more importantly, the correlation with attitudinal changes that are evident in our measurements presented above. The particular classroom episode on which we have focused is not an outlier. This episode is a representative sample of the class from the latter portion of the intervention that exemplified the discursive and pedagogical practices that may be attributed to significant changes in our content and motivation sub-scales. In this episode students worked on an activity called *Coming Together*. In this activity students created a motion for a SimCalc actor, B, such that B started at 2 times their group number of feet (each group was assigned a different group number) and ended in a tie with Actor A. Actor A was defined by the function: $y=2x$ on a domain of [0,6]. Students built a function expression to fit the goal of the activity. Once students developed their functions, the teacher collected them. Before any student work was shown the teacher conducted a class discussion. A discussion about the motion began when the teacher asked what would happen when she ran the animation.

- (1) S5: We're all gonna go different speeds but we're all gonna end at the same position cause that uh end at
- (2) Teacher: Where is everyone going to be at the end of the motion?
S4: Not all different speeds.
S6: 12.
- (5) S1: 12.
Teacher: 12 what?
S1: feet.
Teacher: Feet. Right okay... So at the end

- S4: They're gonna be at point (6,12).
- (10) S5: Group 6 isn't gonna move. {S5 is in group 6}
 S8: yes we move. We go like this. {In the air with her pointer finger outstretched, she gestures a horizontal line}
 S4: They go sideways.
 S1: No they don't move, time goes on.
 S9: Cause they start at 12.
- (15) S1: Yeah.
 S3: It's like they already won.
 S4: It's like they're at rest.
 S5: Yeah but on the world we don't move.
 S4: They're resting for 6 seconds.
- (20) Teacher: S5 says in the world Group 6 is not gonna move.
 S1: Yeah.
 S3: No, they're not gonna move at all.
 S3: That's right. They just stay there.
 Teacher: Do we agree with that?
- (25) {Multiple students reply with yeah}
 S8: Yeah but time is moving.
 Teacher: Time is moving but they aren't.
 S1: Yeah cause you'll like see everyone else move but them.

In this excerpt, the teacher repeated what a student said twice, and facilitated the conversation three times: once to ask a question, once to clarify the units, and once to see if the class has come to an agreement. Student agency was evident as they debated their work and the work of their peers (lines 9-19). The students in Group 6 started at 12 feet and must end at 12 feet, therefore their character would not be moving. The students were building their understanding of how time and position co-vary.

In line (9), a student responded with a multiple representational answer. The class was discussing the motion, which is measured in feet, but his answer was in terms of the graph, the line segments would “end” at the point (6,12). Time was implicit in the motion.

Line (2) showed the teacher accepting the first response and then attempting to ask a different question. S4 did not agree with S5 and he initiated a discussion. While his comment was not addressed in this excerpt, S4 followed up a little later in the class again saying, “not all different speeds.” S4 then explained that some groups would have the same speed, but different velocities, because they were traveling in a different direction. He also conceptualized the symmetry that was created in the class’ set of motions and graphs as evidenced by his discussion of the slopes of the line segments that followed later in the class:

- S4: We were the opposite of them. We were their opposite.
 S6: And so then the next two...
 S4: Cause they were 2 and we were negative 2
 Teacher: So the slope. So you think group...you were saying group 4...
 S6: 5 and 7 I think
 Teacher: So group 5 and group 7 had opposite slopes?
 S6: Yeah
 S4: And group A and group 4

The SimCalc activities allowed discussions to emerge that were not present prior to the 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.

intervention. The students talked to one another about the mathematical objects they created on their calculators and that had been aggregated by the teacher. The networked classroom appeared to have enhanced a rich set of communication events where analysis of mathematical variation was brought to a social plane and where students could understand the core mathematical ideas in focus from a collaborative perspective. (Hegedus, Dalton, Cambridge et al., 2006).

The rich collaborative communication continued as the teacher asked students what the class set of graphs would look like when she displayed them. The students began using metaphors to describe this. A few students mentioned the set of graphs would look like a fan or a rake with the graph of Group 6 as the *handle of the rake* because it was perpendicular to the y-axis. The teacher followed up students' initial response with her own metaphor.

Teacher: How about if I see it as a hand?

S1: Yeah I can see it as a hand.

S2: Kinda, skinny hand.

S: No.

S1: Yeah huh cause look.

S3: A hand with six fingers on it?

S9: Doesn't make sense.

S1: Yeah, a hand.

S4: Yeah a hand with 6 fingers {laughs}.

Teacher: Think about it though. What would be your y-intercept? Where would your y-intercept be?

S9: Your pinky.

S4: At the webbings.

S9: That doesn't make sense.

Teacher: Pretend there's an extra one [an extra finger]

S3: That would be where they end though {See image 2 where S3 is referring to the "webbings" or palm of his hand}

Teacher: That would be where they end—I'm sorry. You're right. So what would my palm be? My palm would be where they?

S3: End. {Referring to the point (6,12)}

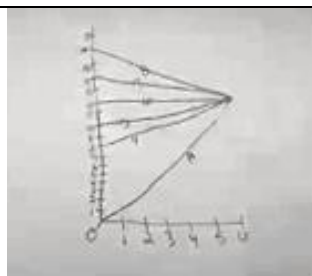


Figure 1.

A student's drawing on the board of the class set of graphs.



Figure 2.

The gestures representing the class set of graphs shown by the teacher and student, S3.

Within one activity, students relied on three major representations SimCalc offered them to make deductions on the behavior of the family of functions. They used this knowledge to help 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.

them derive a function rule that can be generalized for any group in the class. The group relied heavily on the animation space and graphs to understand which groups would have a negative and positive slope, which was at the heart of their debate.

Throughout this entire classroom episode, the teacher acted as a mediator. She prompted or guided students if they were stuck but provided students an opportunity to make their own discoveries. The students debated and argued about the underlying mathematics. They challenged each other and made conjectures, correct or not, with the goal to derive a general expression and understand its meaning.

Conclusion

Several aspects of learning in the SimCalc environment may contribute to lower anxiety measures. While this research is in its early stages, we speculate that three effects may be at work: (i) SimCalc provides a malleable environment with which to explore concepts in personally meaningful ways, (ii) students can make numerous conjectures, some of which may be false, before coming to a final answer, and (iii) the use of multiple representations in the curriculum and software provide for the deliberate generalization of concepts.

At this point, there are many potential explanations for motivation/learning performance relationships in SimCalc classrooms. As longitudinal data accumulates, we will investigate the connection between attitudinal changes and gains in performance using larger sample sizes and more refined analyses. We will also explore whether our hypothesized factors—the richness of the SimCalc context, the reduced emphasis on “one right answer”, and the explicit transfer of concepts to a variety of mathematical representations—contribute to such changes.

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