DESIGN RESEARCH ON PERSONALIZED PROBLEM POSING IN ALGEBRA

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Algebra is an area of pressing national concern around issues of equity and access in education. Recent theories and research suggest that personalization of instruction can allow students to activate their funds of knowledge and can elicit interest in the content to be learned. This paper examines the results of a large-scale teaching experiment where 8th grade students posed, solved, and shared algebra problems related to their out of school interests in topics like sports, video games, and social networking. Results suggest that the teaching experiment improved both learning of and interest in algebra compared to "business as usual" instruction, particularly for those students who were struggling. Theoretical and practical implications are discussed.

Keywords: Middle School Education, Design Experiments, Algebra and Algebraic Thinking

Algebra is a gatekeeper to higher-level mathematics, with significant implications for both equity in education and students' economic attainment (Moses & Cobb, 2001). Failure rates in algebra continue to be high, especially among low-income students and students of color (Allensworth, Nomi, Montgomery, & Lee, 2009). Students' interest in learning math declines over adolescence generally (Frenzel, Gotez, Pekrun, & Watt, 2010), and during algebra courses specifically (McCoy, 2005). Concepts from algebra are not seen as being connected to students' worlds, including their home and community activities (Chazan, 1999). Math curricula are often not designed to be relevant to students from diverse backgrounds (Ladsen-Billings, 1995).

Exploring ways to connect math to students' lives, experiences, and funds of knowledge is critical to making algebra both accessible and captivating. All students bring to the classroom mathematical funds of knowledge (Civil, 2007; Moll & Gonzalez, 1994), ways of reasoning quantitatively from their home and community. Students draw upon rich algebraic ways of reasoning when pursuing their out-of-school interests in areas like sports and video games (Walkington, Sherman, & Howell, 2014). If these funds of knowledge can be brought into the classroom, they may allow students to better access and understand mathematical ideas (Boaler, 1994; Walkington, 2013).

This paper reports a study where 8th grade students pose their own personalized "algebra stories." Personalization refers to the instructional approach of making connections between students' interests in topics like shopping, music, and social networking, and instructional content they will be learning in school (Cordova & Lepper, 1996; Walkington, 2013).

Theoretical Framework

The theory behind personalization draws upon two major ideas – interest as a motivational variable, and mathematical funds of knowledge. Interest is the psychological state of engaging and the predisposition to re-engage with objects, events, or ideas (Hidi & Renninger, 2006). Higher levels of interest have been associated directly with improved performance and learning (Potvin & Hasni, 2014). Higher interest is also connected to important mediators of learning like attention, engagement, persistence, perceived competence, and use of learning strategies (Kim, Jiang, & Song, 2015; Linnenbrink-Garcia, Patall, & Messersmith, 2013), and with motivational variables like self-efficacy, self-regulation, and achievement goals (Harackiewicz et al., 2008). Personalizing instruction by connecting it to students' out-of-school interests may thus elicit their interest for the content to be learned, allowing for increased engagement and motivation.

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Students also bring to the classroom funds of knowledge from their home and community lives that are historically-accumulated and culturally-developed (Civil, 2007); students' out-of-school interests are one dimension of these funds of knowledge. Prior research has explored the creation of instructional school units around children's experience with money and with home-based knowledge of gardening and construction (Civil, 2007). Interviews with families have revealed that they use mathematical practices while cooking, sewing, engaging in construction, and scheduling (Gonzalez, Andrade, Civil, and Moll, 2005). Using students' funds of knowledge can increase their legitimate participation in the classroom (Barton & Tan, 2009). Thus personalizing instruction to students' out-of-school interests may allow students to draw upon their prior knowledge of using quantities and numbers in everyday life in useful ways, allowing them to better understand and access the mathematical content to be learned.

Problem-posing – the activity of having students author mathematical tasks – "improves students' problem-solving skills, attitudes, and confidence in mathematics, and contributes to a broader understanding of mathematical concepts and the development of mathematical thinking" (Singer, Ellerton, & Cai, 2013, p. 2). Learning to pose a mathematically valid story problem is a challenge for students who must come to appreciate the importance of problem features. When posing a story problem, students must first avoid making common errors like posing non-mathematical, trivial, or unsolvable questions (Silver & Cai, 1996). They next must select units of measure and include realistic quantities that relate to one another in a known fashion (Silver & Cai, 2005). Research on personalization has thus far focused on problem-solving instead of problem-posing – the present study extends this research.

Prior research on personalizing mathematics instruction to students' out-of-school interests in topic like sports or movies has found that this approach elicits interest (Hogheim & Reber, 2015), and can promote learning (Cordova & Lepper, 1996; Walkington, 2013). However, effects are small, and producing banks of personalized problems is difficult for curriculum developers. In the present study, we enlist the students as the authors of their own algebra stories. In this way, learning becomes "personalized" as the students themselves write and solve problems based on their out-of-school interests in topics like sports, social networking, and video games. We examine the effects a 4-day teaching experiment which implemented personalized problem posing, sharing, solving. The research questions are: (1) How does participation in the teaching experiment impact students' understanding of algebraic concepts? and (2) How does participation in the teaching experiment impact students' interest in and self-efficacy for algebra?

Method

Procedure and Participants

This paper describes the fourth phase in a five-phase design-based research program (Brown, 1992; Collins, Joseph, & Bielaczyc, 2004). In design research, educational researchers "engineer" learning interventions and theories, with continuous adjustment and experimentation, to allow evidence-based claims to be made. The initial phases of the design research involved interviews and a small-scale pull-out teaching experiment where students posed, solved, and shared personalized problems. We then applied a teaching experiment methodology to four intact classes of 8^{th} grade students to further develop and refine hypotheses. We follow the definition of a teaching experiment in Steffe and Thompson (2000) where students' mathematical development is tracked over time as emerging hypotheses about the "mathematics of students" arise and are tested. We set out to tackle a widely-acknowledged issue at our site – students' struggle to solve algebra story problems - and coordinated pragmatic and theory-based concerns as we determined "in the moment" and after each session how to guide learning.

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The procedure for the teaching experiment was as follows. During a pre-test, students indicated which topics they were interested in: sports, video games, social networking, shopping, food/cooking, cell phones, computers, part-time jobs, and reading/writing. For students in the experimental group, selections were used to place them into groups of 3-5 students who all shared one of these interests. During each class, groups would solve algebra problems about topics the group was interested in like sports or cell phones. The problems they solved were written by the researchers, but were almost always based on problems that students in the classes had previously written. After solving a personalized problem, groups would be asked to write their own problem with a similar type of linear function (e.g., no intercept, negative slope, system) that corresponded to their group's shared interest. They would solve their own problem, and sometimes would trade problems with another group. The class would discuss both the problems students solved and the problems they posed. Learning was personalized in that students were writing and solving problems based on their out-of-school interests.

We also employed a comparison group. The two teachers participating in the teaching experiment taught approximately half of their class sections using "business as usual" instruction, and pre- and post-assessments were distributed to both the 4 classes participating in the teaching experiment and the 3 classes receiving "business as usual" instruction. Although comparing a teaching experiment delivered by a research team to a single teacher implementing their normal instruction may not be balanced, our purpose was to simply explore what the possibilities and limits of this approach might be. The problem-posing intervention may actually be more effective when delivered primarily by the classroom teacher, as teachers have far greater familiarity with their students and the curriculum.

Participants included 171 students (94 experimental and 77 control) in 7 classes of two teachers. Two of the classes (45 students; 1 class in experimental and 1 class in control) were 8th grade Algebra I classes where more advanced students were placed. The other 5 classes (126 students; 3 classes in experimental and 2 classes in control) were regular 8th grade math classes. Students were enrolled in a middle school in a large metropolitan area. Participants were 56% female, 90% Hispanic, 4% African-American, 4% Caucasian, and 2% Other race/ethnicities, with 91% Economically Disadvantaged (ED) and 39% Limited English Proficient (LEP). Eight students (all in the experimental group) had a special classification where they were immigrants who had been in the country for less than a year and spoke only or mainly Spanish.

Measures and Analysis

All participants took a pre-test that measured their knowledge of linear functions. There were 2 forms of the pre-test, which were randomly distributed within each class. Each form contained 3 algebra story problems, and then an additional prompt where students were asked to pose their own story problem. This fourth item was included because we were wondering whether students' willingness to pose a problem at pretest would interact with the degree of benefit they received from the teaching experiment. The post-test contained identical items, with one exception – for students not in Algebra I, instead of the prompt asking them to pose a problem, they were instead asked to solve a problem that involved direct variation (i.e., a directly proportional relationship with no intercept term). Because of how the teaching experiment unfolded, far more time than anticipated was spent on direct variation, so it seemed important at post to measure students' understanding. Pre-tests and post-test items were identical across the experimental group and the control group. Items were drawn from released items on algebra assessments like the state standardized test and the Smarter Balanced assessment.

On the first page of their pre- and post-test, all students were given an 11-item questionnaire. The first 8 items were from the situational interest scale in Linnenbrink-Garcia et al. (2010) (example

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item: "I enjoy the subject of algebra."), and the final 3 items were self-efficacy items written based on Bandura (2006; example item: "I feel confident in my ability to do algebra."). Cronbach's alphas for each scale were between 0.88 and 0.90, suggesting good reliability.

Gains from pre- to post-test were analyzed using mixed effects logistic regression models. The outcome variable was a 0/1 indicator of whether each student got each problem on their post-test correct. Random effects were added for student ID and problem ID. This analysis method was used because it could handle that different students got different forms of the test, and it allowed for there to be a different "difficulty level modifier" (modelled as a random effect) for each individual problem. Fixed effects included a 0/1 variable for condition (control or experimental group), pre-test score (with each part of each problem on the pre-test being counted as 1 point), and which course the student was enrolled in (8th grade math or Algebra I).

Because random assignment was conducted at the level of a classroom, we knew that there could be significant pre-existing differences between students in different class periods. For example, in our sample, special education students tended to be in certain periods, as did students in our subgroup of recent immigrants to the U.S. For this reason, we sought to include as many additional predictors to compensate for pre-existing differences between class periods as possible – including gender, ED, LEP, Talented and Gifted (TAG), and Special Education (SPED) status, students' score on the mid-year standardized mathematics test administered by their district that took place shortly before the teaching experiment, students' initial level of situational interest in and self-efficacy for mathematics, and whether the student was a recent immigrant. We only, however, retained fixed effects that were significantly predictive in the models. In addition, on the pre-test, the final question asked all students to try to pose an algebra problem about their interests. Scoring this problem as "correct" was problematic and therefore it was not included in the calculation of the pre-test score. Instead, we created a 0/1 indicator variable that simply showed whether the student had attempted to pose a problem. We were particularly interested in whether students' willingness to pose a problem at pre-test would moderate the effectiveness of the teaching experiment. Models were initially fit without interaction terms (Model 1) and then all two-way interactions with Condition were subsequently tested (Model 2). For the situational interest and self-efficacy measures, each student's 1-5 ratings for each scale was averaged, and used as the outcome in a linear regression model. Similar fixed effect predictors were tested for inclusion, including Condition, average rating on the pre-questionnaire, and grade level. *D*-type effect sizes were calculated using the method outlined in Chinn (2000); in Cohen (1988), effect sizes of 0.2, 0.5, and 0.8 are considered small, medium, and large, respectively.

Results

Table 1 shows how the experimental and control groups compared on pre-measures and the post-test. While they were very comparable in terms of the measures of interest and self-efficacy, the experimental group had directionally lower scores on both the pre-test and the mid-year district standardized assessment.

Table 1: Comparison of Experimental and Control Group

	Control Group Avg (SD) (*N*=77)	Experimental Group Avg (SD) (*N*=94)
Situational Interest	3.07 (0.87)	3.04 (0.85)
Self-Efficacy	3.00 (0.94)	3.06 (0.98)
Pre-test Score	22.84% (28.05)	20.46% (30.03)
Mid-Year Standardized Test	49.10% (15.40)	44.83% (17.78%)
Post Test	31.28% (29.59)	34.37% (29.31)

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The latter difference neared significance in a one-tailed *t*-test (p = .053). As mentioned previously, these differences are not surprising given the clumsy nature of random assignment at the classroom level. For this reason, it is clear that post-test differences between groups should be interpreted using statistical methods that take into account relevant covariates, like our regression models.

Performance on Algebra Post-Test

Results for the regression analyses predicting performance on the post-test items are given in Table 2. Model 1, the main effects model, shows that being in the personalization condition significantly enhanced post-test performance, with a small-to-medium effect size calculated at d=0.35 (Odds=1.87). Other factors that enhanced post-test performance included higher scores on the pre-test and the district standardized test, being in Algebra I, not being a recent immigrant, and attempting to pose a problem on the pre-test. The latter main effect is somewhat surprising, given that it also had a small-to-medium effect size calculated at d=0.39. This variable might be indicating students' level of proficiency with the English language, which may be important when solving algebra story problems.

Model 2, the interactions model, revealed an interaction between condition and course, where personalization was most beneficial for students not in Algebra I with a medium effect size d=0.53 (Odds = 2.60). There was not a significant effect of personalization on learning for students in Algebra I (B=0.954-1.025=-0.071). The effect of personalization on post-test performance is being driven by the subgroup of students who are most in need of assistance – those placed into the lowest mathematics track. These students were considerably more likely to solve post-test problems correctly if they participated in the teaching experiment, compared to business-as-usual.

Table 2: Mixed Effects Logistic Regression Models Showing Post-Test Performance

	Main Effects Model (Model 1)				**Interactions Model (Model 2)**			
Random Effects:	**Variance**				**Variance**			
Student ID	1.146				1.084			
Problem ID	2.580				2.583			
Fixed Effects:	**B(SE)**	**Odds**	**95% CI Odds**	**Sig.**	**B(SE)**	**Odds**	**95% CI Odds**	**Sig.**
(Intercept)	-4.885 (0.576)	0.008	(0.002, 0.024)	***	-5.157 (0.595)	0.006	(0.002, 0.019)	***
Mid-Year Test Linear Functions	0.046 (0.008)	1.047	(1.031, 1.063)	***	0.047 (0.008)	1.048	(1.032, 1.064)	***
Pre-Test	0.018 (0.006)	1.018	(1.007, 1.03)	**	0.017 (0.006)	1.018	(1.007, 1.029)	**
8th Grade Math	(ref.)				(ref.)			
Algebra 1	1.688 (0.325)	5.410	(2.847, 10.279)	***	2.184 (0.409)	8.880	(3.958, 19.923)	***
Wrote Story Pre	0.699 (0.263)	2.013	(1.198, 3.382)	**	0.811 (0.266)	2.250	(1.332, 3.801)	**
Recent Immigrant	-2.846 (0.952)	0.058	(0.009, 0.38)	**	-2.959 (0.948)	0.052	(0.008, 0.337)	**
Control Condition	(ref.)				(ref.)			
Personalized Condition	0.628 (0.237)	1.873	(1.173, 2.992)	**	0.954 (0.289)	2.595	(1.466, 4.595)	***
Personalized Condition x Algebra 1					-1.025 (0.516)	0.359	(0.13, 0.993)	*

Note. * p<.05, ** p < .01, *** p < .001. (ref.) denotes the reference category to which effects are compared.

Ratings on Interest and Self-Efficacy Post-Questionnaire

Results for the regression analyses predicting interest ratings on the post-questionnaire are in Table 3. For the main effects model (Model 3), the only variables that predicted interest at post were interest rating on the pre-questionnaire and score on the district standardized test. However, in Model 4 which tested for interactions with condition, there was a statistically significant interaction between condition and students' tendency to write a story problem on the pre-test of algebra skill. For students who wrote a story problem at pre-test, there was no difference in interest between the experimental and control groups on ratings of interest (B=0.307-.489=-0.182, *p*=0.165). However, for students who did not write a story problem at pre-test (62.6% of students), there was a significant positive difference in interest ratings at post of 0.307 points (95% CI [0.101,0.514]), *p*=.004), favoring the personalization group. Receiving personalized instruction does seem to be associated with an increase in interest, but this effect is limited to students who prior to the teaching experiment had potentially weaker problem-writing skills. This again suggests the personalized problem-posing activities are benefitting struggling students. Regression results for the self-efficacy items (not shown) showed no significant effects for Condition or for the interaction of Condition with any of the other predictors (*p*s > 0.1).

Table 3: Linear Regression Models Showing Avg. Interest Ratings on the Post Questionnaire

	Main Effects Model (Model 3)			Interactions Model (Model 4)		
Fixed Effects:	**B(SE)**	**95% CI**	**Sig.**	**B(SE)**	**95% CI**	**Sig.**
(Intercept)	0.231 (0.164)	[0,0.643]		0.091 (0.178)	[-0.256,0.440]	
Mid-Year Test	0.007 (0.003)	[0.002,0.012]	**	0.009 (0.003)	[0.004, 0.105]	***
Avg. on Interest Pre-Questionnaire	0.749 (0.050)	[0.651,0.847]	***	0.723 (0.050)	[0.625,0.820]	***
Wrote Story Pre				0.332 (0.121)	[0.096,0.569]	**
Control Condition				(ref.)		
Personalized Condition				0.307 (0.105)	[0.101,0.514]	**
Personalized Condition x Wrote Story				-0.489 (0.171)	[-0.824, -0.154]	**

Note. * p<.05, ** p < .01, *** p < .001. (ref.) denotes the reference category to which effects are compared.

Problems Posed by Students

An analysis of what occurred during the 4 days of the teaching experiment, while important to this research as a whole, is beyond the scope of the current paper – here our research questions focus only on pre-/post- differences. However, we give some examples of problems written by students in Table 4 to provide some context for the quantitative results.

Table 4: Problems Posed by Students

Session of Teaching Experiment	**Example of Problem Students Posed**
Session 1	David is Instagram famous and every minute he gets 40 likes. Fill in the chart with the number of likes he will get in 4 minutes.
Session 2	Lucas is playing GTA Band every time he dies, he loses $40.00. Write a linear equation that shows the relationship between money and every time he dies.
Session 3	The Dallas Stars are destroying the Red Wings tonight. In the first period it was 11-2. If this keeps up for the next two periods, what will be the final score? Make a linear equation.
Session 4	Melanie had 60% of battery on her phone. She lost 10% every hour. Write a linear equation that shows the relationship between % of battery and hours.

Discussion and Significance

We contrasted an approach where students posed, solved, and shared problems related to their out-of-school interests to business-as-usual instruction in 8th grade math classes. The control group experienced direct instruction where they solved problems on worksheets and discussed them as a class. An interesting facet of the comparison is that the control group tended to solve many more problems per class period (10-20 problems), while the experimental group focused in on posing and solving just a few. To an outside observer, the control group likely appeared to be more orderly and efficient. However, the experimental group learned more from the “messiness” involved with grappling with challenging mathematical ideas, and also in some cases saw increases in their interest in learning algebra. This is consistent with other studies on researcher-delivered (rather than student-generated) personalization (e.g., Walkington, 2013). However, compared to this prior research on personalization, here were see a slightly bigger effect size (medium instead of small), and this is also one of the first studies to test personalization with a more diverse student population. This study is also the first classroom study to put students at the center of the personalization process where they are posing their own problems based on their interests and experiences.

This study shows the potential of pedagogical approaches that make mathematics meaningful and relevant, conceptualize students as competent agents who can control their own learning, and that allow for rich mathematical discussions around challenging ideas (e.g., Moses & Cobb, 2001; Boaler, 2002). This study was carried out in an urban middle school in danger of not meeting state mathematics achievement benchmarks, with large class sizes and a diverse student population, many of whom did not speak English as their first language. Approaches that utilize and value the funds of knowledge that all students bring with them to the classroom can improve learning and interest and promote equity (e.g., Civil, 2007). Although funds of knowledge research has been critiqued for not employing multiple methods (Rios-Aguilar, Kiyama, Gravitt, & Moll, 2011) like quantitative analyses of effectiveness, this study expands the research base. An approach where students draw upon their own funds of knowledge, rather than rely solely on the teacher to make connections to their lived home and community experiences, could be significantly easier to scale and more authentic. This study also offers evidence that the activation of interest and student learning of mathematics go hand-in-hand (e.g., Hidi & Renninger, 2006; Mitchell, 1993). Challenging activities can increase the motivation of students struggling in the mathematics classroom, if proper supports (like funds of knowledge) are utilized. And finally, the results of this study inform the next iteration of our design-based research trajectory, the ultimate goal of which is to build an intervention that teachers can implement in different classroom contexts.

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