

The Connected Algebra Classroom: A Randomized Control Trial

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Abstract. The research reported here examines the impact of classroom connectivity technology on student achievement in algebra 1, self-regulated learning (SRL), and dispositions toward mathematics as a result of changing classroom processes. The research design is a randomized cross-over field trial where the control group is exposed to the intervention and implementation in the second year of the study. The field trial took place in 118 school classrooms of beginning algebra, typically a year-long course in the U.S. in eighth or ninth grade and typically labeled Algebra 1. Teachers in the treatment group attended a one-week summer institute in teaching with Texas Instrument's (TI) TI-Navigator™. The primary research question addressed in the paper is: How does implementation of the classroom connectivity technology affect student achievement in Algebra 1, SRL, and dispositions toward mathematics? The treatment group outperformed the control group in algebra performance. Math Self-efficacy/Math Performance Expectancy was positively associated with treatment. No differences were found between treatment and control students' reports of their beliefs about mathematics, confidence, anxiety, or usefulness. No differences were found for motivation, learning strategies, or resource management strategies related to treatment. Students of female teachers performed higher. Teacher efficacy was negatively associated with student performance.

This paper is targeted toward Theme 1, the integration of technology into school learning environments. It describes a research study funded by the U.S. Department of Education.¹ The paper reports the first year of a four-year study.

The Connected Classroom

Study classrooms were equipped with TI-Navigator™, a system connecting each student's handheld with the teacher's computer. Many high school mathematics classrooms are equipped with graphing calculators, four of which are wired to a hub using the connectivity technology. The teacher and students communicate wirelessly through an access point connected to the teacher's computer. Using the *Quick Poll* feature, the teacher can pose an individual question for student response, and *Learning Check* is a feature by which several questions can be sent to the calculator. Student responses may include multiple choice, true/false, and open-ended responses. After students enter their choices, the technology summarizes students' responses resulting in a bar graph that can be displayed using a projector. This immediate display provides the teacher and students with information allowing the teacher to readily assess the degree of student understanding. A third feature is *Screen Capture* by which the teacher can take a "snapshot" of each calculator screen. By inspecting the various screens, the teacher can make hypotheses about what the students are thinking and diagnose errors. Displaying a selection of screens to the class can foster class discussion, when the teacher refers to one screen and asks, for example, "What do you think this person is thinking?" The fourth feature, *Activity Center*, allows the teacher to display a coordinate system. A typical Activity Center lesson might include the teacher giving students two points and asking them to send an equation for the line. The teacher can ask students to send the

equation of a line through a given point parallel to or perpendicular to a line entered by the teacher. Similarly, the teacher can download an image from the Internet, such as the Gateway to the West Arch from St. Louis, MO, USA, and impose it on the coordinate grid. Students are asked to hypothesize the equation of a curve to fit the arch. The teacher can engage the class in discussion diagnosing incorrect responses that are displayed anonymously. Finally, the teacher can aggregate data collected by students, display it on the screen, and send the lists to students for data analysis. Activity Center is typically used to develop conceptual knowledge. Quick Poll and Learning Check are typically used as tools for formative assessment. The teacher has information that may lead to adjust instruction. As aggregate class results are displayed, students receive immediate feedback in a private non-threatening way that can encourage them to reflect and discuss their understanding or methods of solution (Roschelle, Penuel, & Abrahamson, 2004). Screen Capture may be used for either of these purposes.

Theoretical Foundations

Roschelle, Penuel, and Abrahamson (2004) summarized work in connected classrooms and identified 26 studies in mathematics, chemistry, and the humanities reporting positive outcomes. These range from promoting greater student engagement, increasing understanding of complex subject matter, increasing interest and enjoyment, promoting discussion and interactivity, helping students gauge their own level of understanding, increasing teacher awareness of student difficulties, extending content to be covered beyond class time, improving quality of questions asked, and overcoming shyness. This section describes several theoretical perspectives related to teaching and learning in a TI-Navigator setting.

The National Council of Teachers of Mathematics' standards (NCTM, 2000) calls for a vision of mathematics that poses new roles and responsibilities for students and teachers. Instructional priorities are based on new goals that include an emphasis on *conceptual understanding*, on *learning through inquiry and problem solving*, on *oral and written communication*, and on *connections* among mathematical topics and to real-world applications. Teachers are challenged to create classrooms that facilitate mathematical development by engaging students in rich mathematical experiences and in mathematical conversation such as expecting students to explain and justify their mathematical reasoning. Students are expected to participate actively in the classroom rather than passively taking notes. Connected classrooms encourage the type of learning supported by the NCTM standards by promoting active student participation, facilitating opportunities for inquiry, and facilitating, gathering and interpreting information about student learning in a timely manner.

The goals of mathematics education (NCTM, 2000) are consistent with the principles of *self-regulated learning* (SRL). A three-phase sequence of SRL behavior has been proposed (Zimmerman, 2000). During *forethought*, self-regulated learners plan their behaviors by analyzing tasks and setting appropriate goals. While carrying out these plans (*performance control* phase), they monitor and control their behaviors, cognitions, motivations, and emotions. Finally, during the *self-reflection* phase, based on monitoring progress during performance, learners make judgments of their progress and alter their behaviors accordingly. Relationships between self-regulated behavior and academic achievement in problem solving have been demonstrated (Pape & Wang, 2003). The connected classroom technology provides students the infrastructure related to these phases and the mechanism for making explicit both content and strategies that foster an environment for the development of SRL.

Implementation of the classroom connectivity technology and appropriate teaching strategies fosters a classroom environment that more closely aligns with effective practice as described by the National Research Council (NRC, 1999). Effective classroom characteristics including *learner centeredness*, *assessment centeredness*, *knowledge centeredness*, and *community centeredness* are realized in a connected classroom through student active engagement, various feedback mechanisms, exposure of student rationales for actions, and creation of the classroom as a community of learners (Owens et al. 2004; NRC, 1999).

Formative Assessment, an obvious theoretical underpinning of connected classrooms, may be defined as assessment for learning intended to inform students and teachers about knowledge gaps and to reveal learning successes and challenges. Teachers can engage in both planned and interactive formative assessment. This is characterized by gathering student-understanding data, interpreting that data, and modifying instructional strategies accordingly (Bell & Cowie, 2001). When questioning and feedback are frequent and involve student active reflection, and when assessment data are used to inform and adjust instruction, formative assessment has been reported to increase achievement. Improved formative assessment helps low achievers more than others and reducing the range of achievement raises achievement overall (Black & Wiliam, 1998).

Methods

Participants: A total of 118 teachers (Rx=56, C=62; 73.7% female) representing 28 U.S. states and 2 Canadian provinces participated initially. Participating teachers were largely White (Rx=77.0%, C=72.5%), held mathematics degrees (Rx=62.8%, C=81.7%), and were experienced teachers (Rx=13.8 yrs, C=14.7 yrs). From an initial sample of 1,761 students, 1,128 (Rx=615, 50.2% female; C=531, 56.8% female) from 68 classrooms with complete data were included for analyses. Classes with less than 10 students were excluded to minimize selection bias in the analysis. Students within control schools received more free/reduced lunch (26.63%) than treatment schools (16.40%). Free or reduced cost lunch in the U.S. is taken as a proxy for socio-economic status of the students in the school.

Research Design and Procedure: The research design is a randomized cross-over trial where the control group was exposed to the intervention sequentially. Participants were trained to use the classroom connectivity technology during a one-week, summer institute and at a technology conference for teachers. The professional development was patterned after the Teachers Teaching with Technology (T³) model (<http://www.t3ww.org/>) and provided by secondary teachers who use the TI-Navigator and who were T³ instructors. Participants attended the International T³ Conference each year for two years following the initial summer institutes. Participating teachers recruited and enrolled students from one class randomly selected from their Algebra I classes. Students responded to pre-test measures within the first month of school and post measures during the last two months of the school year. Teachers participated in a teacher interview and completed an on-line measure during the spring.

Analytical methods: Psychometric properties of all researcher-constructed measures were examined and are provided below. Items on the algebra pre- and post-measures were also examined using IRT analyses. Teacher interviews were coded using a grounded analysis. Responses to interview questions were initially coded independently by two different researchers. Coding categories were compared, refined, and the responses re-coded using the new coding descriptions. Final coding categories included frequency of use, availability of

technology, comfort level, component use, teacher understanding of students, and teacher planning.

A two-level hierarchical linear modeling technique was employed to model the impact of the intervention for students nested within teacher and the treatment effect examined at the teacher level. Individual student pretest scores were included as a student-level covariate. Covariates at the teacher level include years of teaching experience, teacher gender, percent free/reduced lunch, and class mean algebra score. Additionally, we examined the impact of two implementation variables (i.e., frequency in technology use and perception of instructional change as a result of technology implementation). Effect size of the treatment effect was calculated as the coefficient for the treatment effect divided by the square root of the estimated standard deviation of within class achievement in the unconditional model.

Student-level measures

The **Algebra Pretest and Posttest** each included multiple choice, short-answer, and extended constructed-response items. Thirty-two items (36-point maximum score) on the pretest were adapted by CRESST, UCLA from NAEP and California Standards Test released items ($\rho=0.81$). The Algebra I posttest was developed based on a comparison of mathematics content standards of 13 states (e.g., Ohio, California, New York, Virginia) representing a majority of the participants. Thirty-five questions were selected from released items from California and Virginia mathematics tests, TIMMS, and NAEP ($\rho=0.85$). IRT analysis was conducted to ensure the technical quality of each measure. Using 3PL analysis (Item Difficulty, Item Discrimination and Estimates of Guessing), five items were excluded. The final instrument included 24 multiple-choice, 5 extended-response, and one three-part short-answer questions for a maximum score of 37.

The **Student Beliefs about Mathematics** survey consisted of 34 items reflecting the following constructs: Beliefs about Mathematics ($\alpha=.82$), Confidence ($\alpha=.69$), Math Anxiety ($\alpha=.79$), Mathematics Usefulness ($\alpha=.82$), and Self-Efficacy/Performance Expectations ($\alpha=.88$).

The **Motivated Strategies for Learning Questionnaire** (Pintrich, Smith, Garcia, & McKeachie, 1991) includes 81 Likert-type items that explore students' motivation and learning strategies. Confirmatory factor analysis indicates reasonable factor validity. Scales and Cronbach's alpha values within our sample are: 1) Intrinsic goal orientation ($\alpha = .73$); 2) extrinsic goal orientation ($\alpha = .73$); 3) task value ($\alpha = .83$); 4) control of learning beliefs ($\alpha = .67$); 5) self-efficacy for learning and performance ($\alpha = .92$); 6) test anxiety ($\alpha = .79$); 7) rehearsal ($\alpha = .73$); 8) elaboration ($\alpha = .80$); 9) organization ($\alpha = .73$); 10) critical thinking ($\alpha = .80$); 11) metacognitive self-regulation ($\alpha = .79$); 12) time and study environment ($\alpha = .65$); 13) effort regulation ($\alpha = .64$); 14) peer learning ($\alpha = .59$); and 15) help seeking ($\alpha = .50$).

Teacher-level measures

The **Teacher Instructional Practices and Beliefs Survey** (TIPBS) consisted of 104 items that served as indicators of teacher instructional practice and beliefs about mathematics. Constructs on this measure include *school support for instructional innovation* ($\alpha = .79$), *familiarity with/implementation of NCTM Standards* ($\alpha = .68$), *use of instructional technology* ($\alpha = .86$), *reform classroom discourse* ($\alpha = .73$), *strategy discussion* ($\alpha = .85$), *explanations and*

justifications ($\alpha = .79$), *data analysis* ($\alpha = .90$), *teacher efficacy* ($\alpha = .80$), and *teacher beliefs about mathematics* ($\alpha = .64$).

Level of content coverage was calculated as the proportion of content common to state standards in relation to teachers' reported content covered during the academic year based upon an in-depth review of the textbooks used.

The **Telephone Interview Protocol** was developed to determine the level of technology and pedagogical implementation. This 30-40 minute interview focused on technology availability, use patterns, comfort level, and pedagogy implementation.

Results

Students in the treatment classrooms significantly outperformed controls on the algebra posttest after controlling for student pretest scores, teacher's years of experience, teacher's gender, and percent of free/reduced lunch ($ES=0.30$). The treatment group scored about two points higher than the control group, which is approximately a 14% mean learning gain.

Additional findings include:

- Level of teacher knowledge about students as a result of TI-Navigator use was positively related to student performance ($ES=0.36$).
- Frequency and level of technology implementation as well as level of instructional change with technology were not associated with the outcome.
- Teacher's years of teaching was positively associated with student performance.
- Students of female teachers performed higher than students of male teachers.
- Level of content coverage (implementation) and percent free/reduced lunch were not associated with student performance.
- Contrary to hypothesis, teacher efficacy was negatively associated with student performance ($ES = .49$).
- None of the other teacher survey constructs were associated with student outcome.

Two subsets of questions on the Algebra 1 posttest were also examined. For the Visual Dimension, we found that: 1) treatment status ($ES = 0.34$), 2) frequency of technology use ($ES = 0.32$), 3) level of teacher knowledge about students as a result of TI-Navigator use ($ES = 0.40$), and 4) level of instructional change with technology ($ES = 0.48$) were all positively associated with the algebra test scores after controlling for percentage of students eligible for free/reduced lunch in the school. For the mechanical and purely symbolic questions, we found that none of the variables were positively associated with the outcome after controlling for percentage of free lunch students in the school.

To examine the impact of treatment condition on student disposition and SRL, we compared students' responses on the *Student Views about Mathematics* and *MSLQ* surveys between treatment group and control group after controlling for their responses on the Pre-test. Based on our HLM analysis, we found that changes in students' math efficacy/math performance expectancy were positively associated with treatment status and the levels of implementation ($ES = 0.16$). No differences were found between treatment and control students' reports of their beliefs about mathematics, confidence, anxiety, usefulness, motivation, learning strategies, or resource management strategies.

Interpretations

The study reported is set within an interdisciplinary research project focused on teaching and learning of mathematics and science at grades 7—10. This randomized control trial draws a national sample of teachers. The national factor encourages wide application of outcomes. On the other hand, this factor has been a source of difficulty in keeping pace with day-by-day developments in the classrooms. Outcomes provide evidence for connected classroom contexts that may aid mathematics conceptual development by improving classroom formative assessment, classroom discourse, and self-regulated learning. Informal analysis based on classroom observations aid in interpretations. Teachers do not make full use of the potential of the connected classroom for formative assessment. In the connected classroom, teachers obtain information about student's knowledge, but they may not change their instructional procedure based on the information obtained. From the telephone interviews, there is stronger evidence for technology implementation than for change in instruction. The most obvious discourse pattern is community building in the classroom. Students appear to cooperate with the teacher and assist others in learning. Many classrooms are more learner centered than they might be without the connectivity. The visual dimension, which may be interpreted to also imply conceptual knowledge is improved with connectivity, particularly through Activity Center. Observers see an environment ripe for student self-regulation, but we have been unable to detect a relationship with the instrument we are using.

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